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(54) **INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES**

(71) Applicant: **Ethicon LLC**, Guaynabo, PR (US)

(72) Inventors: **Eitan T. Wiener**, Cincinnati, OH (US); **Frederick E. Shelton, IV**, Hillsboro, OH (US); **David C. Yates**, West Chester, OH (US)

(73) Assignee: **Ethicon LLC**, Guaynabo, PR (US)

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(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,082,426 A	3/1963	Miles
3,503,396 A	3/1970	Pierie et al.

(Continued)

FOREIGN PATENT DOCUMENTS

AU	2015201140 A1	3/2015
CA	2795323 A1	5/2014

(Continued)

OTHER PUBLICATIONS

US 10,504,709, 08/2018, Karancsi et al. (withdrawn).

(Continued)

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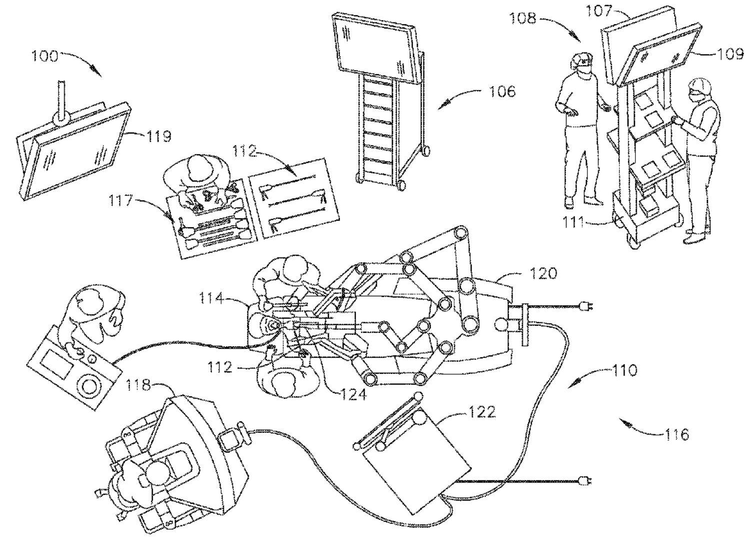
(57) **ABSTRACT**

A surgical hub is configured to transmit generator data associated with a surgical procedure from a generator of the surgical hub to a cloud-based system. The surgical hub comprises a processor and a memory storing instructions executable by the processor to: receive generator data; encrypt the generator data; generate a message authentication code based on the generator data; generate a datagram comprising: the encrypted generator data, the generated message authentication code, a source identifier and a destination identifier; and transmit the datagram to the cloud-based system. The datagram allows for the cloud-based system to: decrypt the encrypted generator data; verify the integrity of the generator data based on the message authentication code; authenticate the surgical hub as the source of the datagram; and validate a transmission path followed by the datagram between the surgical hub and the cloud based system.

20 Claims, 57 Drawing Sheets



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(56) **References Cited**

U.S. PATENT DOCUMENTS

3,584,628	A	6/1971	Green
3,759,017	A	9/1973	Young
4,448,193	A	5/1984	Ivanov
4,523,695	A	6/1985	Braun et al.
4,701,193	A	10/1987	Robertson et al.
4,735,603	A	4/1988	Goodson et al.
4,788,977	A	12/1988	Farin et al.
5,042,460	A	8/1991	Sakurai et al.
5,084,057	A	1/1992	Green et al.
5,100,402	A	3/1992	Fan
5,151,102	A	9/1992	Kamiyama et al.
5,156,315	A	10/1992	Green et al.
5,197,962	A	3/1993	Sansom et al.
5,242,474	A	9/1993	Herbst et al.
5,253,793	A	10/1993	Green et al.
RE34,519	E	1/1994	Fox et al.
5,318,516	A	6/1994	Cosmescu
5,322,055	A	6/1994	Davison et al.
5,342,349	A	8/1994	Kaufman
5,383,880	A	1/1995	Hooven
5,396,900	A	3/1995	Slater et al.
5,397,046	A	3/1995	Savage et al.
5,403,312	A	4/1995	Yates et al.
5,403,327	A	4/1995	Thornton et al.
5,413,267	A	5/1995	Solyntjes et al.
5,417,699	A	5/1995	Klein et al.
5,439,468	A	8/1995	Schulze et al.
5,445,304	A	8/1995	Plyley et al.
5,465,895	A	11/1995	Knodel et al.
5,467,911	A	11/1995	Tsuruta et al.
5,474,566	A	12/1995	Alesi et al.
5,496,315	A	3/1996	Weaver et al.
5,503,320	A	4/1996	Webster et al.
5,531,743	A	7/1996	Nettekoven et al.
5,545,148	A	8/1996	Wurster
5,610,379	A	3/1997	Muz et al.
5,613,966	A	3/1997	Makower et al.
5,624,452	A	4/1997	Yates
5,643,291	A	7/1997	Pier et al.
5,654,750	A	8/1997	Weil et al.
5,673,841	A	10/1997	Schulze et al.
5,673,842	A	10/1997	Bittner et al.
5,675,227	A	10/1997	Roos et al.
5,693,052	A	12/1997	Weaver
5,695,502	A	12/1997	Pier et al.
5,697,926	A	12/1997	Weaver
5,706,998	A	1/1998	Plyley et al.
5,725,536	A	3/1998	Oberlin et al.
5,725,542	A	3/1998	Yoon
5,735,848	A	4/1998	Yates et al.
5,746,209	A	5/1998	Yost et al.
5,749,362	A	5/1998	Funda et al.
5,749,893	A	5/1998	Vidal et al.
5,752,644	A	5/1998	Bolanos et al.
5,762,255	A	6/1998	Chrisman et al.
5,766,186	A	6/1998	Faraz et al.
5,769,791	A	6/1998	Benaron et al.
5,797,537	A	8/1998	Oberlin et al.
D399,561	S	10/1998	Ellingson
5,817,093	A	10/1998	Williamson, IV et al.
5,820,009	A	10/1998	Melling et al.
5,836,909	A	11/1998	Cosmescu
5,843,080	A	12/1998	Fleenor et al.
5,846,237	A	12/1998	Nettekoven
5,849,022	A	12/1998	Sakashita et al.
5,873,873	A	2/1999	Smith et al.
5,878,938	A	3/1999	Bittner et al.
5,893,849	A	4/1999	Weaver
5,906,625	A	5/1999	Bito et al.
5,942,333	A	8/1999	Arnett et al.
5,947,996	A	9/1999	Logeman
5,968,032	A	10/1999	Sleister
5,980,510	A	11/1999	Tsonton et al.
5,997,528	A	12/1999	Bisch et al.
6,010,054	A	1/2000	Johnson et al.
6,030,437	A	2/2000	Gourrier et al.
6,036,637	A	3/2000	Kudo
6,039,735	A	3/2000	Greep
6,059,799	A	5/2000	Aranyi et al.
6,066,137	A	5/2000	Greep
6,079,606	A	6/2000	Milliman et al.
6,090,107	A	7/2000	Borgmeier et al.
6,099,537	A	8/2000	Sugai et al.
6,155,473	A	12/2000	Tompkins et al.
6,214,000	B1	4/2001	Fleenor et al.
6,273,887	B1	8/2001	Yamauchi et al.
6,301,495	B1	10/2001	Gueziec et al.
6,302,881	B1	10/2001	Farin
6,325,808	B1	12/2001	Bernard et al.
6,325,811	B1	12/2001	Messerly
6,341,164	B1	1/2002	Dilkie et al.
6,391,102	B1	5/2002	Bodden et al.
6,443,973	B1	9/2002	Whitman
6,461,352	B2	10/2002	Morgan et al.
6,530,933	B1	3/2003	Yeung et al.
6,551,243	B2	4/2003	Bocionek et al.
6,569,109	B2	5/2003	Sakurai et al.
6,582,424	B2	6/2003	Fleenor et al.
6,585,791	B1	7/2003	Garito et al.
6,618,626	B2	9/2003	West, Jr. et al.
6,648,223	B2	11/2003	Boukhny et al.
6,685,704	B2	2/2004	Greep
6,699,187	B2	3/2004	Webb et al.
6,742,895	B2	6/2004	Robin
6,752,816	B2	6/2004	Culp et al.
6,773,444	B2	8/2004	Messerly
6,778,846	B1	8/2004	Martinez et al.
6,781,683	B2	8/2004	Kacyra et al.
6,783,524	B2	8/2004	Anderson et al.
6,783,525	B2	8/2004	Greep et al.
6,852,219	B2	2/2005	Hammond

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,869,430	B2	3/2005	Balbierz et al.
6,869,435	B2	3/2005	Blake, III
6,911,033	B2	6/2005	de Guillebon et al.
6,937,892	B2	8/2005	Leyde et al.
6,945,981	B2	9/2005	Donofrio et al.
6,951,559	B1	10/2005	Greep
6,978,921	B2	12/2005	Shelton, IV et al.
6,988,649	B2	1/2006	Shelton, IV et al.
7,000,818	B2	2/2006	Shelton, IV et al.
7,030,146	B2	4/2006	Baynes et al.
7,032,798	B2	4/2006	Whitman et al.
7,041,941	B2	5/2006	Faries, Jr. et al.
7,044,352	B2	5/2006	Shelton, IV et al.
7,044,911	B2	5/2006	Drinan et al.
7,048,775	B2	5/2006	Jornitz et al.
7,053,752	B2	5/2006	Wang et al.
7,077,853	B2	7/2006	Kramer et al.
7,077,856	B2	7/2006	Whitman
7,081,096	B2	7/2006	Brister et al.
7,097,640	B2	8/2006	Wang et al.
7,103,688	B2	9/2006	Strong
7,118,564	B2	10/2006	Ritchie et al.
7,121,460	B1	10/2006	Parsons et al.
7,143,923	B2	12/2006	Shelton, IV et al.
7,143,925	B2	12/2006	Shelton, IV et al.
7,147,139	B2	12/2006	Schwemberger et al.
7,169,145	B2	1/2007	Isaacson et al.
7,177,533	B2	2/2007	McFarlin et al.
7,182,775	B2	2/2007	de Guillebon et al.
7,208,005	B2	4/2007	Frecker et al.
7,230,529	B2	6/2007	Ketcherside, Jr. et al.
7,232,447	B2	6/2007	Gellman et al.
7,236,817	B2	6/2007	Papas et al.
7,246,734	B2	7/2007	Shelton, IV
7,278,563	B1	10/2007	Green
7,294,106	B2	11/2007	Birkenbach et al.
7,294,116	B1	11/2007	Ellman et al.
7,296,724	B2	11/2007	Green et al.
7,317,955	B2	1/2008	McGreevy
7,328,828	B2	2/2008	Ortiz et al.
7,362,228	B2	4/2008	Nycz et al.
7,371,227	B2	5/2008	Zeiner
7,380,695	B2	6/2008	Doll et al.
7,383,088	B2	6/2008	Spinelli et al.
7,391,173	B2	6/2008	Schena
7,407,074	B2	8/2008	Ortiz et al.
7,422,139	B2	9/2008	Shelton, IV et al.
7,423,972	B2	9/2008	Shaham et al.
7,457,804	B2	11/2008	Uber, III et al.
7,464,847	B2	12/2008	Viola et al.
7,464,849	B2	12/2008	Shelton, IV et al.
7,515,961	B2	4/2009	Germanson et al.
7,575,144	B2	8/2009	Ortiz et al.
7,621,192	B2	11/2009	Conti et al.
7,621,898	B2	11/2009	Lalomia et al.
7,637,410	B2	12/2009	Marczyk
7,641,092	B2	1/2010	Kruszynski et al.
7,667,839	B2	2/2010	Bates
7,670,334	B2	3/2010	Hueil et al.
7,694,865	B2	4/2010	Scirica
7,699,860	B2	4/2010	Huitema et al.
7,720,306	B2	5/2010	Gardiner et al.
7,721,934	B2	5/2010	Shelton, IV et al.
7,736,357	B2	6/2010	Lee, Jr. et al.
7,742,176	B2	6/2010	Braunecker et al.
7,753,245	B2	7/2010	Boudreaux et al.
7,766,905	B2	8/2010	Paterson et al.
7,770,773	B2	8/2010	Whitman et al.
7,776,037	B2	8/2010	Odom
7,782,789	B2	8/2010	Stultz et al.
7,784,663	B2	8/2010	Shelton, IV
7,803,151	B2	9/2010	Whitman
7,818,041	B2	10/2010	Kim et al.
7,837,079	B2	11/2010	Holsten et al.
7,837,680	B2	11/2010	Isaacson et al.
7,845,537	B2	12/2010	Shelton, IV et al.
7,862,560	B2	1/2011	Marion
7,862,579	B2	1/2011	Ortiz et al.
7,892,337	B2	2/2011	Palmerton et al.
7,913,891	B2	3/2011	Doll et al.
7,918,230	B2	4/2011	Whitman et al.
7,918,377	B2	4/2011	Measamer et al.
7,920,706	B2	4/2011	Asokan et al.
7,955,322	B2	6/2011	Devengenzo et al.
7,963,433	B2	6/2011	Whitman et al.
7,966,269	B2	6/2011	Bauer et al.
7,967,180	B2	6/2011	Scirica
7,976,553	B2	7/2011	Shelton, IV et al.
7,979,157	B2	7/2011	Anvari
7,980,443	B2	7/2011	Scheib et al.
7,982,776	B2	7/2011	Dunki-Jacobs et al.
7,988,028	B2	8/2011	Farascioni et al.
7,993,140	B2	8/2011	Sakezles
7,995,045	B2	8/2011	Dunki-Jacobs
8,005,947	B2	8/2011	Morris et al.
8,007,513	B2	8/2011	Nalagatla et al.
8,010,180	B2	8/2011	Quaid et al.
8,012,170	B2	9/2011	Whitman et al.
8,015,976	B2	9/2011	Shah
8,035,685	B2	10/2011	Jensen
8,038,686	B2	10/2011	Huitema et al.
8,043,560	B2	10/2011	Okumoto et al.
8,054,184	B2	11/2011	Cline et al.
8,062,306	B2	11/2011	Nobis et al.
8,062,330	B2	11/2011	Prommersberger et al.
8,066,721	B2	11/2011	Kortenbach et al.
8,075,571	B2	12/2011	Vitali et al.
8,096,459	B2	1/2012	Ortiz et al.
8,120,301	B2	2/2012	Goldberg et al.
8,123,764	B2	2/2012	Meade et al.
8,131,565	B2	3/2012	Dicks et al.
8,147,486	B2	4/2012	Honour et al.
8,157,145	B2	4/2012	Shelton, IV et al.
8,157,150	B2	4/2012	Viola et al.
8,160,098	B1	4/2012	Yan et al.
8,161,977	B2	4/2012	Shelton, IV et al.
8,172,836	B2	5/2012	Ward
8,181,839	B2	5/2012	Beetel
8,185,409	B2	5/2012	Putnam et al.
8,206,345	B2	6/2012	Abboud et al.
8,210,411	B2	7/2012	Yates et al.
8,220,688	B2	7/2012	Laurent et al.
8,225,979	B2	7/2012	Farascioni et al.
8,229,549	B2	7/2012	Whitman et al.
8,257,387	B2	9/2012	Cunningham
8,262,560	B2	9/2012	Whitman
8,292,888	B2	10/2012	Whitman
8,308,040	B2	11/2012	Huang et al.
8,321,581	B2	11/2012	Katis et al.
8,328,065	B2	12/2012	Shah
8,335,590	B2	12/2012	Costa et al.
8,346,392	B2	1/2013	Walser et al.
8,364,222	B2	1/2013	Cook et al.
8,365,975	B1	2/2013	Manoux et al.
8,388,652	B2	3/2013	Viola
8,393,514	B2	3/2013	Shelton, IV et al.
8,397,972	B2	3/2013	Kostrzewski
8,398,541	B2	3/2013	DiMaio et al.
8,403,946	B2	3/2013	Whitfield et al.
8,406,859	B2	3/2013	Zuzak et al.
8,422,035	B2	4/2013	Hinderling et al.
8,423,182	B2	4/2013	Robinson et al.
8,428,722	B2	4/2013	Verhoef et al.
8,439,910	B2	5/2013	Greep et al.
8,444,663	B2	5/2013	Houser et al.
8,452,615	B2	5/2013	Abri
8,454,506	B2	6/2013	Rothman et al.
8,461,744	B2	6/2013	Wiener et al.
8,468,030	B2	6/2013	Stroup et al.
8,469,973	B2	6/2013	Meade et al.
8,472,630	B2	6/2013	Konrad et al.
8,476,227	B2	7/2013	Kaplan et al.
8,489,235	B2	7/2013	Moll et al.
8,499,992	B2	8/2013	Whitman et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,503,759	B2	8/2013	Greer et al.
8,505,801	B2	8/2013	Ehrenfels et al.
8,512,365	B2	8/2013	Wiener et al.
8,521,331	B2	8/2013	Itkowitz
8,523,043	B2	9/2013	Ullrich et al.
8,546,996	B2	10/2013	Messerly et al.
8,560,047	B2	10/2013	Haider et al.
8,561,870	B2	10/2013	Baxter, III et al.
8,562,598	B2	10/2013	Falkenstein et al.
8,566,115	B2	10/2013	Moore
8,573,459	B2	11/2013	Smith et al.
8,573,465	B2	11/2013	Shelton, IV
8,591,536	B2	11/2013	Robertson
8,595,607	B2	11/2013	Nekoomaram et al.
8,596,513	B2	12/2013	Olson et al.
8,608,044	B2	12/2013	Hueil et al.
8,608,045	B2	12/2013	Smith et al.
8,616,431	B2	12/2013	Timm et al.
8,620,473	B2	12/2013	Diolaiti et al.
8,623,027	B2	1/2014	Price et al.
8,627,483	B2	1/2014	Rachlin et al.
8,627,995	B2	1/2014	Smith et al.
8,628,518	B2	1/2014	Blumenkranz et al.
8,628,545	B2	1/2014	Cabrera et al.
8,632,525	B2	1/2014	Kerr et al.
8,652,086	B2	2/2014	Gerg et al.
8,652,128	B2	2/2014	Ward
8,657,176	B2	2/2014	Shelton, IV et al.
8,657,177	B2	2/2014	Scirica et al.
8,663,220	B2	3/2014	Wiener et al.
8,666,544	B2	3/2014	Moll et al.
8,682,049	B2	3/2014	Zhao et al.
8,682,489	B2	3/2014	Itkowitz et al.
8,685,056	B2	4/2014	Evans et al.
8,701,962	B2	4/2014	Kostrzewski
8,733,613	B2	5/2014	Huitema et al.
8,740,840	B2	6/2014	Foley et al.
8,740,866	B2	6/2014	Reasoner et al.
8,752,749	B2	6/2014	Moore et al.
8,757,465	B2	6/2014	Woodard, Jr. et al.
8,761,717	B1	6/2014	Buchheit
8,763,879	B2	7/2014	Shelton, IV et al.
8,768,251	B2	7/2014	Claus et al.
8,771,270	B2	7/2014	Burbank
8,775,196	B2	7/2014	Simpson et al.
8,779,648	B2	7/2014	Giordano et al.
8,794,497	B2	8/2014	Zingman
8,799,008	B2	8/2014	Johnson et al.
8,799,009	B2	8/2014	Mellin et al.
8,801,703	B2	8/2014	Gregg et al.
8,814,996	B2	8/2014	Giurgiutiu et al.
8,818,556	B2	8/2014	Sanchez et al.
8,820,603	B2	9/2014	Shelton, IV et al.
8,820,608	B2	9/2014	Miyamoto
8,827,134	B2	9/2014	Viola et al.
8,840,003	B2	9/2014	Morgan et al.
8,851,354	B2	10/2014	Swensgard et al.
8,852,174	B2	10/2014	Burbank
8,875,973	B2	11/2014	Whitman
8,882,662	B2	11/2014	Charles
8,905,977	B2	12/2014	Shelton et al.
8,912,746	B2	12/2014	Reid et al.
8,914,098	B2	12/2014	Brennan et al.
8,918,207	B2	12/2014	Prisco
8,920,414	B2	12/2014	Stone et al.
8,920,433	B2	12/2014	Barrier et al.
8,930,203	B2	1/2015	Kiaie et al.
8,930,214	B2	1/2015	Woolford
8,931,679	B2	1/2015	Kostrzewski
8,945,095	B2	2/2015	Blumenkranz et al.
8,945,163	B2	2/2015	Voegele et al.
8,956,581	B2	2/2015	Rosenbaum et al.
8,960,519	B2	2/2015	Whitman et al.
8,960,520	B2	2/2015	McCuen
8,962,062	B2	2/2015	Podhajsky et al.
8,967,443	B2	3/2015	McCuen
8,967,455	B2	3/2015	Zhou
8,968,276	B2	3/2015	Zemlok et al.
8,968,309	B2	3/2015	Roy et al.
8,968,337	B2	3/2015	Whitfield et al.
8,968,358	B2	3/2015	Reschke
8,974,429	B2	3/2015	Gordon et al.
8,986,302	B2	3/2015	Aldridge et al.
8,989,903	B2	3/2015	Weir et al.
8,991,678	B2	3/2015	Wellman et al.
8,992,565	B2	3/2015	Brisson et al.
8,998,797	B2	4/2015	Omori
9,002,518	B2	4/2015	Manzo et al.
9,011,366	B2	4/2015	Dean et al.
9,011,427	B2	4/2015	Price et al.
9,016,539	B2	4/2015	Kostrzewski et al.
9,017,326	B2	4/2015	DiNardo et al.
9,020,240	B2	4/2015	Pettersson et al.
9,023,071	B2	5/2015	Miller et al.
9,027,431	B2	5/2015	Tang et al.
9,028,494	B2	5/2015	Shelton, IV et al.
9,035,568	B2	5/2015	Ganton et al.
9,038,882	B2	5/2015	Racenet et al.
9,043,027	B2	5/2015	Durant et al.
9,044,227	B2	6/2015	Shelton, IV et al.
9,044,244	B2	6/2015	Ludwin et al.
9,044,261	B2	6/2015	Houser
9,050,063	B2	6/2015	Roe et al.
9,050,083	B2	6/2015	Yates et al.
9,050,120	B2	6/2015	Swarup et al.
9,052,809	B2	6/2015	Vesto
9,055,035	B2	6/2015	Porsch et al.
9,060,770	B2	6/2015	Shelton, IV et al.
9,060,775	B2	6/2015	Wiener et al.
9,066,650	B2	6/2015	Sekiguchi
9,072,535	B2	7/2015	Shelton, IV et al.
9,072,536	B2	7/2015	Shelton, IV et al.
9,078,653	B2	7/2015	Leimbach et al.
9,078,727	B2	7/2015	Miller
9,084,606	B2	7/2015	Greep
9,089,360	B2	7/2015	Messerly et al.
9,095,362	B2	8/2015	Dachs, II et al.
9,095,367	B2	8/2015	Olson et al.
9,101,358	B2	8/2015	Kerr et al.
9,101,359	B2	8/2015	Smith et al.
9,101,374	B1	8/2015	Hoch et al.
9,106,270	B2	8/2015	Puterbaugh et al.
9,107,573	B2	8/2015	Birnkrant
9,107,662	B2	8/2015	Kostrzewski
9,107,684	B2	8/2015	Ma
9,107,688	B2	8/2015	Kimball et al.
9,107,689	B2	8/2015	Robertson et al.
9,107,694	B2	8/2015	Hendriks et al.
9,114,494	B1	8/2015	Mah
9,116,597	B1	8/2015	Gulasky
9,119,655	B2	9/2015	Bowling et al.
9,119,657	B2	9/2015	Shelton, IV et al.
9,123,155	B2	9/2015	Cunningham et al.
9,129,054	B2	9/2015	Nawana et al.
9,137,254	B2	9/2015	Bilbrey et al.
9,138,129	B2	9/2015	Diolaiti
9,149,322	B2	10/2015	Knowlton
9,161,803	B2	10/2015	Yates et al.
9,168,054	B2	10/2015	Turner et al.
9,179,912	B2	11/2015	Yates et al.
9,183,723	B2	11/2015	Sherman et al.
9,186,143	B2	11/2015	Timm et al.
9,192,375	B2	11/2015	Skinlo et al.
9,192,447	B2	11/2015	Choi et al.
9,192,707	B2	11/2015	Gerber et al.
9,202,078	B2	12/2015	Abuelsaad et al.
9,204,879	B2	12/2015	Shelton, IV
9,204,995	B2	12/2015	Scheller et al.
9,216,062	B2	12/2015	Duque et al.
9,218,053	B2	12/2015	Komuro et al.
9,226,766	B2	1/2016	Aldridge et al.
9,226,767	B2	1/2016	Stulen et al.
9,237,891	B2	1/2016	Shelton, IV
9,241,728	B2	1/2016	Price et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,241,731	B2	1/2016	Boudreaux et al.
9,250,172	B2	2/2016	Harris et al.
9,255,907	B2	2/2016	Heanue et al.
9,265,585	B2	2/2016	Wingardner et al.
9,272,406	B2	3/2016	Aronhalt et al.
9,277,956	B2	3/2016	Zhang
9,280,884	B1	3/2016	Schultz et al.
9,282,974	B2	3/2016	Shelton, IV
9,283,054	B2	3/2016	Morgan et al.
9,289,212	B2	3/2016	Shelton, IV et al.
9,295,514	B2	3/2016	Shelton, IV et al.
9,301,691	B2	4/2016	Hufnagel et al.
9,301,753	B2	4/2016	Aldridge et al.
9,301,759	B2	4/2016	Spivey et al.
9,301,810	B2	4/2016	Amiri et al.
9,307,894	B2	4/2016	von Grunberg et al.
9,307,914	B2	4/2016	Fahey
9,307,986	B2	4/2016	Hall et al.
9,314,246	B2	4/2016	Shelton, IV et al.
9,314,308	B2	4/2016	Parihar et al.
9,326,767	B2	5/2016	Koch et al.
9,331,422	B2	5/2016	Nazzaro et al.
9,332,987	B2	5/2016	Leimbach et al.
9,333,042	B2	5/2016	Diolaiti et al.
9,345,481	B2	5/2016	Hall et al.
9,345,490	B2	5/2016	Ippisch
9,351,726	B2	5/2016	Leimbach et al.
9,351,727	B2	5/2016	Leimbach et al.
9,358,003	B2	6/2016	Hall et al.
9,358,685	B2	6/2016	Meier et al.
9,360,449	B2	6/2016	Duric
9,364,231	B2	6/2016	Wenchell
9,364,249	B2	6/2016	Kimball et al.
9,364,294	B2	6/2016	Razzaque et al.
9,375,282	B2	6/2016	Nau, Jr. et al.
9,375,539	B2	6/2016	Stearns et al.
9,381,003	B2	7/2016	Todor et al.
9,381,058	B2	7/2016	Houser et al.
9,386,984	B2	7/2016	Aronhalt et al.
9,386,988	B2	7/2016	Baxter, III et al.
9,387,295	B1	7/2016	Mastri et al.
9,393,017	B2	7/2016	Flanagan et al.
9,393,037	B2	7/2016	Olson et al.
9,398,905	B2	7/2016	Martin
9,398,911	B2	7/2016	Auld
9,402,629	B2	8/2016	Ehrenfels et al.
9,414,776	B2	8/2016	Sillay et al.
9,419,018	B2	8/2016	Sasagawa et al.
9,421,014	B2	8/2016	Ingmanson et al.
9,433,470	B2	9/2016	Choi
9,439,622	B2	9/2016	Case et al.
9,439,736	B2	9/2016	Olson
9,450,701	B2	9/2016	Do et al.
9,451,958	B2	9/2016	Shelton, IV et al.
9,463,022	B2	10/2016	Swayze et al.
9,468,438	B2	10/2016	Baber et al.
9,480,492	B2	11/2016	Aranyi et al.
9,485,475	B2	11/2016	Speier et al.
9,492,146	B2	11/2016	Kostrzewski et al.
9,492,237	B2	11/2016	Kang et al.
9,498,215	B2	11/2016	Duque et al.
9,498,231	B2	11/2016	Haider et al.
9,516,239	B2	12/2016	Blanquart et al.
9,519,753	B1	12/2016	Gerdeman et al.
9,526,407	B2	12/2016	Hoeg et al.
9,526,499	B2	12/2016	Kostrzewski et al.
9,526,587	B2	12/2016	Zhao et al.
9,539,007	B2	1/2017	Dhakad et al.
9,539,020	B2	1/2017	Conlon et al.
9,542,481	B2	1/2017	Halter et al.
9,546,662	B2	1/2017	Shener-Irmakoglu et al.
9,554,794	B2	1/2017	Baber et al.
9,554,854	B2	1/2017	Yates et al.
9,561,038	B2	2/2017	Shelton, IV et al.
9,561,045	B2	2/2017	Hinman et al.
9,572,592	B2	2/2017	Price et al.
9,585,657	B2	3/2017	Shelton, IV et al.
9,592,095	B2	3/2017	Panescu et al.
9,597,081	B2	3/2017	Swayze et al.
9,603,024	B2	3/2017	Wang et al.
9,610,114	B2	4/2017	Baxter, III et al.
9,622,808	B2	4/2017	Beller et al.
9,629,623	B2	4/2017	Lytle, IV et al.
9,629,629	B2	4/2017	Leimbach et al.
9,630,318	B2	4/2017	Ibarz Gabardos et al.
9,636,188	B2	5/2017	Gattani et al.
9,641,596	B2	5/2017	Unagami et al.
9,641,815	B2	5/2017	Richardson et al.
9,649,110	B2	5/2017	Parihar et al.
9,649,111	B2	5/2017	Shelton, IV et al.
9,649,126	B2	5/2017	Robertson et al.
9,649,169	B2	5/2017	Cinquin et al.
9,652,655	B2	5/2017	Satish et al.
9,655,616	B2	5/2017	Aranyi
9,656,092	B2	5/2017	Golden
9,662,116	B2	5/2017	Smith et al.
9,662,177	B2	5/2017	Weir et al.
9,668,729	B2	6/2017	Williams et al.
9,668,732	B2	6/2017	Patel et al.
9,668,765	B2	6/2017	Grace et al.
9,681,870	B2	6/2017	Baxter, III et al.
9,686,306	B2	6/2017	Chizeck et al.
9,687,230	B2	6/2017	Leimbach et al.
9,690,362	B2	6/2017	Leimbach et al.
9,700,292	B2	7/2017	Nawana et al.
9,700,309	B2	7/2017	Jaworek et al.
9,700,312	B2	7/2017	Kostrzewski et al.
9,706,993	B2	7/2017	Hessler et al.
9,710,644	B2	7/2017	Reybok et al.
9,713,424	B2	7/2017	Spaide
9,717,498	B2	8/2017	Aranyi et al.
9,717,525	B2	8/2017	Ahluwalia et al.
9,717,548	B2	8/2017	Couture
9,724,094	B2	8/2017	Baber et al.
9,724,118	B2	8/2017	Schulte et al.
9,733,663	B2	8/2017	Leimbach et al.
9,737,301	B2	8/2017	Baber et al.
9,737,310	B2	8/2017	Whitfield et al.
9,737,335	B2	8/2017	Butler et al.
9,737,355	B2	8/2017	Yates et al.
9,740,826	B2	8/2017	Raghavan et al.
9,743,016	B2	8/2017	Nestares et al.
9,743,929	B2	8/2017	Leimbach et al.
9,743,946	B2	8/2017	Faller et al.
9,743,947	B2	8/2017	Price et al.
9,750,499	B2	9/2017	Leimbach et al.
9,750,522	B2	9/2017	Scheib et al.
9,750,523	B2	9/2017	Tsubuku
9,753,135	B2	9/2017	Bosch
9,757,126	B2	9/2017	Cappola
9,757,128	B2	9/2017	Baber et al.
9,757,142	B2	9/2017	Shimizu
9,757,152	B2	9/2017	Ogilvie et al.
9,764,164	B2	9/2017	Wiener et al.
9,770,541	B2	9/2017	Carr et al.
9,777,913	B2	10/2017	Talbert et al.
9,782,164	B2	10/2017	Mumaw et al.
9,782,169	B2	10/2017	Kimsey et al.
9,782,212	B2	10/2017	Wham et al.
9,782,214	B2	10/2017	Houser et al.
9,788,836	B2	10/2017	Overmyer et al.
9,788,851	B2	10/2017	Dannaher et al.
9,788,902	B2	10/2017	Inoue et al.
9,788,907	B1 *	10/2017	Alvi A61B 90/361
9,795,436	B2	10/2017	Yates et al.
9,801,626	B2	10/2017	Parihar et al.
9,801,627	B2	10/2017	Harris et al.
9,801,679	B2	10/2017	Trees et al.
9,802,033	B2	10/2017	Hibner et al.
9,804,618	B2	10/2017	Leimbach et al.
9,805,472	B2	10/2017	Chou et al.
9,808,244	B2	11/2017	Leimbach et al.
9,808,245	B2	11/2017	Richard et al.
9,808,246	B2	11/2017	Shelton, IV et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,808,248	B2	11/2017	Hoffman
9,814,457	B2	11/2017	Martin et al.
9,814,460	B2	11/2017	Kimsey et al.
9,814,462	B2	11/2017	Woodard, Jr. et al.
9,814,463	B2	11/2017	Williams et al.
9,820,699	B2	11/2017	Bingley et al.
9,820,738	B2	11/2017	Lytle, IV et al.
9,820,741	B2	11/2017	Kostrzewski
9,826,976	B2	11/2017	Parihar et al.
9,826,977	B2	11/2017	Leimbach et al.
9,827,054	B2	11/2017	Richmond et al.
9,827,059	B2	11/2017	Robinson et al.
9,833,241	B2	12/2017	Huitema et al.
9,839,419	B2	12/2017	Deck et al.
9,839,424	B2	12/2017	Zergiebel et al.
9,839,428	B2	12/2017	Baxter, III et al.
9,839,470	B2	12/2017	Gilbert et al.
9,839,487	B2	12/2017	Dachs, II
9,844,368	B2	12/2017	Boudreaux et al.
9,844,369	B2	12/2017	Huitema et al.
9,844,374	B2	12/2017	Lytle, IV et al.
9,844,375	B2	12/2017	Overmyer et al.
9,844,379	B2	12/2017	Shelton, IV et al.
9,848,058	B2	12/2017	Johnson et al.
9,848,877	B2	12/2017	Shelton, IV et al.
9,861,354	B2	1/2018	Saliman et al.
9,861,363	B2	1/2018	Chen et al.
9,861,428	B2	1/2018	Trees et al.
9,867,612	B2	1/2018	Parihar et al.
9,867,651	B2	1/2018	Wham
9,867,914	B2	1/2018	Bonano et al.
9,872,609	B2	1/2018	Levy
9,872,683	B2	1/2018	Hopkins et al.
9,877,718	B2	1/2018	Weir et al.
9,877,721	B2	1/2018	Schellin et al.
9,883,860	B2	2/2018	Leimbach
9,888,914	B2	2/2018	Martin et al.
9,888,919	B2	2/2018	Leimbach et al.
9,888,921	B2	2/2018	Williams et al.
9,895,148	B2	2/2018	Shelton, IV et al.
9,900,787	B2	2/2018	Ou
9,901,342	B2	2/2018	Shelton, IV et al.
9,901,406	B2	2/2018	State et al.
9,905,000	B2	2/2018	Chou et al.
9,907,550	B2	3/2018	Sniffin et al.
9,913,642	B2	3/2018	Leimbach et al.
9,913,645	B2	3/2018	Zerkle et al.
9,918,778	B2	3/2018	Walberg et al.
9,918,788	B2	3/2018	Paul et al.
9,922,304	B2	3/2018	DeBusk et al.
9,924,941	B2	3/2018	Burbank
9,924,961	B2	3/2018	Shelton, IV et al.
9,931,040	B2	4/2018	Homyk et al.
9,931,118	B2	4/2018	Shelton, IV et al.
9,931,124	B2	4/2018	Gokharu
9,936,942	B2	4/2018	Chin et al.
9,936,955	B2	4/2018	Miller et al.
9,936,961	B2	4/2018	Chien et al.
9,937,012	B2	4/2018	Hares et al.
9,937,014	B2	4/2018	Bowling et al.
9,937,626	B2	4/2018	Rockrohr
9,938,972	B2	4/2018	Walley
9,943,309	B2	4/2018	Shelton, IV et al.
9,943,377	B2	4/2018	Yates et al.
9,943,379	B2	4/2018	Gregg, II et al.
9,943,918	B2	4/2018	Grogan et al.
9,949,785	B2	4/2018	Price et al.
9,962,157	B2	5/2018	Sapre
9,968,355	B2	5/2018	Shelton, IV et al.
9,980,778	B2	5/2018	Ohline et al.
9,987,000	B2	6/2018	Shelton, IV et al.
9,993,248	B2	6/2018	Shelton, IV et al.
9,993,258	B2	6/2018	Shelton, IV et al.
10,004,491	B2	6/2018	Martin et al.
10,004,497	B2	6/2018	Overmyer et al.

10,004,500	B2	6/2018	Shelton, IV et al.
10,004,501	B2	6/2018	Shelton, IV et al.
10,004,527	B2	6/2018	Gee et al.
D822,206	S	7/2018	Shelton, IV et al.
10,010,322	B2	7/2018	Shelton, IV et al.
10,010,324	B2	7/2018	Huitema et al.
10,013,049	B2	7/2018	Leimbach et al.
10,016,199	B2	7/2018	Baber et al.
10,021,318	B2	7/2018	Hugosson et al.
10,022,120	B2	7/2018	Martin et al.
10,022,391	B2	7/2018	Ruderman Chen et al.
10,022,568	B2	7/2018	Messerly et al.
10,028,761	B2	7/2018	Leimbach et al.
10,028,788	B2	7/2018	Kang
10,034,704	B2	7/2018	Asher et al.
10,037,641	B2	7/2018	Hyde et al.
D826,405	S	8/2018	Shelton, IV et al.
10,039,564	B2	8/2018	Hibner et al.
10,039,565	B2	8/2018	Vezzu
10,041,822	B2	8/2018	Zemlok
10,044,791	B2	8/2018	Kamen et al.
10,045,776	B2	8/2018	Shelton, IV et al.
10,045,779	B2	8/2018	Savage et al.
10,045,781	B2	8/2018	Cropper et al.
10,045,813	B2	8/2018	Mueller
10,048,379	B2	8/2018	Markendorf et al.
10,052,044	B2	8/2018	Shelton, IV et al.
10,052,102	B2	8/2018	Baxter, III et al.
10,054,441	B2	8/2018	Schorr et al.
10,076,326	B2	9/2018	Yates et al.
10,080,618	B2	9/2018	Marshall et al.
10,085,748	B2	10/2018	Morgan et al.
10,085,749	B2	10/2018	Cappola et al.
10,098,527	B2	10/2018	Weisenburgh, II et al.
10,098,635	B2	10/2018	Burbank
10,098,705	B2	10/2018	Brisson et al.
10,105,140	B2	10/2018	Malinouskas et al.
10,105,142	B2	10/2018	Baxter, III et al.
10,111,658	B2	10/2018	Chowaniec et al.
10,111,665	B2	10/2018	Aranyi et al.
10,111,679	B2	10/2018	Baber et al.
10,117,649	B2	11/2018	Baxter et al.
10,117,651	B2	11/2018	Whitman et al.
10,117,702	B2	11/2018	Danziger et al.
10,118,119	B2	11/2018	Sappok et al.
10,130,359	B2	11/2018	Hess et al.
10,130,360	B2	11/2018	Olson et al.
10,130,367	B2	11/2018	Cappola et al.
10,133,248	B2	11/2018	Fitzsimmons et al.
10,135,242	B2	11/2018	Baber et al.
10,136,887	B2	11/2018	Shelton, IV et al.
10,136,949	B2	11/2018	Felder et al.
10,143,526	B2	12/2018	Walker et al.
10,143,948	B2	12/2018	Bonifas et al.
10,149,680	B2	12/2018	Parihar et al.
10,152,789	B2	12/2018	Carnes et al.
10,159,044	B2	12/2018	Hrabak
10,159,481	B2	12/2018	Whitman et al.
10,159,483	B2	12/2018	Beckman et al.
10,164,466	B2	12/2018	Calderoni
10,166,025	B2	1/2019	Leimbach et al.
10,169,862	B2	1/2019	Andre et al.
10,172,687	B2	1/2019	Garbus et al.
10,175,096	B2	1/2019	Dickerson
10,175,127	B2	1/2019	Collins et al.
10,178,992	B2	1/2019	Wise et al.
10,179,413	B2	1/2019	Rockrohr
10,180,463	B2	1/2019	Beckman et al.
10,182,814	B2	1/2019	Okoniewski
10,182,816	B2	1/2019	Shelton, IV et al.
10,182,818	B2	1/2019	Hensel et al.
10,188,385	B2	1/2019	Kerr et al.
10,189,157	B2	1/2019	Schlegel et al.
10,194,907	B2	2/2019	Marczyk et al.
10,194,913	B2	2/2019	Nalagatla et al.
10,201,349	B2	2/2019	Leimbach et al.
10,201,364	B2	2/2019	Leimbach et al.
10,201,365	B2	2/2019	Boudreaux et al.
10,205,708	B1	2/2019	Fletcher et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

10,206,605	B2	2/2019	Shelton, IV et al.
10,206,752	B2	2/2019	Hares et al.
10,213,201	B2	2/2019	Shelton, IV et al.
10,213,266	B2	2/2019	Zemlok et al.
10,213,268	B2	2/2019	Dachs, II
10,219,491	B2	3/2019	Stiles, Jr. et al.
10,226,250	B2	3/2019	Beckman et al.
10,226,302	B2	3/2019	Lacal et al.
10,231,634	B2	3/2019	Zand et al.
10,231,733	B2	3/2019	Ehrenfels et al.
10,238,413	B2	3/2019	Hibner et al.
10,245,027	B2	4/2019	Shelton, IV et al.
10,245,028	B2	4/2019	Shelton, IV et al.
10,245,029	B2	4/2019	Hunter et al.
10,245,030	B2	4/2019	Hunter et al.
10,245,033	B2	4/2019	Overmyer et al.
10,245,037	B2	4/2019	Conklin et al.
10,245,038	B2	4/2019	Hopkins et al.
10,251,661	B2	4/2019	Collings et al.
10,258,331	B2	4/2019	Shelton, IV et al.
10,258,359	B2	4/2019	Kapadia
10,258,362	B2	4/2019	Conlon
10,258,415	B2	4/2019	Harrah et al.
10,258,418	B2	4/2019	Shelton, IV et al.
10,258,425	B2	4/2019	Mustufa et al.
10,263,171	B2	4/2019	Wiener et al.
10,265,035	B2	4/2019	Fehre et al.
10,265,068	B2	4/2019	Harris et al.
10,265,072	B2	4/2019	Shelton, IV et al.
10,265,090	B2	4/2019	Ingmanson et al.
10,265,130	B2	4/2019	Hess et al.
10,271,840	B2	4/2019	Sapre
10,271,844	B2	4/2019	Valentine et al.
10,271,850	B2	4/2019	Williams
10,271,851	B2	4/2019	Shelton, IV et al.
D847,989	S	5/2019	Shelton, IV et al.
10,278,698	B2	5/2019	Racenet
10,278,778	B2	5/2019	State et al.
10,285,698	B2	5/2019	Cappola et al.
10,285,705	B2	5/2019	Shelton, IV et al.
10,292,704	B2	5/2019	Harris et al.
10,292,707	B2	5/2019	Shelton, IV et al.
10,292,758	B2	5/2019	Boudreaux et al.
10,292,771	B2	5/2019	Wood et al.
10,299,792	B2	5/2019	Huitema et al.
10,299,870	B2	5/2019	Connolly et al.
D850,617	S	6/2019	Shelton, IV et al.
10,307,159	B2	6/2019	Harris et al.
10,307,170	B2	6/2019	Parfett et al.
10,307,199	B2	6/2019	Farritor et al.
10,311,036	B1	6/2019	Hussam et al.
10,313,137	B2	6/2019	Aarnio et al.
10,314,577	B2	6/2019	Laurent et al.
10,314,582	B2	6/2019	Shelton, IV et al.
10,321,907	B2	6/2019	Shelton, IV et al.
10,321,964	B2	6/2019	Grover et al.
10,327,764	B2	6/2019	Harris et al.
10,335,147	B2	7/2019	Rector et al.
10,335,149	B2	7/2019	Baxter, III et al.
10,335,227	B2	7/2019	Heard
10,342,543	B2	7/2019	Shelton, IV et al.
10,342,602	B2	7/2019	Strobl et al.
10,342,623	B2	7/2019	Huelman et al.
10,343,102	B2	7/2019	Reasoner et al.
10,357,246	B2	7/2019	Shelton, IV et al.
10,357,247	B2	7/2019	Shelton, IV et al.
10,362,179	B2	7/2019	Harris
10,363,037	B2	7/2019	Aronhalt et al.
10,368,861	B2	8/2019	Baxter, III et al.
10,368,865	B2	8/2019	Harris et al.
10,368,867	B2	8/2019	Harris et al.
10,368,876	B2	8/2019	Bhatnagar et al.
10,368,894	B2	8/2019	Madan et al.
10,376,263	B2	8/2019	Morgan et al.
10,376,305	B2	8/2019	Yates et al.
10,376,337	B2	8/2019	Kilroy et al.
10,376,338	B2	8/2019	Taylor et al.
10,378,893	B2	8/2019	Mankovskii
10,383,518	B2	8/2019	Abu-Tarif et al.
10,383,699	B2	8/2019	Kilroy et al.
10,390,718	B2	8/2019	Chen et al.
10,390,794	B2	8/2019	Kuroiwa et al.
10,390,825	B2	8/2019	Shelton, IV et al.
10,390,831	B2	8/2019	Holsten et al.
10,390,895	B2	8/2019	Henderson et al.
10,398,434	B2	9/2019	Shelton, IV et al.
10,398,517	B2	9/2019	Eckert et al.
10,398,521	B2	9/2019	Itkowitz et al.
10,404,521	B2	9/2019	McChord et al.
10,404,801	B2	9/2019	Martch
10,405,857	B2	9/2019	Shelton, IV et al.
10,405,863	B2	9/2019	Wise et al.
10,413,291	B2	9/2019	Worthington et al.
10,413,293	B2	9/2019	Shelton, IV et al.
10,413,297	B2	9/2019	Harris et al.
10,417,446	B2	9/2019	Takeyama
10,420,552	B2	9/2019	Shelton, IV et al.
10,420,558	B2	9/2019	Nalagatla et al.
10,420,559	B2	9/2019	Marczyk et al.
10,420,620	B2	9/2019	Rockrohr
10,420,865	B2	9/2019	Reasoner et al.
10,422,727	B2	9/2019	Pliskin
10,426,466	B2	10/2019	Contini et al.
10,426,467	B2	10/2019	Miller et al.
10,426,468	B2	10/2019	Contini et al.
10,426,471	B2	10/2019	Shelton, IV et al.
10,433,837	B2	10/2019	Worthington et al.
10,433,844	B2	10/2019	Shelton, IV et al.
10,433,849	B2	10/2019	Shelton, IV et al.
10,441,279	B2	10/2019	Shelton, IV et al.
10,441,345	B2	10/2019	Aldridge et al.
10,448,948	B2	10/2019	Shelton, IV et al.
10,448,950	B2	10/2019	Shelton, IV et al.
10,456,137	B2	10/2019	Vendely et al.
10,456,140	B2	10/2019	Shelton, IV et al.
10,456,193	B2	10/2019	Yates et al.
10,463,365	B2	11/2019	Williams
10,463,367	B2	11/2019	Kostrzewski et al.
10,463,371	B2	11/2019	Kostrzewski
10,463,436	B2	11/2019	Jackson et al.
10,470,762	B2	11/2019	Leimbach et al.
10,470,764	B2	11/2019	Baxter, III et al.
10,470,768	B2	11/2019	Harris et al.
10,470,791	B2	11/2019	Houser
10,471,254	B2	11/2019	Sano et al.
10,478,181	B2	11/2019	Shelton, IV et al.
10,478,190	B2	11/2019	Miller et al.
10,478,544	B2	11/2019	Friederichs et al.
10,485,450	B2	11/2019	Gupta et al.
10,485,542	B2	11/2019	Shelton, IV et al.
10,485,543	B2	11/2019	Shelton, IV et al.
10,492,783	B2	12/2019	Shelton, IV et al.
10,492,785	B2	12/2019	Overmyer et al.
10,496,788	B2	12/2019	Amarasingham et al.
10,498,269	B2	12/2019	Zemlok et al.
10,499,891	B2	12/2019	Chaplin et al.
10,499,914	B2	12/2019	Huang et al.
10,499,915	B2	12/2019	Aranyi
10,499,994	B2	12/2019	Luks et al.
10,507,068	B2	12/2019	Kopp et al.
10,512,461	B2	12/2019	Gupta et al.
10,517,588	B2	12/2019	Gupta et al.
10,517,595	B2	12/2019	Hunter et al.
10,517,596	B2	12/2019	Hunter et al.
10,517,686	B2	12/2019	Vokrot et al.
10,524,789	B2	1/2020	Swayze et al.
10,531,874	B2	1/2020	Morgan et al.
10,531,929	B2	1/2020	Widenhouse et al.
10,532,330	B2	1/2020	Diallo et al.
10,536,617	B2	1/2020	Liang et al.
10,537,324	B2	1/2020	Shelton, IV et al.
10,537,325	B2	1/2020	Bakos et al.
10,537,351	B2	1/2020	Shelton, IV et al.
10,542,979	B2	1/2020	Shelton, IV et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

10,542,982	B2	1/2020	Beckman et al.
10,542,991	B2	1/2020	Shelton, IV et al.
10,548,504	B2	2/2020	Shelton, IV et al.
10,548,612	B2	2/2020	Martinez et al.
10,548,673	B2	2/2020	Harris et al.
10,552,574	B2	2/2020	Sweeney
10,555,675	B2	2/2020	Satish et al.
10,555,748	B2	2/2020	Yates et al.
10,555,750	B2	2/2020	Conlon et al.
10,555,769	B2	2/2020	Worrell et al.
10,561,422	B2	2/2020	Schellin et al.
10,561,471	B2	2/2020	Nichogi
10,568,625	B2	2/2020	Harris et al.
10,568,626	B2	2/2020	Shelton, IV et al.
10,568,632	B2	2/2020	Miller et al.
10,575,868	B2	3/2020	Hall et al.
10,582,928	B2	3/2020	Hunter et al.
10,582,931	B2	3/2020	Mujawar
10,586,074	B2	3/2020	Rose et al.
10,588,625	B2	3/2020	Weaner et al.
10,588,629	B2	3/2020	Malinouskas et al.
10,588,630	B2	3/2020	Shelton, IV et al.
10,588,631	B2	3/2020	Shelton, IV et al.
10,588,632	B2	3/2020	Shelton, IV et al.
10,595,952	B2	3/2020	Forrest et al.
10,610,223	B2	4/2020	Wellman et al.
10,631,916	B2	4/2020	Horner et al.
10,639,027	B2	5/2020	Shelton, IV et al.
10,639,036	B2	5/2020	Yates et al.
10,639,185	B2	5/2020	Agrawal et al.
10,653,476	B2	5/2020	Ross
10,674,897	B2	6/2020	Levy
10,679,758	B2	6/2020	Fox et al.
10,695,134	B2	6/2020	Barral et al.
10,716,615	B2	7/2020	Shelton, IV et al.
10,729,458	B2	8/2020	Stoddard et al.
10,751,768	B2	8/2020	Hersey et al.
10,765,376	B2	9/2020	Brown, III et al.
2002/0049551	A1	4/2002	Friedman et al.
2003/0093503	A1	5/2003	Yamaki et al.
2004/0078236	A1	4/2004	Stoodley et al.
2004/0199180	A1	10/2004	Knodel et al.
2004/0199659	A1	10/2004	Ishikawa et al.
2004/0243148	A1	12/2004	Wasielewski
2004/0243435	A1	12/2004	Williams
2005/0063575	A1	3/2005	Ma et al.
2005/0065438	A1	3/2005	Miller
2005/0131390	A1	6/2005	Heinrich et al.
2005/0149001	A1	7/2005	Uchikubo et al.
2005/0149356	A1	7/2005	Cyr et al.
2005/0222631	A1	10/2005	Dalal et al.
2005/0277913	A1	12/2005	McCary
2006/0020272	A1	1/2006	Gildenberg
2006/0116908	A1	6/2006	Dew et al.
2006/0241399	A1	10/2006	Fabian
2007/0010838	A1	1/2007	Shelton et al.
2007/0016235	A1	1/2007	Tanaka et al.
2007/0027459	A1	2/2007	Horvath et al.
2007/0078678	A1	4/2007	DiSilvestro et al.
2007/0167702	A1	7/2007	Hasser et al.
2007/0168461	A1	7/2007	Moore
2007/0175955	A1	8/2007	Shelton et al.
2007/0225556	A1	9/2007	Ortiz et al.
2007/0244478	A1	10/2007	Bahney
2007/0249990	A1	10/2007	Cosmescu
2007/0270660	A1	11/2007	Caylor et al.
2007/0293218	A1	12/2007	Meylan et al.
2008/0013460	A1	1/2008	Allen et al.
2008/0015664	A1	1/2008	Podhajsky
2008/0015912	A1	1/2008	Rosenthal et al.
2008/0033404	A1	2/2008	Romoda et al.
2008/0040151	A1	2/2008	Moore
2008/0059658	A1	3/2008	Williams
2008/0077158	A1	3/2008	Haider et al.
2008/0083414	A1	4/2008	Messerges

2008/0255413	A1	10/2008	Zemlok et al.
2008/0262654	A1	10/2008	Omori et al.
2008/0281678	A1	11/2008	Keuls et al.
2008/0296346	A1	12/2008	Shelton, IV et al.
2009/0036750	A1	2/2009	Weinstein et al.
2009/0036794	A1	2/2009	Stubhaug et al.
2009/0043253	A1	2/2009	Podaima
2009/0046146	A1	2/2009	Hoyt
2009/0076409	A1	3/2009	Wu et al.
2009/0090763	A1	4/2009	Zemlok et al.
2009/0099866	A1	4/2009	Newman
2009/0182577	A1	7/2009	Squilla et al.
2009/0206131	A1	8/2009	Weisenburgh, II et al.
2009/0259149	A1	10/2009	Tahara et al.
2009/0259221	A1	10/2009	Tahara et al.
2009/0307681	A1	12/2009	Armado et al.
2009/0326321	A1	12/2009	Jacobsen et al.
2009/0326336	A1	12/2009	Lemke et al.
2010/0065604	A1	3/2010	Weng
2010/0070417	A1	3/2010	Flynn et al.
2010/0132334	A1	6/2010	Duclos et al.
2010/0191100	A1	7/2010	Anderson et al.
2010/0198248	A1	8/2010	Vakharia
2010/0217991	A1	8/2010	Choi
2010/0235689	A1	9/2010	Tian et al.
2010/0250571	A1	9/2010	Pierce et al.
2010/0292535	A1	11/2010	Paskar
2011/0087238	A1	4/2011	Wang et al.
2011/0105895	A1	5/2011	Kornblau et al.
2011/0118708	A1	5/2011	Burbank et al.
2011/0119075	A1	5/2011	Dhoble
2011/0125149	A1	5/2011	El-Galley et al.
2011/0237883	A1	9/2011	Chun
2011/0306840	A1	12/2011	Allen et al.
2012/0116381	A1	5/2012	Houser et al.
2012/0130217	A1	5/2012	Kauphusman et al.
2012/0191091	A1	7/2012	Allen
2012/0203785	A1	8/2012	Awada
2012/0211542	A1	8/2012	Racenet
2012/0245958	A1	9/2012	Lawrence et al.
2012/0292367	A1	11/2012	Morgan et al.
2012/0319859	A1	12/2012	Taub et al.
2013/0024213	A1	1/2013	Poon
2013/0046279	A1	2/2013	Niklewski et al.
2013/0066647	A1	3/2013	Andrie et al.
2013/0090526	A1	4/2013	Suzuki et al.
2013/0093829	A1	4/2013	Rosenblatt et al.
2013/0105552	A1	5/2013	Weir et al.
2013/0116218	A1	5/2013	Kaplan et al.
2013/0165776	A1	6/2013	Blomqvist
2013/0178853	A1	7/2013	Hyink et al.
2013/0206813	A1	8/2013	Nalagatla
2013/0214025	A1	8/2013	Zemlok et al.
2013/0253480	A1	9/2013	Kimball et al.
2013/0256373	A1	10/2013	Schmid et al.
2013/0277410	A1	10/2013	Fernandez et al.
2013/0317837	A1	11/2013	Ballantyne et al.
2013/0321425	A1	12/2013	Greene et al.
2013/0325809	A1	12/2013	Kim et al.
2013/0331874	A1	12/2013	Ross et al.
2013/0331875	A1	12/2013	Ross et al.
2014/0001234	A1	1/2014	Shelton, IV et al.
2014/0006132	A1	1/2014	Barker
2014/0006943	A1	1/2014	Robbins et al.
2014/0029411	A1	1/2014	Nayak et al.
2014/0035762	A1	2/2014	Shelton, IV et al.
2014/0066700	A1	3/2014	Wilson et al.
2014/0081255	A1	3/2014	Johnson et al.
2014/0081659	A1	3/2014	Nawana et al.
2014/0087999	A1	3/2014	Kaplan et al.
2014/0092089	A1	4/2014	Kasuya et al.
2014/0107697	A1	4/2014	Patani et al.
2014/0108983	A1	4/2014	William et al.
2014/0128885	A1	5/2014	Dachs, II et al.
2014/0171923	A1	6/2014	Aranyi
2014/0187856	A1	7/2014	Holoien et al.
2014/0204190	A1	7/2014	Rosenblatt, III et al.
2014/0246475	A1	9/2014	Hall et al.
2014/0249557	A1	9/2014	Koch et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2014/0252064	A1	9/2014	Mozdzierz et al.	
2014/0263541	A1	9/2014	Leimbach et al.	
2014/0263552	A1	9/2014	Hall et al.	
2014/0303660	A1	10/2014	Boyden et al.	
2015/0025549	A1	1/2015	Kilroy et al.	
2015/0032150	A1	1/2015	Ishida et al.	
2015/0051617	A1	2/2015	Takemura et al.	
2015/0053737	A1	2/2015	Leimbach et al.	
2015/0066000	A1	3/2015	An et al.	
2015/0070187	A1	3/2015	Wiesner et al.	
2015/0108198	A1	4/2015	Estrella et al.	
2015/0122870	A1	5/2015	Zemlok et al.	
2015/0133945	A1	5/2015	Dushyant et al.	
2015/0199109	A1	7/2015	Lee	
2015/0238355	A1	8/2015	Vezzu et al.	
2015/0257816	A1	9/2015	Ineson	
2015/0272557	A1	10/2015	Overmyer et al.	
2015/0272571	A1	10/2015	Leimbach et al.	
2015/0272580	A1	10/2015	Leimbach et al.	
2015/0272582	A1	10/2015	Leimbach et al.	
2015/0297200	A1	10/2015	Fitzsimmons et al.	
2015/0297222	A1	10/2015	Huitema et al.	
2015/0297228	A1	10/2015	Huitema et al.	
2015/0297233	A1	10/2015	Huitema et al.	
2015/0297311	A1	10/2015	Tesar	
2015/0302157	A1	10/2015	Collar et al.	
2015/0310174	A1	10/2015	Coudert et al.	
2015/0313538	A1	11/2015	Bechtel et al.	
2015/0317899	A1	11/2015	Dumbauld et al.	
2015/0332003	A1	11/2015	Stamm et al.	
2015/0332196	A1	11/2015	Stiller et al.	
2015/0374369	A1	12/2015	Yates et al.	
2016/0000437	A1	1/2016	Giordano et al.	
2016/0015471	A1	1/2016	Piron et al.	
2016/0034648	A1	2/2016	Mohlenbrock et al.	
2016/0038253	A1	2/2016	Piron et al.	
2016/0066913	A1	3/2016	Swayze et al.	
2016/0095585	A1	4/2016	Zergiebel et al.	
2016/0106934	A1	4/2016	Hiraga et al.	
2016/0166256	A1	6/2016	Baxter, III et al.	
2016/0192960	A1	7/2016	Bueno et al.	
2016/0199125	A1	7/2016	Jones	
2016/0203282	A1*	7/2016	Azizian	G16H 20/40 700/275
2016/0206202	A1	7/2016	Frangioni	
2016/0235303	A1	8/2016	Fleming et al.	
2016/0249910	A1	9/2016	Shelton, IV et al.	
2016/0253472	A1	9/2016	Pedersen et al.	
2016/0256154	A1	9/2016	Shelton, IV et al.	
2016/0256160	A1	9/2016	Shelton, IV et al.	
2016/0296246	A1	10/2016	Schaller	
2016/0302210	A1	10/2016	Thornton et al.	
2016/0310055	A1	10/2016	Zand et al.	
2016/0310203	A1	10/2016	Gaspredes et al.	
2016/0321400	A1	11/2016	Durrant et al.	
2016/0323283	A1	11/2016	Kang et al.	
2016/0324537	A1	11/2016	Green et al.	
2016/0342916	A1	11/2016	Arceneaux et al.	
2016/0350490	A1	12/2016	Martinez et al.	
2016/0374665	A1	12/2016	DiNardo et al.	
2016/0374723	A1	12/2016	Frankhouser et al.	
2016/0374762	A1	12/2016	Case et al.	
2016/0374775	A1	12/2016	Prpa et al.	
2017/0000516	A1	1/2017	Stulen et al.	
2017/0000553	A1	1/2017	Wiener et al.	
2017/0000554	A1	1/2017	Yates et al.	
2017/0020291	A1	1/2017	Magana	
2017/0027603	A1	2/2017	Pandey	
2017/0056017	A1	3/2017	Vendely et al.	
2017/0056116	A1	3/2017	Kostrzewski	
2017/0061375	A1	3/2017	Laster et al.	
2017/0068792	A1	3/2017	Reiner	
2017/0086829	A1	3/2017	Vendely et al.	
2017/0086910	A1	3/2017	Wiener et al.	
2017/0086911	A1	3/2017	Wiener et al.	
2017/0086914	A1	3/2017	Wiener et al.	
2017/0086930	A1	3/2017	Thompson et al.	
2017/0105754	A1	4/2017	Boudreaux et al.	
2017/0132374	A1	5/2017	Lee et al.	
2017/0132785	A1	5/2017	Wshah et al.	
2017/0143284	A1	5/2017	Sehnert et al.	
2017/0143442	A1	5/2017	Tesar et al.	
2017/0151026	A1	6/2017	Panescu et al.	
2017/0156076	A1	6/2017	Eom et al.	
2017/0164997	A1	6/2017	Johnson et al.	
2017/0165012	A1	6/2017	Chaplin et al.	
2017/0171231	A1	6/2017	Reybok, Jr. et al.	
2017/0172565	A1	6/2017	Heneveld	
2017/0172614	A1	6/2017	Scheib et al.	
2017/0172672	A1	6/2017	Bailey et al.	
2017/0177807	A1	6/2017	Fabian	
2017/0181745	A1	6/2017	Penna et al.	
2017/0196637	A1	7/2017	Shelton, IV et al.	
2017/0202591	A1	7/2017	Shelton, IV et al.	
2017/0202605	A1	7/2017	Shelton, IV et al.	
2017/0202607	A1	7/2017	Shelton, IV et al.	
2017/0224331	A1	8/2017	Worthington et al.	
2017/0224332	A1	8/2017	Hunter et al.	
2017/0224334	A1	8/2017	Worthington et al.	
2017/0224428	A1	8/2017	Kopp	
2017/0231627	A1	8/2017	Shelton, IV et al.	
2017/0231628	A1	8/2017	Shelton, IV et al.	
2017/0249432	A1	8/2017	Grantcharov	
2017/0252095	A1	9/2017	Johnson	
2017/0255751	A1	9/2017	Sanmugalingham	
2017/0281164	A1	10/2017	Harris et al.	
2017/0281169	A1	10/2017	Harris et al.	
2017/0281171	A1	10/2017	Shelton, IV et al.	
2017/0281173	A1	10/2017	Shelton, IV et al.	
2017/0281174	A1	10/2017	Harris et al.	
2017/0281186	A1	10/2017	Shelton, IV et al.	
2017/0281187	A1	10/2017	Shelton, IV et al.	
2017/0281189	A1	10/2017	Nalagatla et al.	
2017/0290585	A1	10/2017	Shelton, IV et al.	
2017/0290586	A1	10/2017	Wellman	
2017/0296169	A1	10/2017	Yates et al.	
2017/0296173	A1	10/2017	Shelton, IV et al.	
2017/0296177	A1	10/2017	Harris et al.	
2017/0296185	A1	10/2017	Swensgard et al.	
2017/0296213	A1	10/2017	Swensgard et al.	
2017/0303419	A1	10/2017	Collins et al.	
2017/0303984	A1	10/2017	Malackowski	
2017/0304020	A1	10/2017	Ng et al.	
2017/0325813	A1	11/2017	Aranyi et al.	
2017/0354470	A1	12/2017	Farritor et al.	
2017/0360438	A1	12/2017	Cappola	
2017/0360439	A1	12/2017	Chen et al.	
2017/0360499	A1	12/2017	Greep et al.	
2017/0367695	A1	12/2017	Shelton, IV et al.	
2017/0367696	A1	12/2017	Shelton, IV et al.	
2017/0367697	A1	12/2017	Shelton, IV et al.	
2017/0367698	A1	12/2017	Shelton, IV et al.	
2017/0367754	A1	12/2017	Narisawa	
2018/0008260	A1	1/2018	Baxter, III et al.	
2018/0008359	A1	1/2018	Randle	
2018/0013571	A1*	1/2018	Aarnio	H04L 9/3234
2018/0014848	A1	1/2018	Messerly et al.	
2018/0049817	A1	2/2018	Swayze et al.	
2018/0050196	A1	2/2018	Pawsey et al.	
2018/0055529	A1	3/2018	Messerly et al.	
2018/0064498	A1	3/2018	Kapadia et al.	
2018/0065248	A1	3/2018	Barral et al.	
2018/0092706	A1	4/2018	Anderson et al.	
2018/0098816	A1	4/2018	Govari et al.	
2018/0110523	A1	4/2018	Shelton, IV	
2018/0110576	A1	4/2018	Kopp	
2018/0116662	A1	5/2018	Shelton, IV et al.	
2018/0122506	A1*	5/2018	Grantcharov	A61B 5/0022
2018/0125590	A1	5/2018	Giordano et al.	
2018/0132895	A1	5/2018	Silver	
2018/0140366	A1	5/2018	Kapadia	
2018/0153574	A1	6/2018	Faller et al.	
2018/0153628	A1	6/2018	Grover et al.	
2018/0153632	A1	6/2018	Tokarchuk et al.	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2018/0161716	A1	6/2018	Li et al.
2018/0168575	A1	6/2018	Simms et al.
2018/0168577	A1	6/2018	Aronhalt et al.
2018/0168578	A1	6/2018	Aronhalt et al.
2018/0168579	A1	6/2018	Aronhalt et al.
2018/0168580	A1	6/2018	Hunter et al.
2018/0168584	A1	6/2018	Harris et al.
2018/0168586	A1	6/2018	Shelton, IV et al.
2018/0168589	A1	6/2018	Swayze et al.
2018/0168590	A1	6/2018	Overmyer et al.
2018/0168591	A1	6/2018	Swayze et al.
2018/0168592	A1	6/2018	Overmyer et al.
2018/0168593	A1	6/2018	Overmyer et al.
2018/0168594	A1	6/2018	Shelton, IV et al.
2018/0168597	A1	6/2018	Fanelli et al.
2018/0168598	A1	6/2018	Shelton, IV et al.
2018/0168600	A1	6/2018	Shelton, IV et al.
2018/0168601	A1	6/2018	Bakos et al.
2018/0168602	A1	6/2018	Bakos et al.
2018/0168603	A1	6/2018	Morgan et al.
2018/0168604	A1	6/2018	Shelton, IV et al.
2018/0168605	A1	6/2018	Baber et al.
2018/0168606	A1	6/2018	Shelton, IV et al.
2018/0168607	A1	6/2018	Shelton, IV et al.
2018/0168608	A1	6/2018	Shelton, IV et al.
2018/0168609	A1	6/2018	Fanelli et al.
2018/0168610	A1	6/2018	Shelton, IV et al.
2018/0168614	A1	6/2018	Shelton, IV et al.
2018/0168615	A1	6/2018	Shelton, IV et al.
2018/0168616	A1	6/2018	Shelton, IV et al.
2018/0168617	A1	6/2018	Shelton, IV et al.
2018/0168618	A1	6/2018	Scott et al.
2018/0168619	A1	6/2018	Scott et al.
2018/0168621	A1	6/2018	Shelton, IV et al.
2018/0168623	A1	6/2018	Simms et al.
2018/0168624	A1	6/2018	Shelton, IV et al.
2018/0168625	A1	6/2018	Posada et al.
2018/0168626	A1	6/2018	Shelton, IV et al.
2018/0168627	A1	6/2018	Weaner et al.
2018/0168628	A1	6/2018	Hunter et al.
2018/0168629	A1	6/2018	Shelton, IV et al.
2018/0168630	A1	6/2018	Shelton, IV et al.
2018/0168631	A1	6/2018	Harris et al.
2018/0168632	A1	6/2018	Harris et al.
2018/0168633	A1	6/2018	Shelton, IV et al.
2018/0168637	A1	6/2018	Harris et al.
2018/0168638	A1	6/2018	Harris et al.
2018/0168639	A1	6/2018	Shelton, IV et al.
2018/0168641	A1	6/2018	Harris et al.
2018/0168642	A1	6/2018	Shelton, IV et al.
2018/0168643	A1	6/2018	Shelton, IV et al.
2018/0168644	A1	6/2018	Shelton, IV et al.
2018/0168647	A1	6/2018	Shelton, IV et al.
2018/0168648	A1	6/2018	Shelton, IV et al.
2018/0168649	A1	6/2018	Shelton, IV et al.
2018/0168650	A1	6/2018	Shelton, IV et al.
2018/0168651	A1	6/2018	Shelton, IV et al.
2018/0168715	A1	6/2018	Strobl
2018/0168748	A1	6/2018	Kapadia
2018/0168759	A1	6/2018	Kilroy et al.
2018/0168763	A1	6/2018	Scheib et al.
2018/0177557	A1	6/2018	Kapadia et al.
2018/0199995	A1	7/2018	Odermatt et al.
2018/0214025	A1	8/2018	Homyk et al.
2018/0221598	A1	8/2018	Silver
2018/0228557	A1	8/2018	Darisse et al.
2018/0242967	A1	8/2018	Meade
2018/0243035	A1	8/2018	Kopp
2018/0250080	A1	9/2018	Kopp
2018/0250084	A1	9/2018	Kopp et al.
2018/0263710	A1	9/2018	Sakaguchi et al.
2018/0263717	A1	9/2018	Kopp
2018/0271603	A1	9/2018	Nir et al.
2018/0296286	A1	10/2018	Peine et al.
2018/0304471	A1	10/2018	Tokuchi
2018/0310935	A1	11/2018	Wixey
2018/0310986	A1	11/2018	Batchelor et al.
2018/0310997	A1	11/2018	Peine et al.
2018/0317826	A1	11/2018	Muhsin et al.
2018/0317915	A1	11/2018	McDonald, II
2018/0338806	A1	11/2018	Grubbs
2018/0358112	A1	12/2018	Sharifi Sedeh et al.
2018/0360449	A1	12/2018	Shelton, IV et al.
2018/0360452	A1	12/2018	Shelton, IV et al.
2018/0360454	A1	12/2018	Shelton, IV et al.
2018/0360456	A1	12/2018	Shelton, IV et al.
2018/0368930	A1	12/2018	Esterberg et al.
2018/0369511	A1	12/2018	Zergiebel et al.
2019/0000446	A1	1/2019	Shelton, IV et al.
2019/0000448	A1	1/2019	Shelton, IV et al.
2019/0000464	A1	1/2019	Shelton, IV et al.
2019/0000465	A1	1/2019	Shelton, IV et al.
2019/0000478	A1	1/2019	Messerly et al.
2019/0000530	A1	1/2019	Yates et al.
2019/0000565	A1	1/2019	Shelton, IV et al.
2019/0000569	A1	1/2019	Crawford et al.
2019/0001079	A1	1/2019	Zergiebel et al.
2019/0005641	A1	1/2019	Yamamoto
2019/0006047	A1	1/2019	Gorek et al.
2019/0008600	A1	1/2019	Pedros et al.
2019/0029712	A1	1/2019	Stoddard et al.
2019/0038364	A1	2/2019	Enoki
2019/0053801	A1	2/2019	Wixey et al.
2019/0053866	A1	2/2019	Seow et al.
2019/0054620	A1	2/2019	Griffiths et al.
2019/0069949	A1	3/2019	Vrba et al.
2019/0069962	A1	3/2019	Tabandeh et al.
2019/0069964	A1	3/2019	Hagn
2019/0070550	A1	3/2019	Lalomia et al.
2019/0070731	A1	3/2019	Bowling et al.
2019/0090969	A1	3/2019	Jarc et al.
2019/0099180	A1	4/2019	Leimbach et al.
2019/0099227	A1	4/2019	Rockrohr
2019/0104919	A1	4/2019	Shelton, IV et al.
2019/0125320	A1	5/2019	Shelton, IV et al.
2019/0125321	A1	5/2019	Shelton, IV et al.
2019/0125324	A1	5/2019	Scheib et al.
2019/0125335	A1	5/2019	Shelton, IV et al.
2019/0125336	A1	5/2019	Deck et al.
2019/0125337	A1	5/2019	Shelton, IV et al.
2019/0125338	A1	5/2019	Shelton, IV et al.
2019/0125339	A1	5/2019	Shelton, IV et al.
2019/0125344	A1	5/2019	DiNardo et al.
2019/0125347	A1	5/2019	Stokes et al.
2019/0125348	A1	5/2019	Shelton, IV et al.
2019/0125352	A1	5/2019	Shelton, IV et al.
2019/0125353	A1	5/2019	Shelton, IV et al.
2019/0125354	A1	5/2019	Deck et al.
2019/0125355	A1	5/2019	Shelton, IV et al.
2019/0125356	A1	5/2019	Shelton, IV et al.
2019/0125357	A1	5/2019	Shelton, IV et al.
2019/0125358	A1	5/2019	Shelton, IV et al.
2019/0125359	A1	5/2019	Shelton, IV et al.
2019/0125360	A1	5/2019	Shelton, IV et al.
2019/0125361	A1	5/2019	Shelton, IV et al.
2019/0125365	A1	5/2019	Parfett et al.
2019/0125377	A1	5/2019	Shelton, IV
2019/0125378	A1	5/2019	Shelton, IV et al.
2019/0125379	A1	5/2019	Shelton, IV et al.
2019/0125381	A1	5/2019	Scheib et al.
2019/0125382	A1	5/2019	Scheib et al.
2019/0125383	A1	5/2019	Scheib et al.
2019/0125384	A1	5/2019	Scheib et al.
2019/0125385	A1	5/2019	Scheib et al.
2019/0125386	A1	5/2019	Shelton, IV et al.
2019/0125387	A1	5/2019	Parihar et al.
2019/0125388	A1	5/2019	Shelton, IV et al.
2019/0125389	A1	5/2019	Shelton, IV et al.
2019/0125390	A1	5/2019	Shelton, IV et al.
2019/0125430	A1	5/2019	Shelton, IV et al.
2019/0125431	A1	5/2019	Shelton, IV et al.
2019/0125432	A1	5/2019	Shelton, IV et al.
2019/0125454	A1	5/2019	Stokes et al.
2019/0125455	A1	5/2019	Shelton, IV et al.

(56) References Cited

U.S. PATENT DOCUMENTS

2019/0125456	A1	5/2019	Shelton, IV et al.
2019/0125457	A1	5/2019	Parihar et al.
2019/0125458	A1	5/2019	Shelton, IV et al.
2019/0125459	A1	5/2019	Shelton, IV et al.
2019/0125476	A1	5/2019	Shelton, IV et al.
2019/0133703	A1	5/2019	Seow et al.
2019/0142449	A1	5/2019	Shelton, IV et al.
2019/0142535	A1	5/2019	Seow et al.
2019/0145942	A1	5/2019	Dutriez et al.
2019/0150975	A1	5/2019	Kawasaki et al.
2019/0159778	A1	5/2019	Shelton, IV et al.
2019/0162179	A1	5/2019	O'Shea et al.
2019/0164285	A1	5/2019	Nye et al.
2019/0192157	A1	6/2019	Scott et al.
2019/0192236	A1	6/2019	Shelton, IV et al.
2019/0200844	A1	7/2019	Shelton, IV et al.
2019/0200863	A1	7/2019	Shelton, IV et al.
2019/0200905	A1	7/2019	Shelton, IV et al.
2019/0200906	A1	7/2019	Shelton, IV et al.
2019/0200977	A1	7/2019	Shelton, IV et al.
2019/0200980	A1	7/2019	Shelton, IV et al.
2019/0200981	A1	7/2019	Harris et al.
2019/0200984	A1	7/2019	Shelton, IV et al.
2019/0200985	A1	7/2019	Shelton, IV et al.
2019/0200986	A1	7/2019	Shelton, IV et al.
2019/0200987	A1	7/2019	Shelton, IV et al.
2019/0200988	A1	7/2019	Shelton, IV
2019/0200996	A1	7/2019	Shelton, IV et al.
2019/0200997	A1	7/2019	Shelton, IV et al.
2019/0200998	A1	7/2019	Shelton, IV et al.
2019/0201018	A1	7/2019	Shelton, IV et al.
2019/0201019	A1	7/2019	Shelton, IV et al.
2019/0201020	A1	7/2019	Shelton, IV et al.
2019/0201021	A1	7/2019	Shelton, IV et al.
2019/0201023	A1	7/2019	Shelton, IV et al.
2019/0201024	A1	7/2019	Shelton, IV et al.
2019/0201025	A1	7/2019	Shelton, IV et al.
2019/0201026	A1	7/2019	Shelton, IV et al.
2019/0201027	A1	7/2019	Shelton, IV et al.
2019/0201028	A1	7/2019	Shelton, IV et al.
2019/0201029	A1	7/2019	Shelton, IV et al.
2019/0201030	A1	7/2019	Shelton, IV et al.
2019/0201033	A1	7/2019	Yates et al.
2019/0201034	A1	7/2019	Shelton, IV et al.
2019/0201036	A1	7/2019	Nott et al.
2019/0201037	A1	7/2019	Houser et al.
2019/0201038	A1	7/2019	Yates et al.
2019/0201039	A1	7/2019	Widenhouse et al.
2019/0201040	A1	7/2019	Messerly et al.
2019/0201041	A1	7/2019	Kimball et al.
2019/0201042	A1	7/2019	Nott et al.
2019/0201043	A1	7/2019	Shelton, IV et al.
2019/0201044	A1	7/2019	Shelton, IV et al.
2019/0201045	A1	7/2019	Yates et al.
2019/0201046	A1	7/2019	Shelton, IV et al.
2019/0201047	A1	7/2019	Yates et al.
2019/0201073	A1	7/2019	Nott et al.
2019/0201074	A1	7/2019	Yates et al.
2019/0201075	A1	7/2019	Shelton, IV et al.
2019/0201077	A1	7/2019	Yates et al.
2019/0201079	A1	7/2019	Shelton, IV et al.
2019/0201080	A1	7/2019	Messerly et al.
2019/0201081	A1	7/2019	Shelton, IV et al.
2019/0201082	A1	7/2019	Shelton, IV et al.
2019/0201083	A1	7/2019	Shelton, IV et al.
2019/0201084	A1	7/2019	Shelton, IV et al.
2019/0201085	A1	7/2019	Shelton, IV et al.
2019/0201086	A1	7/2019	Shelton, IV et al.
2019/0201087	A1	7/2019	Shelton, IV et al.
2019/0201088	A1	7/2019	Shelton, IV et al.
2019/0201090	A1	7/2019	Shelton, IV et al.
2019/0201091	A1	7/2019	Yates et al.
2019/0201092	A1	7/2019	Yates et al.
2019/0201102	A1	7/2019	Shelton, IV et al.
2019/0201104	A1	7/2019	Shelton, IV et al.
2019/0201105	A1	7/2019	Shelton, IV et al.
2019/0201111	A1	7/2019	Shelton, IV et al.
2019/0201112	A1	7/2019	Wiener et al.
2019/0201113	A1	7/2019	Shelton, IV et al.
2019/0201114	A1	7/2019	Shelton, IV et al.
2019/0201115	A1	7/2019	Shelton, IV et al.
2019/0201116	A1	7/2019	Shelton, IV et al.
2019/0201117	A1	7/2019	Yates et al.
2019/0201118	A1	7/2019	Shelton, IV et al.
2019/0201119	A1	7/2019	Harris et al.
2019/0201120	A1	7/2019	Shelton, IV et al.
2019/0201122	A1	7/2019	Shelton, IV et al.
2019/0201123	A1	7/2019	Shelton, IV et al.
2019/0201124	A1	7/2019	Shelton, IV et al.
2019/0201125	A1	7/2019	Shelton, IV et al.
2019/0201126	A1	7/2019	Shelton, IV et al.
2019/0201127	A1	7/2019	Shelton, IV et al.
2019/0201128	A1	7/2019	Yates et al.
2019/0201129	A1	7/2019	Shelton, IV et al.
2019/0201130	A1	7/2019	Shelton, IV et al.
2019/0201135	A1	7/2019	Shelton, IV et al.
2019/0201136	A1	7/2019	Shelton, IV et al.
2019/0201137	A1	7/2019	Shelton, IV et al.
2019/0201138	A1	7/2019	Yates et al.
2019/0201139	A1	7/2019	Shelton, IV et al.
2019/0201140	A1	7/2019	Yates et al.
2019/0201141	A1	7/2019	Shelton, IV et al.
2019/0201142	A1	7/2019	Shelton, IV et al.
2019/0201143	A1	7/2019	Shelton, IV et al.
2019/0201144	A1	7/2019	Shelton, IV et al.
2019/0201145	A1	7/2019	Shelton, IV et al.
2019/0201146	A1	7/2019	Shelton, IV et al.
2019/0201158	A1	7/2019	Shelton, IV et al.
2019/0201159	A1	7/2019	Shelton, IV et al.
2019/0201593	A1	7/2019	Shelton, IV et al.
2019/0201594	A1	7/2019	Shelton, IV et al.
2019/0201597	A1	7/2019	Shelton, IV et al.
2019/0204201	A1	7/2019	Shelton, IV et al.
2019/0205001	A1	7/2019	Messerly et al.
2019/0205441	A1	7/2019	Shelton, IV et al.
2019/0205566	A1	7/2019	Shelton, IV et al.
2019/0205567	A1	7/2019	Shelton, IV et al.
2019/0206003	A1	7/2019	Harris et al.
2019/0206004	A1	7/2019	Shelton, IV et al.
2019/0206050	A1	7/2019	Yates et al.
2019/0206216	A1	7/2019	Shelton, IV et al.
2019/0206542	A1	7/2019	Shelton, IV et al.
2019/0206551	A1	7/2019	Yates et al.
2019/0206555	A1	7/2019	Morgan et al.
2019/0206556	A1	7/2019	Shelton, IV et al.
2019/0206561	A1	7/2019	Shelton, IV et al.
2019/0206562	A1	7/2019	Shelton, IV et al.
2019/0206563	A1	7/2019	Shelton, IV et al.
2019/0206564	A1	7/2019	Shelton, IV et al.
2019/0206565	A1	7/2019	Shelton, IV
2019/0206569	A1	7/2019	Shelton, IV et al.
2019/0206576	A1	7/2019	Shelton, IV et al.
2019/0207773	A1	7/2019	Shelton, IV et al.
2019/0207857	A1	7/2019	Shelton, IV et al.
2019/0208641	A1	7/2019	Yates et al.
2019/0223291	A1	7/2019	Seow et al.
2019/0254759	A1	8/2019	Azizian
2019/0269476	A1	9/2019	Bowling et al.
2019/0274662	A1	9/2019	Rockman et al.
2019/0274705	A1	9/2019	Sawhney et al.
2019/0274706	A1	9/2019	Nott et al.
2019/0274707	A1	9/2019	Sawhney et al.
2019/0274708	A1	9/2019	Boudreaux
2019/0274709	A1	9/2019	Scoggins
2019/0274710	A1	9/2019	Black
2019/0274711	A1	9/2019	Scoggins et al.
2019/0274712	A1	9/2019	Faller et al.
2019/0274713	A1	9/2019	Scoggins et al.
2019/0274714	A1	9/2019	Cuti et al.
2019/0274716	A1	9/2019	Nott et al.
2019/0274717	A1	9/2019	Nott et al.
2019/0274718	A1	9/2019	Denzinger et al.
2019/0274719	A1	9/2019	Stulen
2019/0274720	A1	9/2019	Gee et al.

(56) References Cited

U.S. PATENT DOCUMENTS

2019/0274749	A1	9/2019	Brady et al.
2019/0274750	A1	9/2019	Jayme et al.
2019/0274752	A1	9/2019	Denzinger et al.
2019/0290389	A1	9/2019	Kopp
2019/0298340	A1	10/2019	Shelton, IV et al.
2019/0298341	A1	10/2019	Shelton, IV et al.
2019/0298342	A1	10/2019	Shelton, IV et al.
2019/0298343	A1	10/2019	Shelton, IV et al.
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2019/0298354	A1	10/2019	Shelton, IV et al.
2019/0298355	A1	10/2019	Shelton, IV et al.
2019/0298356	A1	10/2019	Shelton, IV et al.
2019/0298357	A1	10/2019	Shelton, IV et al.
2019/0298464	A1	10/2019	Abbott
2019/0298481	A1	10/2019	Rosenberg et al.
2019/0307520	A1	10/2019	Peine et al.
2019/0314015	A1	10/2019	Shelton, IV et al.
2019/0321117	A1	10/2019	Itkowitz et al.
2019/0343594	A1	11/2019	Garcia Kilroy et al.
2019/0374140	A1	12/2019	Tucker et al.
2020/0054317	A1	2/2020	Pisarnwongs et al.
2020/0054320	A1	2/2020	Harris et al.
2020/0054321	A1	2/2020	Harris et al.
2020/0054322	A1	2/2020	Harris et al.
2020/0054323	A1	2/2020	Harris et al.
2020/0054325	A1	2/2020	Harris et al.
2020/0054326	A1	2/2020	Harris et al.
2020/0054327	A1	2/2020	Harris et al.
2020/0054328	A1	2/2020	Harris et al.
2020/0054329	A1	2/2020	Shelton, IV et al.
2020/0054330	A1	2/2020	Harris et al.
2020/0054331	A1	2/2020	Harris et al.
2020/0100830	A1	4/2020	Henderson et al.
2020/0178971	A1	6/2020	Harris et al.
2020/0261075	A1	8/2020	Boudreaux et al.
2020/0261076	A1	8/2020	Boudreaux et al.
2020/0261077	A1	8/2020	Shelton, IV et al.
2020/0261078	A1	8/2020	Bakos et al.
2020/0261080	A1	8/2020	Bakos et al.
2020/0261081	A1	8/2020	Boudreaux et al.
2020/0261082	A1	8/2020	Boudreaux et al.
2020/0261083	A1	8/2020	Bakos et al.
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2020/0261087	A1	8/2020	Timm et al.
2020/0261088	A1	8/2020	Harris et al.
2020/0261089	A1	8/2020	Shelton, IV et al.

FOREIGN PATENT DOCUMENTS

CN	101617950	A	1/2010
CN	104490448	B	3/2017
CN	206097107	U	4/2017
DE	3824913	A1	2/1990
DE	4002843	C1	4/1991
DE	102005051367	A1	4/2007
DE	102016207666	A1	11/2017
EP	0000756	B1	10/1981
EP	2732772	A1	5/2014
EP	3047806	A1	7/2016
EP	3056923	A1	8/2016
EP	3095399	A2	11/2016
EP	3120781	A2	1/2017
EP	3135225	A2	3/2017
EP	3141181	A1	3/2017
GB	2509523	A	7/2014
JP	S5373315	A	6/1978
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KR	20140104587	A	8/2014
KR	101587721	B1	1/2016
WO	WO-9734533	A1	9/1997
WO	WO-0024322	A1	5/2000
WO	WO-0108578	A1	2/2001
WO	WO-0112089	A1	2/2001
WO	WO-0120892	A3	11/2001
WO	WO-2007137304	A2	11/2007
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WO	WO-2008069816	A1	6/2008
WO	WO-2008147555	A2	12/2008
WO	WO-2011112931	A1	9/2011
WO	WO-2013143573	A1	10/2013
WO	WO-2014134196	A1	9/2014
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WO	WO-2017205308	A1	11/2017
WO	WO-2017210499	A1	12/2017
WO	WO-2017210501	A1	12/2017
WO	WO-2018152141	A1	8/2018

OTHER PUBLICATIONS

Flores et al., "Large-scale Offloading in the Internet of Things," 2017 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops), IEEE, pp. 479-484, Mar. 13, 2017.

Kalantarian et al., "Computation Offloading for Real-Time Health-Monitoring Devices," 2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EBMC), IEEE, pp. 4971-4974, Aug. 16, 2016.

Yuyi Mao et al., "A Survey on Mobile Edge Computing: The Communication Perspective," IEEE Communications Surveys & Tutorials, pp. 2322-2358, Jun. 13, 2017.

Benkmann et al., "Concept of iterative optimization of minimally invasive surgery," 2017 22nd International Conference on Methods and Models in Automation and Robotics (MMAR), IEEE pp. 443-446, Aug. 28, 2017.

Trautman, Peter, "Breaking the Human-Robot Deadlock: Surpassing Shared Control Performance Limits with Sparse Human-Robot Interaction," Robotics: Science and Systems XIII, pp. 1-10, Jul. 12, 2017.

Khazaei et al., "Health Informatics for Neonatal Intensive Care Units: An Analytical Modeling Perspective," IEEE Journal of Translational Engineering in Health and Medicine, vol. 3, pp. 1-9, Oct. 21, 2015.

Yang et al., "A dynamic stategy for packet scheduling and bandwidth allocation based on channel quality in IEEE 802.16e OFDMA system," Journal of Network and Computer Applications, vol. 39, pp. 52-60, May 2, 2013.

Takahashi et al., "Automatic smoke evacuation in laparoscopic surgery: a simplified method for objective evaluation," Surgical Endoscopy, vol. 27, No. 8, pp. 2980-2987, Feb. 23, 2013.

Miksch et al., "Utilizing temporal data abstraction for data validation and therapy planning for artificially ventilated newborn infants," Artificial Intelligence in Medicine, vol. 8, No. 6, pp. 543-576 (1996).

Horn et al., "Effective data validation of high-frequency data: Time-point-time-interval-, and trend-based methods," Computers in Biology and Medic, New York, NY, vol. 27, No. 5, pp. 389-409 (1997).

Stacey et al., "Temporal abstraction in intelligent clinical data analysis: A survey, " Artificial Intelligence in Medicine, vol. 39, No. 1, pp. 1-24 (2006).

Zoccali, Bruno, "A Method for Approximating Component Temperatures at Altitude Conditions Based on CFD Analysis at Sea Level Conditions," (white paper), www.tdmginc.com, Dec. 6, 2018 (9 pages).

Slocinski et al., "Distance measure for impedance spectra for quantified evaluations," Lecture Notes on Impedance Spectroscopy, vol. 3, Taylor and Francis Group (Jul. 2012)—Book Not Attached.

(56) References Cited

OTHER PUBLICATIONS

Engel et al. "A safe robot system for craniofacial surgery", 2013 IEEE International Conference on Robotics and Automation (ICRA); May 6-10, 2013; Karlsruhe, Germany, vol. 2, Jan. 1, 2001, pp. 2020-2024.

Bonaci et al., "To Make a Robot Secure: An Experimental Analysis of Cyber Security Threats Against Teleoperated Surgical Robots," May 13, 2015. Retrieved from the Internet: URL:https://arxiv.org/pdf/1504.04339v2.pdf [retrieved on Aug. 24, 2019].

Homa Alemzadeh et al., "Targeted Attacks on Teleoperated Surgical Robots: Dynamic Model-Based Detection and Mitigation," 2016 46th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN), IEEE, Jun. 28, 2016, pp. 395-406.

Phumzile Malindi, "5. QoS in Telemedicine," "Telemedicine," Jun. 20, 2011, IntechOpen, pp. 119-138.

Staub et al., "Contour-based Surgical Instrument Tracking Supported by Kinematic Prediction," Proceedings of the 2010 3rd IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics, Sep. 1, 2010, pp. 746-752.

Allan et al., "3-D Pose Estimation of Articulated Instruments in Robotic Minimally Invasive Surgery," IEEE Transactions on Medical Imaging, vol. 37, No. 5, May 1, 2018, pp. 1204-1213.

Kassahun et al., "Surgical Robotics Beyond Enhanced Dexterity Instrumentation: A Survey of the Machine Learning Techniques and their Role in Intelligent and Autonomous Surgical Actions." International Journal of Computer Assisted Radiology and Surgery, vol. 11, No. 4, Oct. 8, 2015, pp. 553-568.

Weede et al. "An Intelligent and Autonomous Endoscopic Guidance System for Minimally Invasive Surgery," 2013 IEEE International Conference on Robotics ad Automation (ICRA), May 6-10, 2013. Karlsruhe, Germany, May 1, 2011, pp. 5762-5768.

Altenberg et al., "Genes of Glycolysis are Ubiquitously Overexpressed in 24 Cancer Classes," Genomics, vol. 84, pp. 1014-1020 (2004).

Harold I. Brandon and V. Leroy Young, Mar. 1997, Surgical Services Management vol. 3 No. 3. retrieved from the internet <https://www.surgimedics.com/Research%20Articles/Electrosurgical%20Plume/Characterization%20And%20Removal%20Of%20Electrosurgical%20Smoke.pdf> (Year: 1997).

Marshall Brain, How Microcontrollers Work, 2006, retrieved from the internet <https://web.archive.org/web/20060221235221/http://electronics.howstuffworks.com/microcontroller.htm/printable> (Year: 2006).

CRC Press, "The Measurement, Instrumentation and Sensors Handbook," 1999, Section VII, Chapter 41, Peter O'Shea, "Phase Measurement," pp. 1303-1321, ISBN 0-8493-2145-X.

Jiang, "'Sound of Silence' : a secure indoor wireless ultrasonic communication system," Article, 2014, pp. 46-50, Snapshots of Doctoral Research at University College Cork, School of Engineering—Electrical & Electronic Engineering, UCC, Cork, Ireland.

Li, et al., "Short-range ultrasonic communications in air using quadrature modulation," Journal, Oct. 30, 2009, pp. 2060-2072, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 56, No. 10, IEEE.

Salamon, "AI Detects Polyps Better Than Colonoscopists" Online Article, Jun. 3, 2018, Medscape Medical News, Digestive Disease Week (DDW) 2018: Presentation 133.

Misawa, et al. "Artificial Intelligence-Assisted Polyp Detection for Colonoscopy: Initial Experience," Article, Jun. 2018, pp. 2027-2029, vol. 154, Issue 8, American Gastroenterolgy Association.

Dottorato, "Analysis and Design of the Rectangular Microstrip Patch Antennas for TM0n0 operating mode," Article, Oct. 8, 2010, pp. 1-9, Microwave Journal.

Miller, et al., "Impact of Powered and Tissue-Specific Endoscopic Stapling Technology on Clinical and Economic Outcomes of Video-Assisted Thoracic Surgery Lobectomy Procedures: A Retrospective, Observational Study," Article, Apr. 2018, pp. 707-723, vol. 35 (Issue 5), Advances in Therapy.

Hsiao-Wei Tang, "ARCM", Video, Sep. 2012, YouTube, 5 screenshots, Retrieved from internet: <https://www.youtube.com/watch?v=UldQaxb3fRw&feature=youtu.be>.

Giannios, et al., "Visible to near-infrared refractive properties of freshly-excised human-liver tissues: marking hepatic malignancies," Article, Jun. 14, 2016, pp. 1-10, Scientific Reports 6, Article No. 27910, Nature.

Vander Heiden, et al., "Understanding the Warburg effect: the metabolic requirements of cell proliferation," Article, May 22, 2009, pp. 1-12, vol. 324, Issue 5930, Science.

Hirayama et al., "Quantitative Metabolome Profiling of Colon and Stomach Cancer Microenvironment by Capillary Electrophoresis Time-of-Flight Mass Spectrometry," Article, Jun. 2009, pp. 4918-4925, vol. 69, Issue 11, Cancer Research.

Cengiz, et al., "A Tale of Two Compartments: Interstitial Versus Blood Glucose Monitoring," Article, Jun. 2009, pp. S11-S16, vol. 11, Supplement 1, Diabetes Technology & Therapeutics.

Shen, et al., "An iridium nanoparticles dispersed carbon based thick film electrochemical biosensor and its application for a single use, disposable glucose biosensor," Article, Feb. 3, 2007, pp. 106-113, vol. 125, Issue 1, Sensors and Actuators B: Chemical, Science Direct.

"ATM-MPLS Network Interworking Version 2.0, af-aic-0178.001" ATM Standard, The ATM Forum Technical Committee, published Aug. 2003.

IEEE Std 802.3—2012 (Revision of IEEE Std 802.3-2008, published Dec. 28, 2012.

IEEE Std No. 177, "Standard Definitions and Methods of Measurement for Piezoelectric Vibrators," published May 1966, The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y.

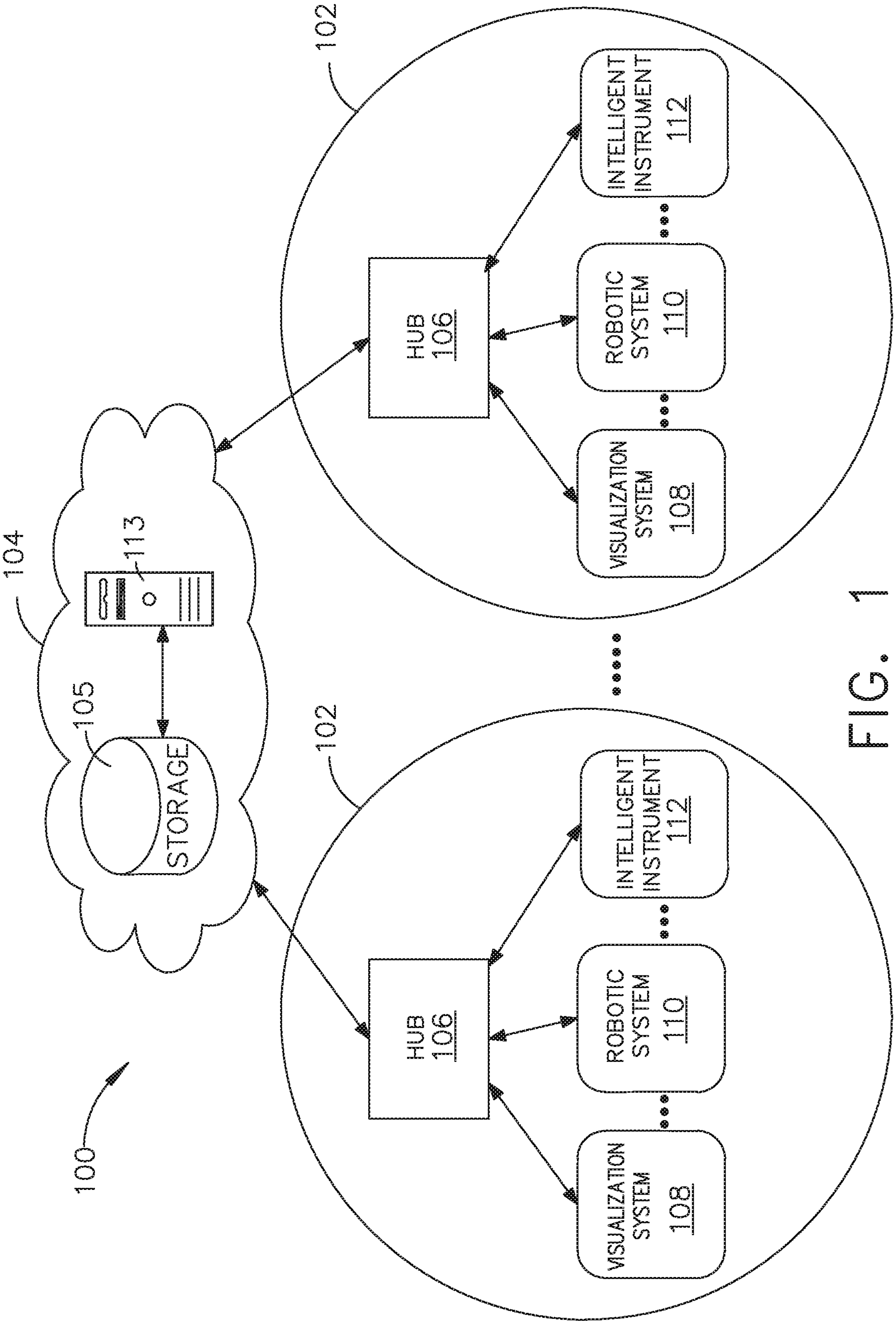
Choi et al., A haptic augmented reality surgeon console for a laparoscopic surgery robot system, 2013, IEEE, pp. 355-357 (Year: 2013).

Shi et al., An intuitive control console for robotic syrgery system, 2014, IEEE, pp. 404-407 (Year: 2014).

Sun et al., Innovative effector design for simulation training in robotic surgery, 2010, IEEE, pp. 1735-1759 (Year: 2010).

Xie et al., Development of stereo vision and master-slave controller for a compact surgical robot system, 2015, IEEE, pp. 403-407 (Year: 2015).

* cited by examiner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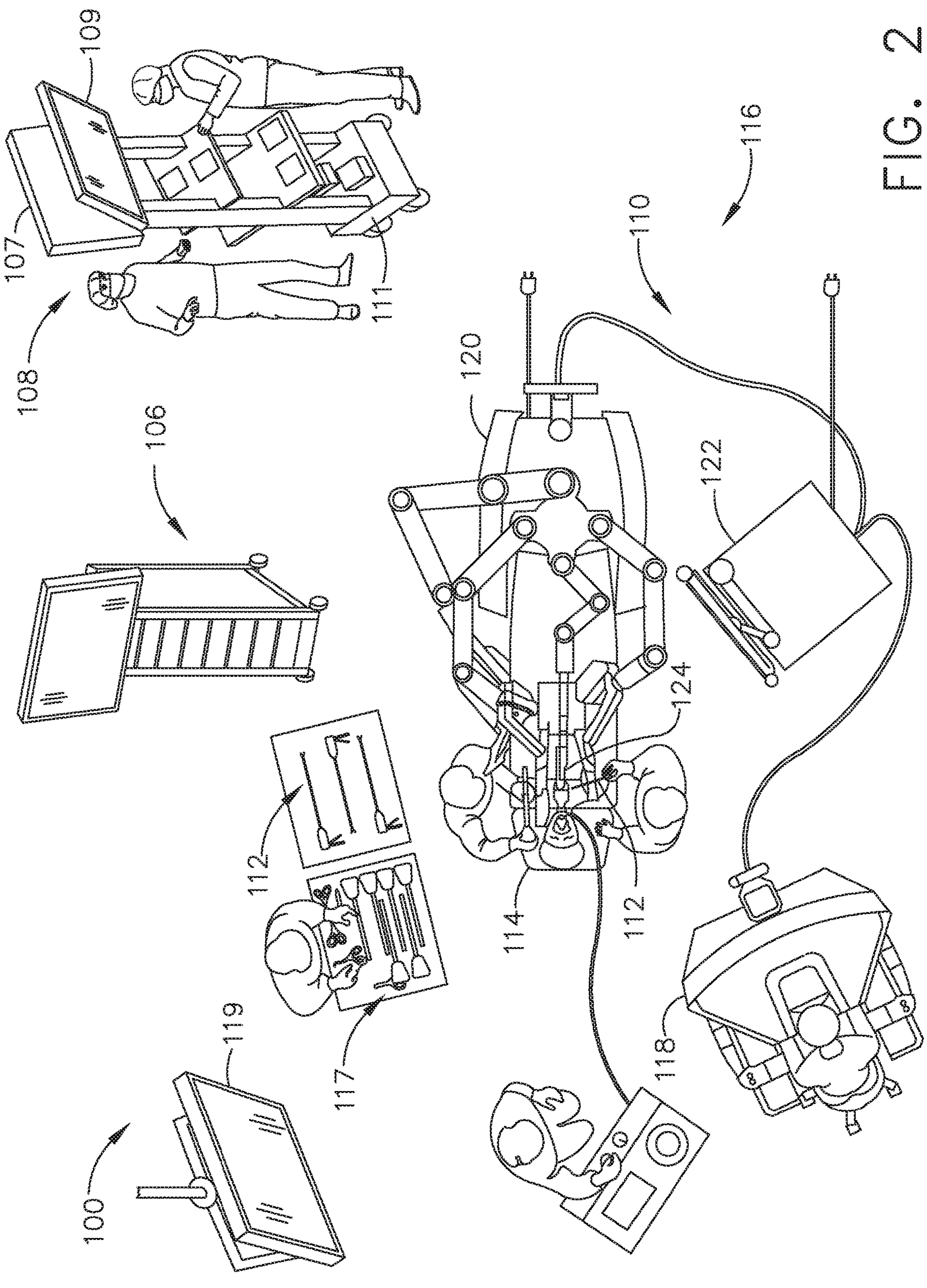
104
105
STORAGE
113
102
HUB 106
VISUALIZATION SYSTEM 108
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112
102
HUB 106
VISUALIZATION SYSTEM 108
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112

FIG. 1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106
107
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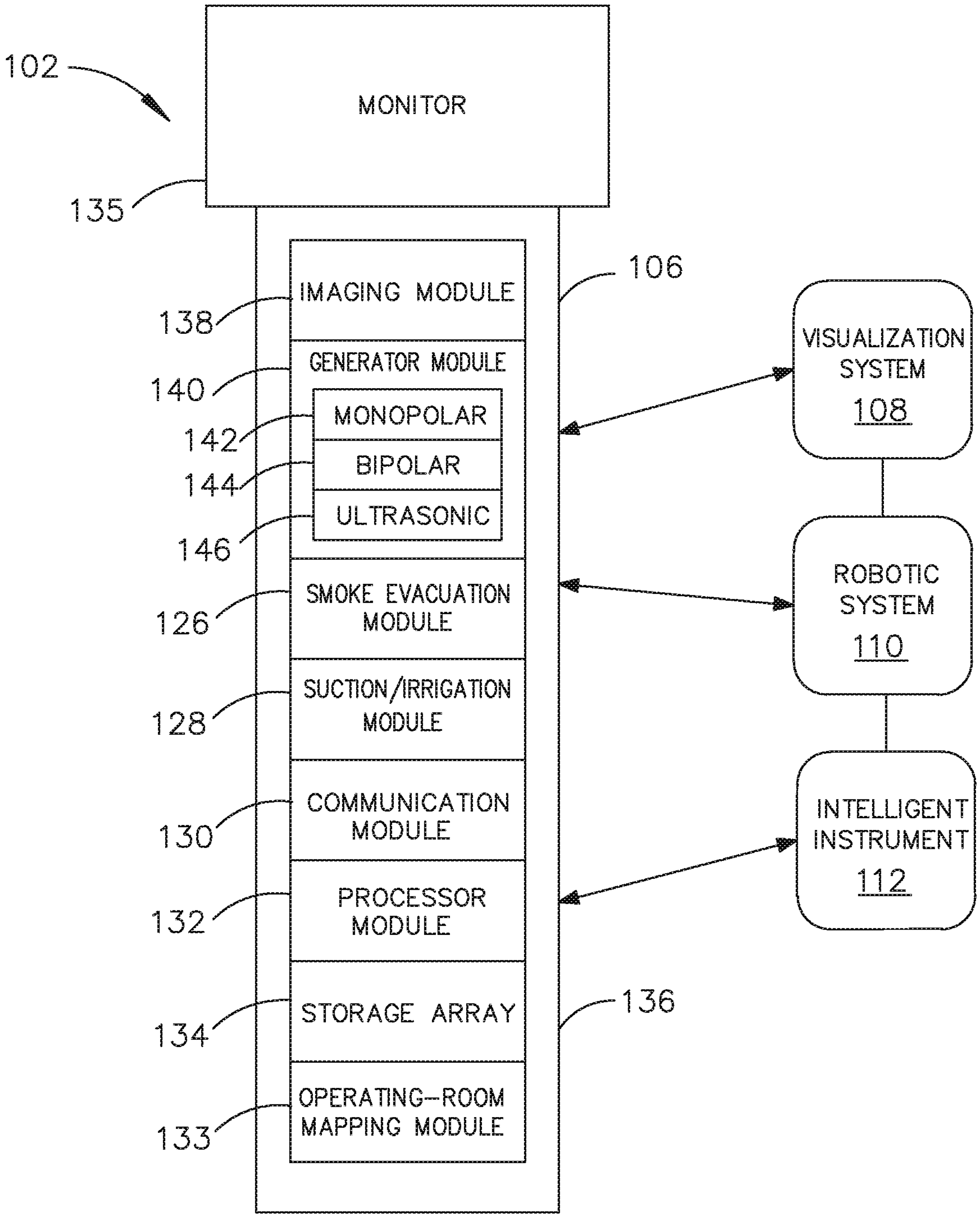
109
110
111
112
112
112
114
116
117
118
119
120
122
124

FIG. 2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MONITOR
135
106
IMAGING MODULE
138
GENERATOR MODULE
140
MONOPOLAR
142
BIPOLAR
144
ULTRASONIC
146
SMOKE EVACUATION MODULE
126
SUCTION/IRRIGATION MODULE
128
COMMUNICATION MODULE
130
PROCESSOR MODULE
132
STORAGE ARRAY
134
136
OPERATING-ROOM MAPPING MODULE
133
VISUALIZATION SYSTEM
108
ROBOTIC SYSTEM
110
INTELLIGENT INSTRUMENT
112

FIG. 3

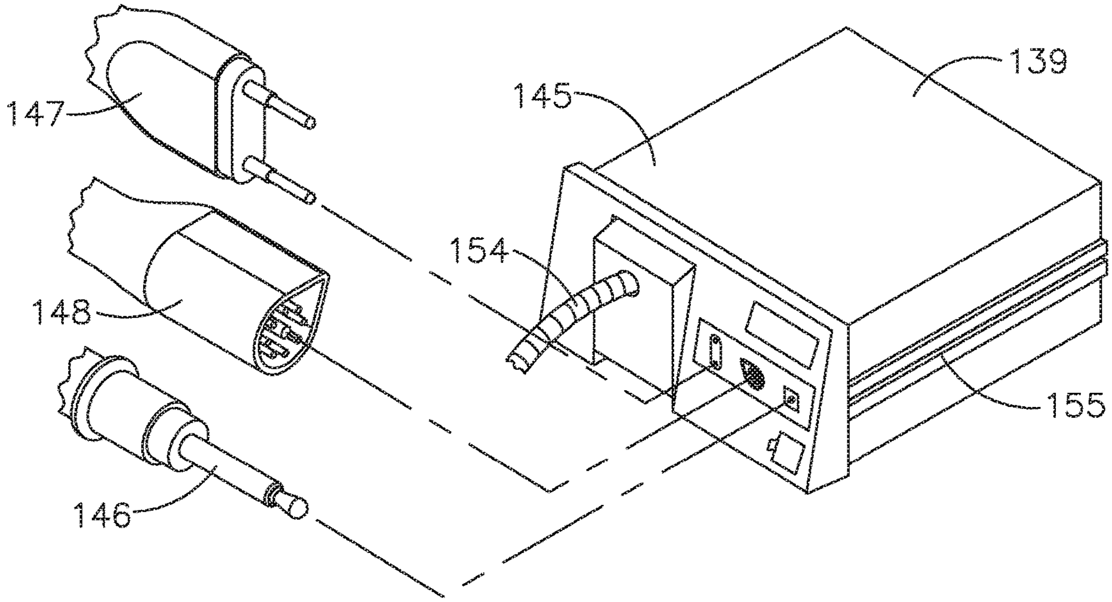
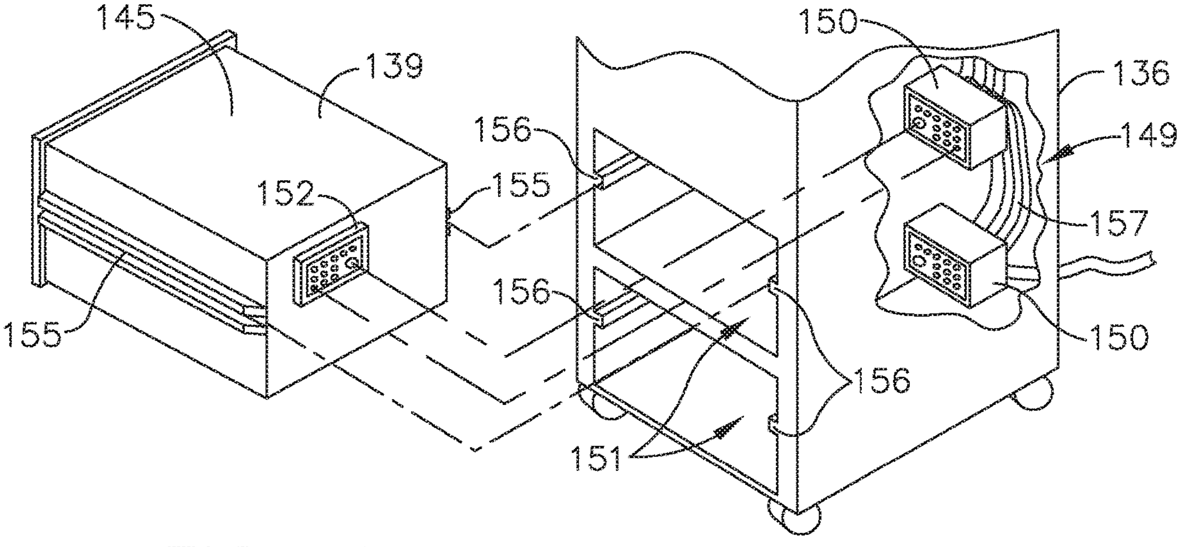

147
145
139
154
148
155
146

FIG. 5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150
156
151

FIG. 4

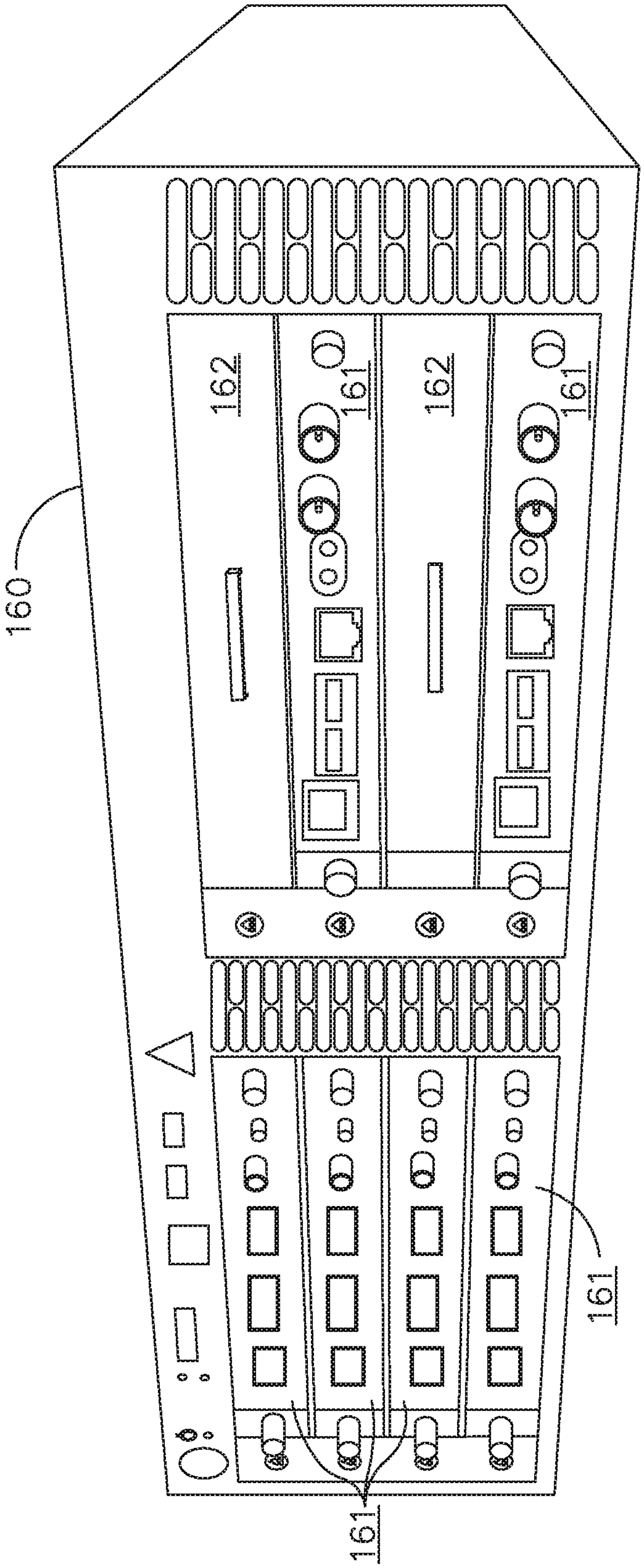


FIG. 6

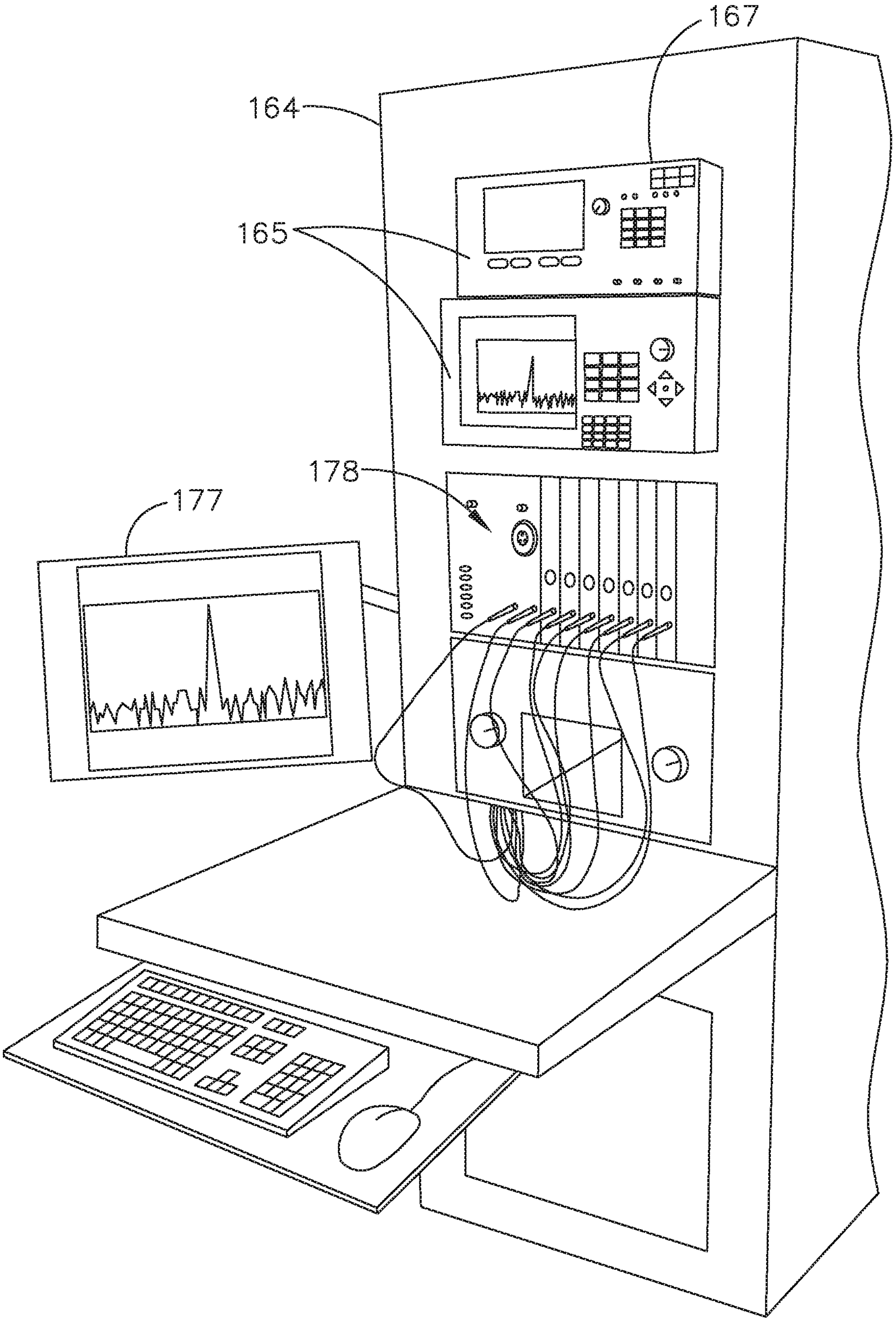
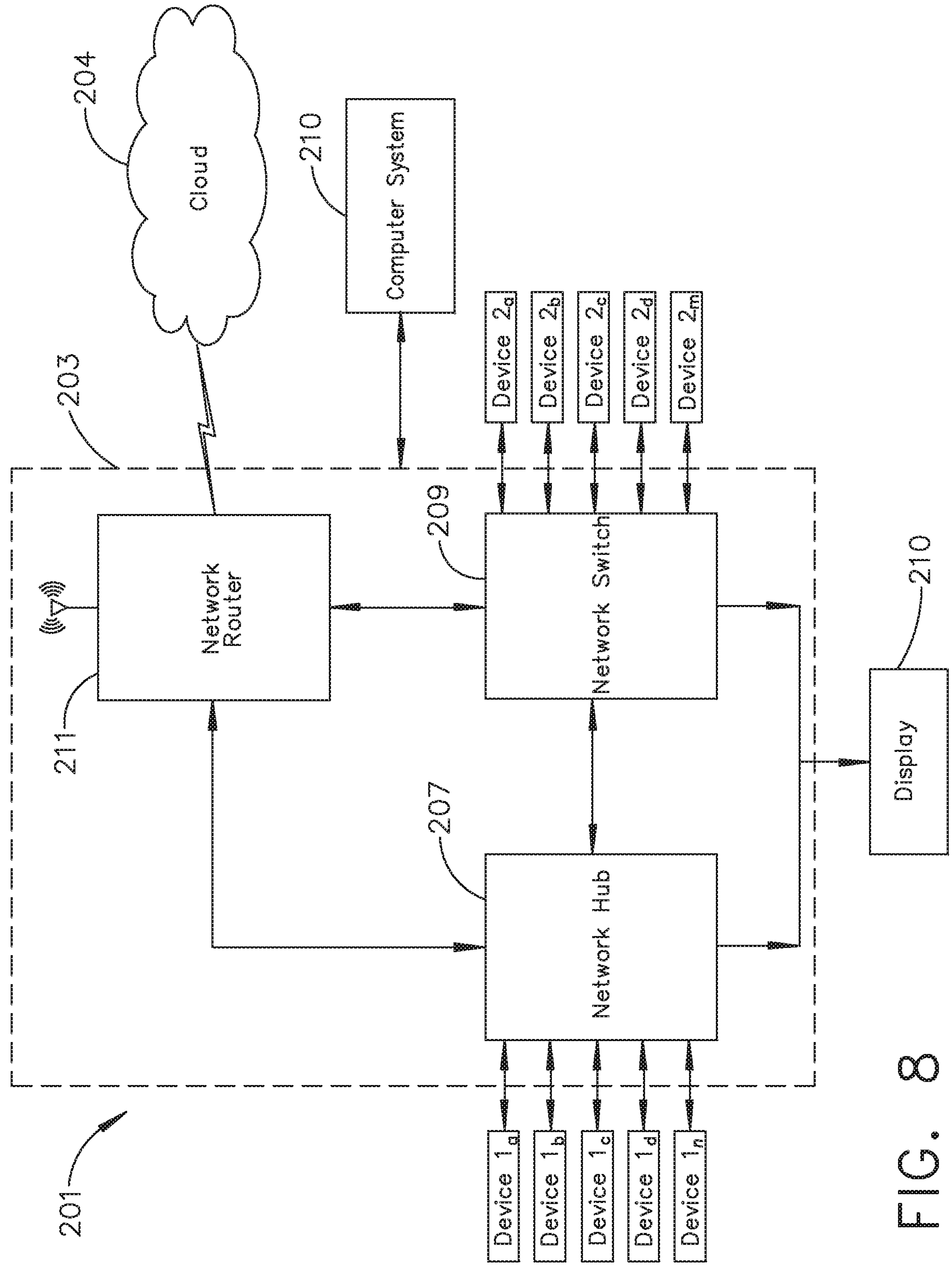


FIG. 7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Cloud
210
Computer System
203
Device 2_a
Device 2_b
Device 2_c
Device 2_d
Device 2_m
209
Network Switch
Network Router
211
210
Display
207
Network Hub
Device 1_a
Device 1_b
Device 1_c
Device 1_d
Device 1_n
201

FIG. 8

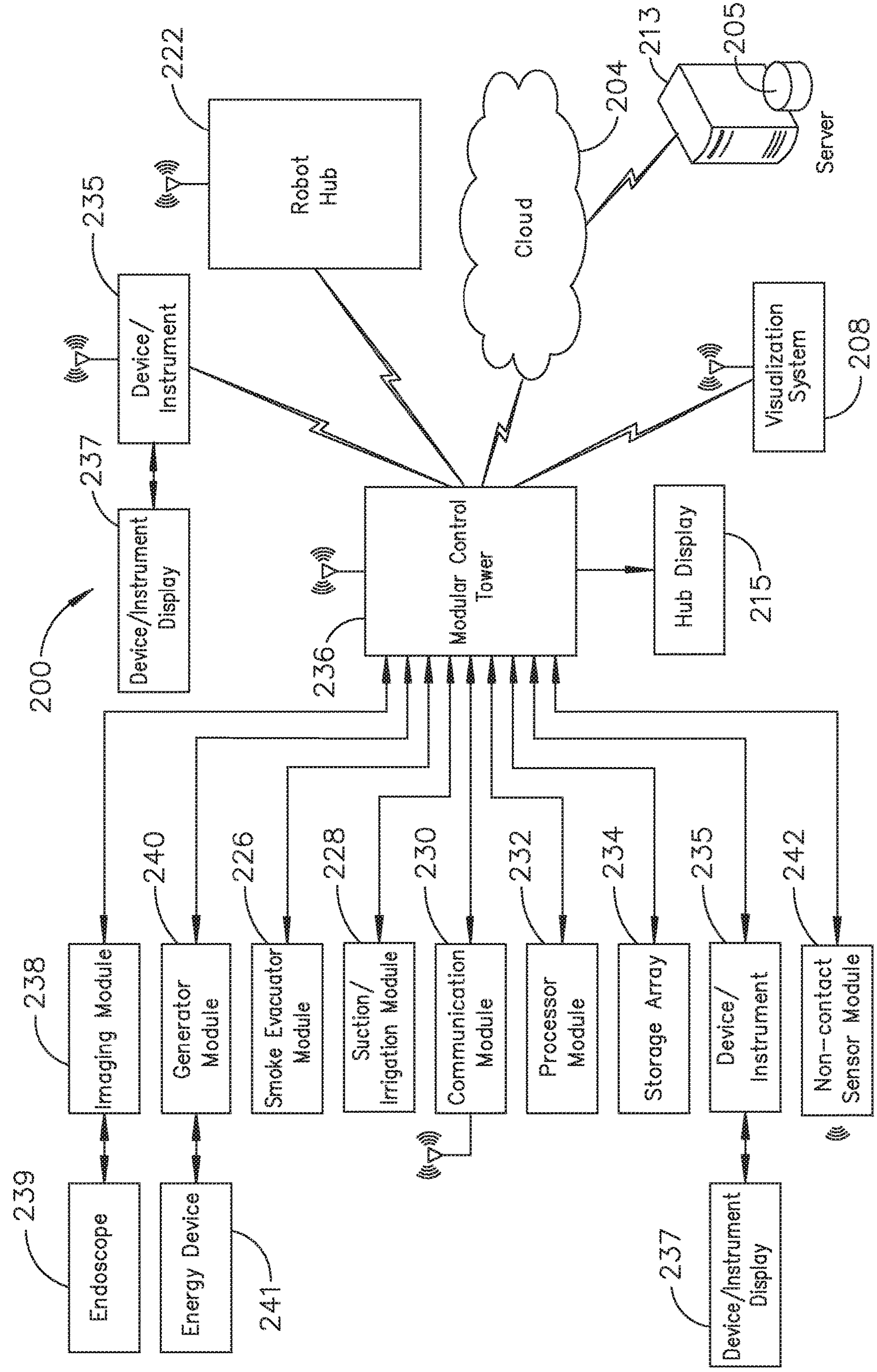
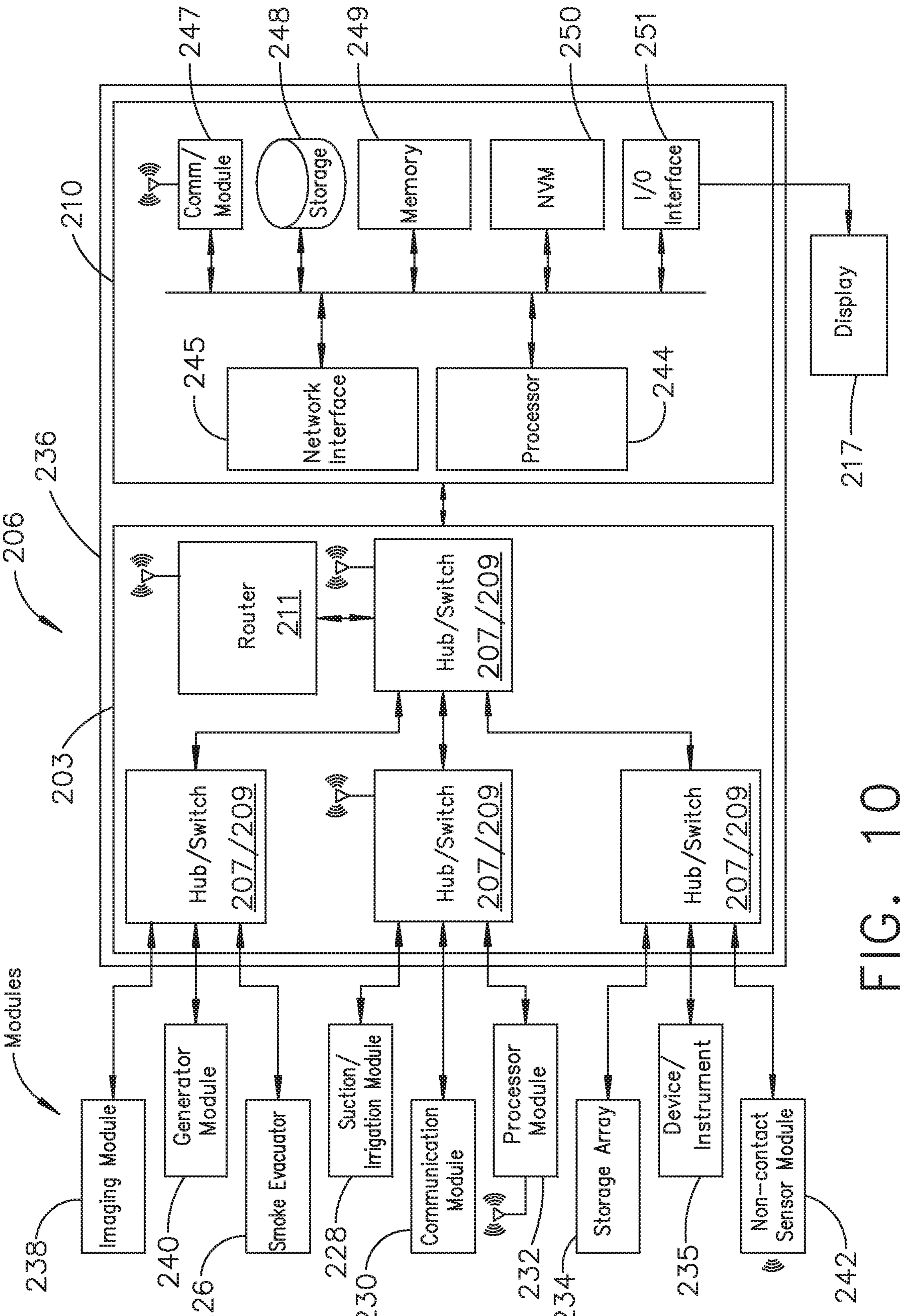

200
Device/Instrument Display
237
Device/Instrument
235
Robot Hub
222
Cloud
204
213
205
Server
Visualization System
208
Modular Control Tower
236
Hub Display
215
Imaging Module
238
Generator Module
240
Smoke Evacuator Module
226
Suction/Irrigation Module
228
Communication Module
230
Processor Module
232
Storage Array
234
Device/Instrument
235
Non-contact Sensor Module
242
Endoscope
239
Energy Device
241
Device/Instrument Display
237

FIG. 9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236
210
203
Comm/ Module
247
Storage
248
Memory
249
NVM
250
I/O Interface
251
Network Interface
245
Processor
244
Display
217
Router
211
Hub/Switch
207/209
Hub/Switch
207/209
Hub/Switch
207/209
Hub/Switch
207/209
Modules
Imaging Module
238
Generator Module
240
Smoke Evacuator
226
Suction/ Irrigation Module
228
Communication Module
230
Processor Module
232
Storage Array
234
Device/ Instrument
235
Non-contact Sensor Module
242

FIG. 10

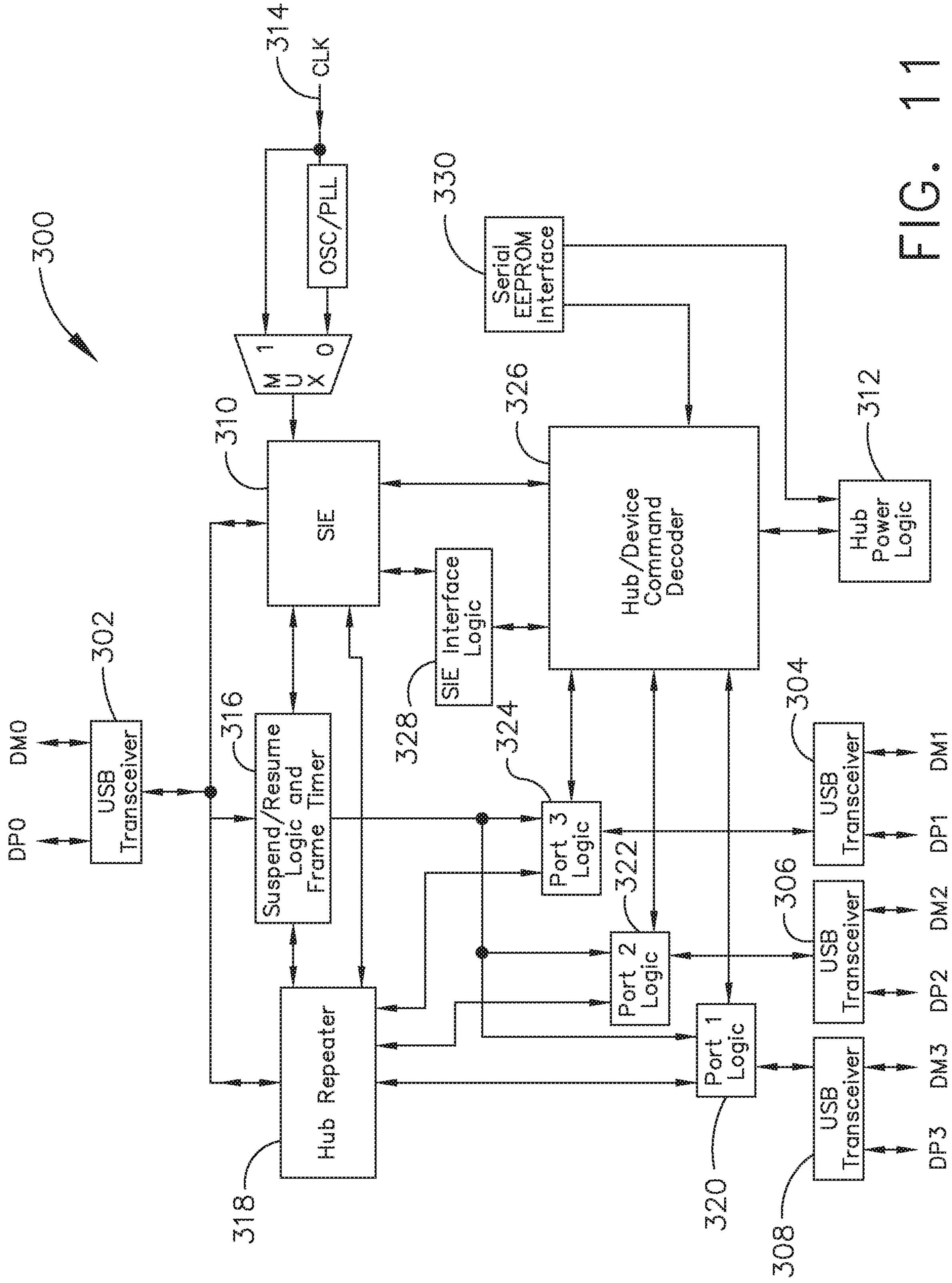

300
314
CLK
OSC/PLL
M U X
1
0
330
Serial EEPROM Interface
310
SIE
326
Hub/Device Command Decoder
312
Hub Power Logic
302
DM0
DP0
USB Transceiver
316
Suspend/Resume Logic and Frame Timer
328
SIE Interface Logic
324
Port 3 Logic
304
USB Transceiver
DM1
DP1
322
Port 2 Logic
306
USB Transceiver
DM2
DP2
Hub Repeater
318
Port 1 Logic
320
USB Transceiver
DM3
DP3
308

FIG. 11

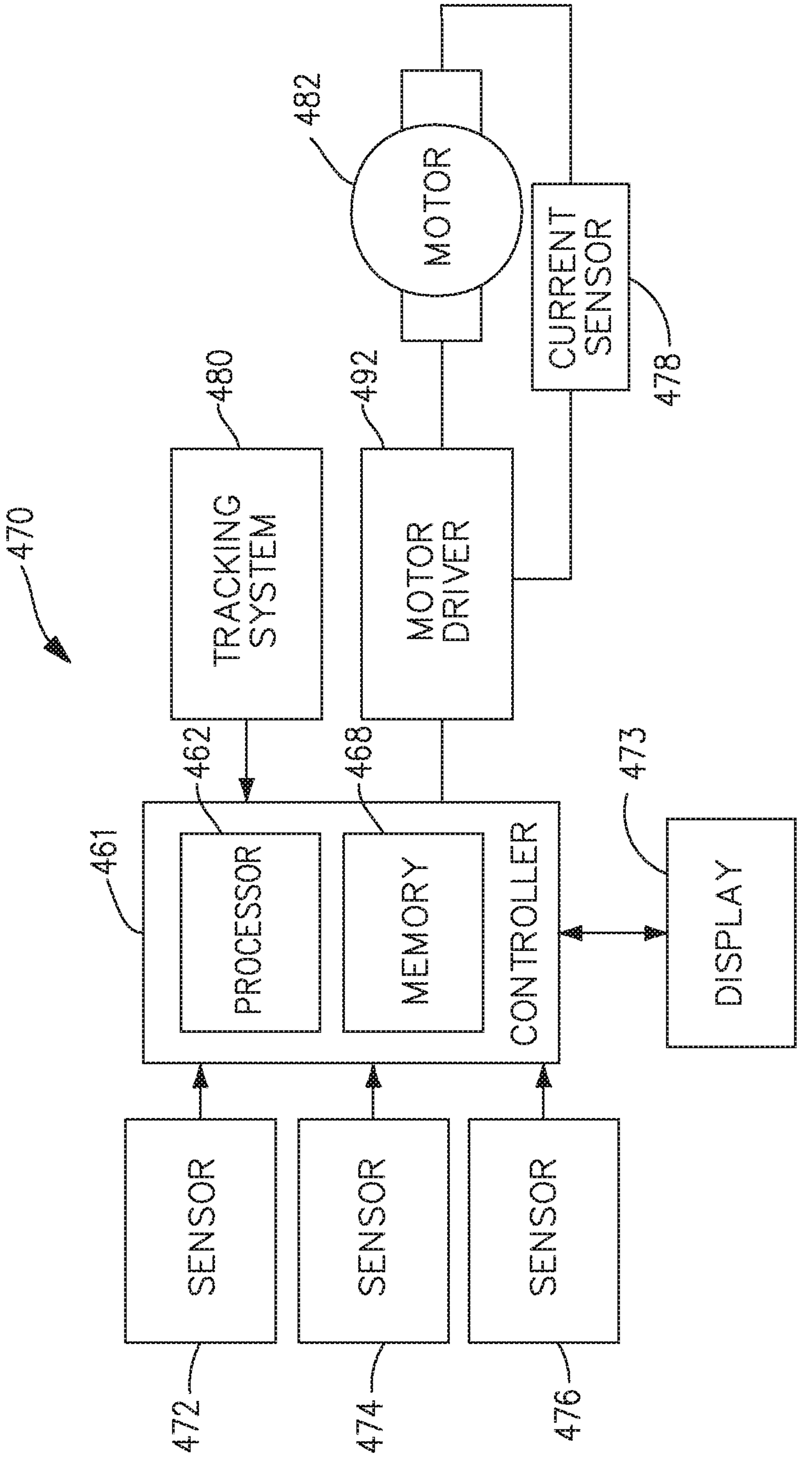

470
TRACKING SYSTEM
480
MOTOR DRIVER
492
MOTOR
482
CURRENT SENSOR
478
PROCESSOR
462
MEMORY
468
CONTROLLER
461
DISPLAY
473
SENSOR
472
SENSOR
474
SENSOR
476

FIG. 12

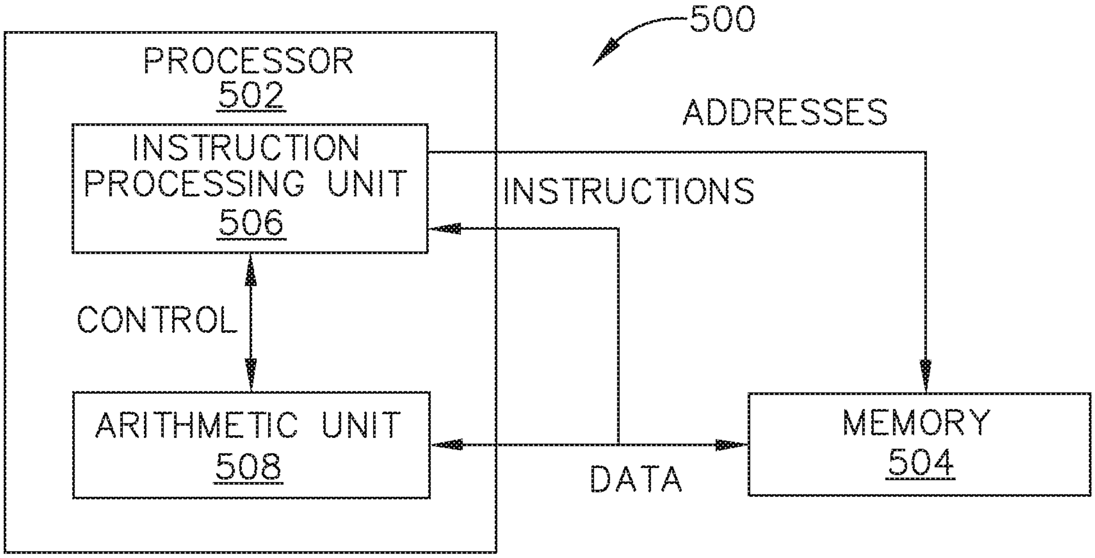


FIG. 13

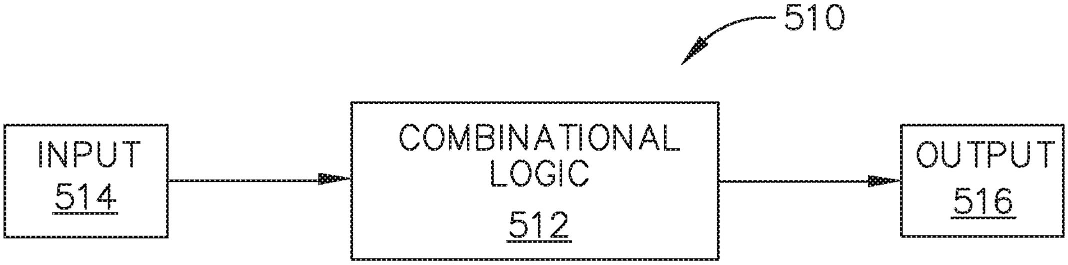


FIG. 14

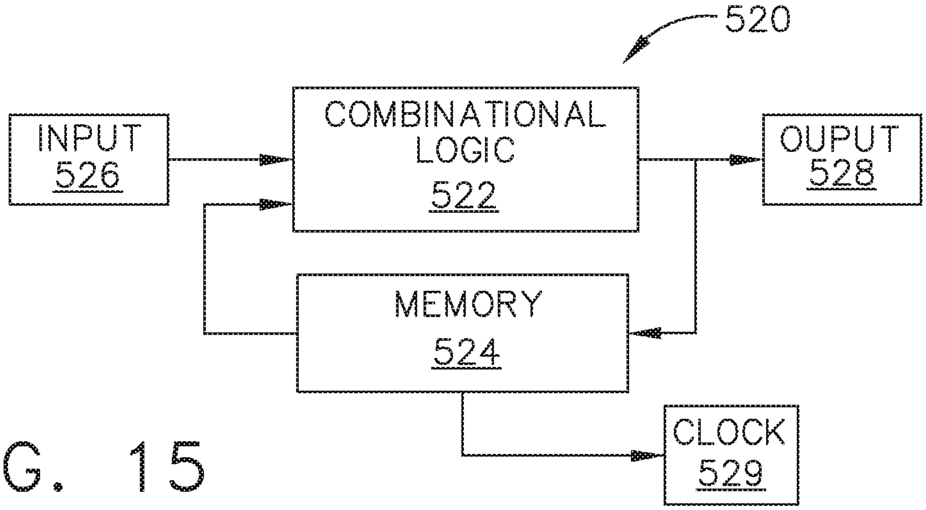


FIG. 15

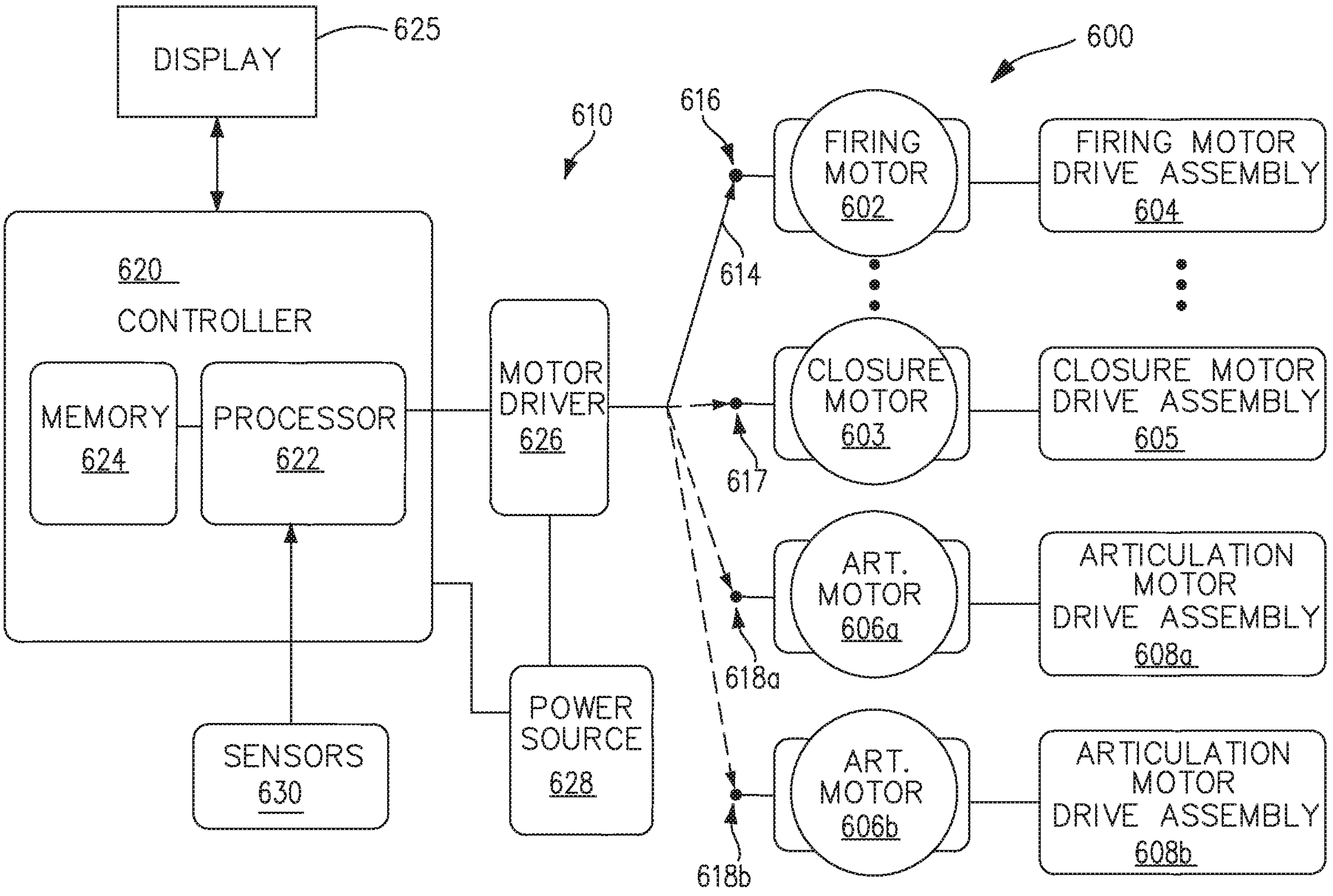

DISPLAY
625
600
610
616
620
CONTROLLER
MEMORY
624
PROCESSOR
622
MOTOR
DRIVER
626
614
617
618a
618b
FIRING
MOTOR
602
FIRING MOTOR
DRIVE ASSEMBLY
604
CLOSURE
MOTOR
603
CLOSURE MOTOR
DRIVE ASSEMBLY
605
ART.
MOTOR
606a
ARTICULATION
MOTOR
DRIVE ASSEMBLY
608a
ART.
MOTOR
606b
ARTICULATION
MOTOR
DRIVE ASSEMBLY
608b
SENSORS
630
POWER
SOURCE
628

FIG. 16

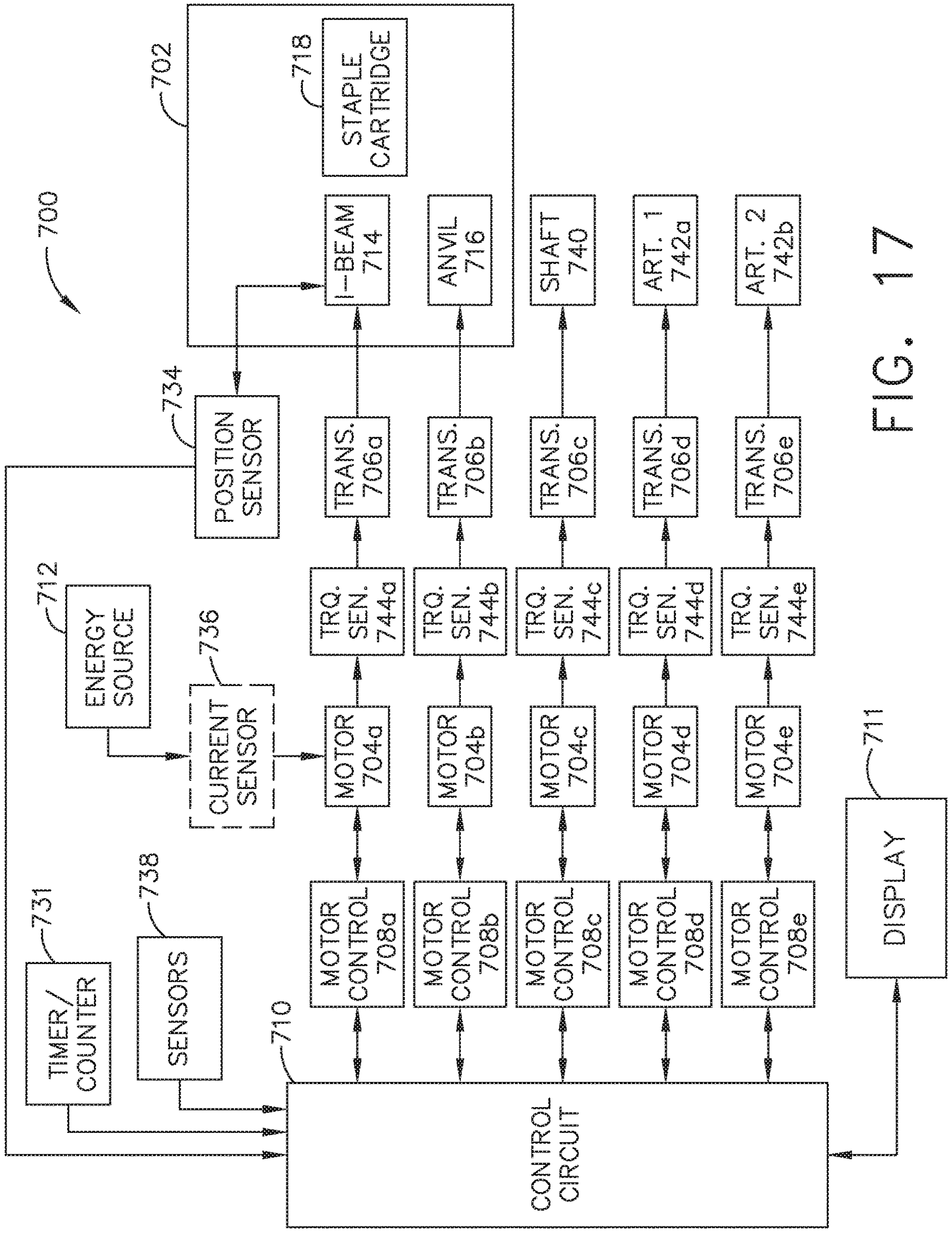

700
702
718
STAPLE CARTRIDGE
I—BEAM 714
ANVIL 716
SHAFT 740
ART. 1 742a
ART. 2 742b
734
POSITION SENSOR
TRANS. 706a
TRANS. 706b
TRANS. 706c
TRANS. 706d
TRANS. 706e
712
ENERGY SOURCE
736
CURRENT SENSOR
TRQ. SEN. 744a
TRQ. SEN. 744b
TRQ. SEN. 744c
TRQ. SEN. 744d
TRQ. SEN. 744e
MOTOR 704a
MOTOR 704b
MOTOR 704c
MOTOR 704d
MOTOR 704e
731
TIMER/ COUNTER
738
SENSORS
MOTOR CONTROL 708a
MOTOR CONTROL 708b
MOTOR CONTROL 708c
MOTOR CONTROL 708d
MOTOR CONTROL 708e
711
DISPLAY
710
CONTROL CIRCUIT

FIG. 17

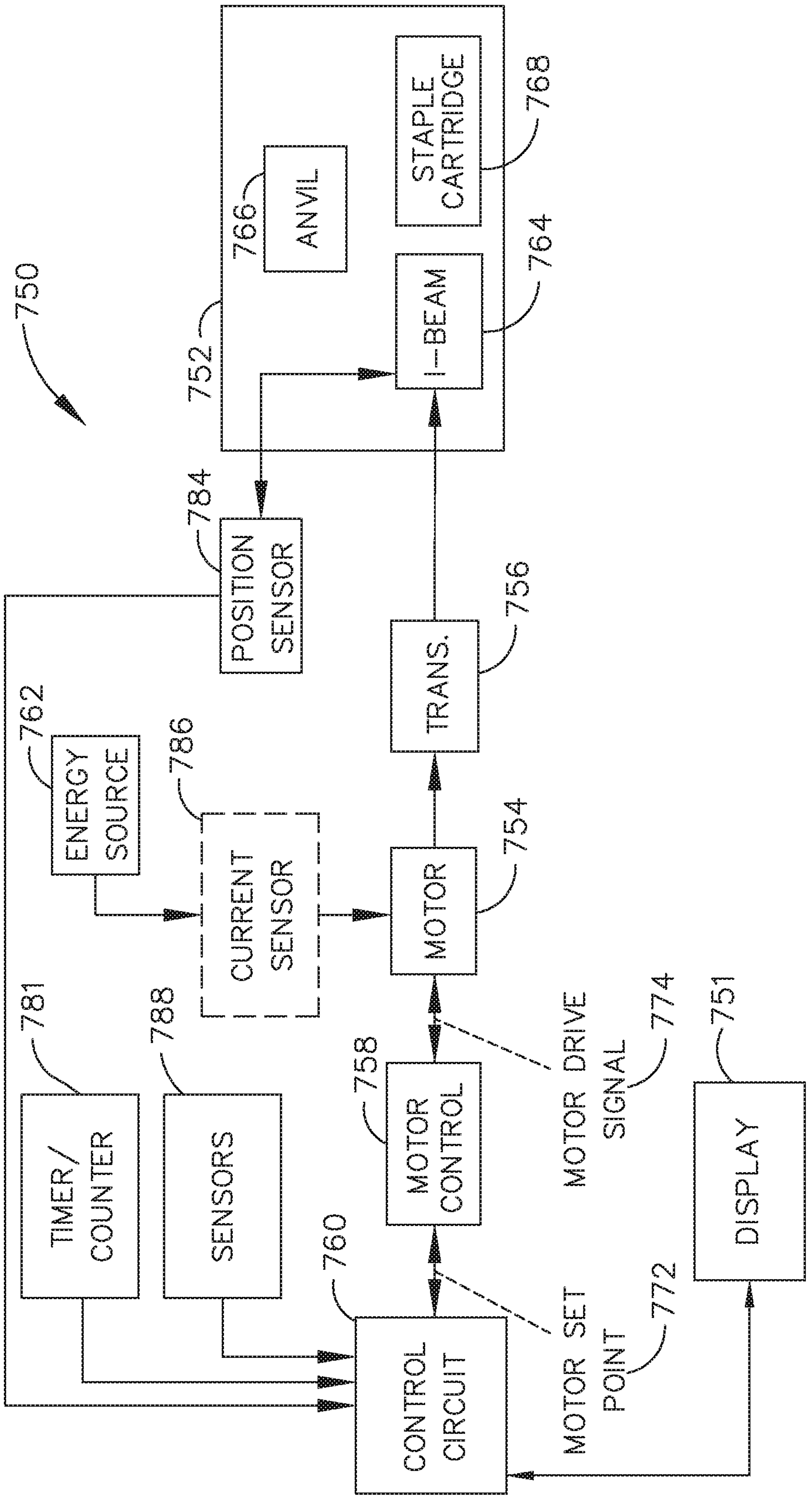

750
752
ANVIL
766
STAPLE CARTRIDGE
768
I—BEAM
764
POSITION SENSOR
784
TRANS.
756
ENERGY SOURCE
762
CURRENT SENSOR
786
MOTOR
754
TIMER / COUNTER
781
SENSORS
788
MOTOR CONTROL
758
MOTOR DRIVE SIGNAL
774
DISPLAY
751
CONTROL CIRCUIT
760
MOTOR SET POINT
772

FIG. 18

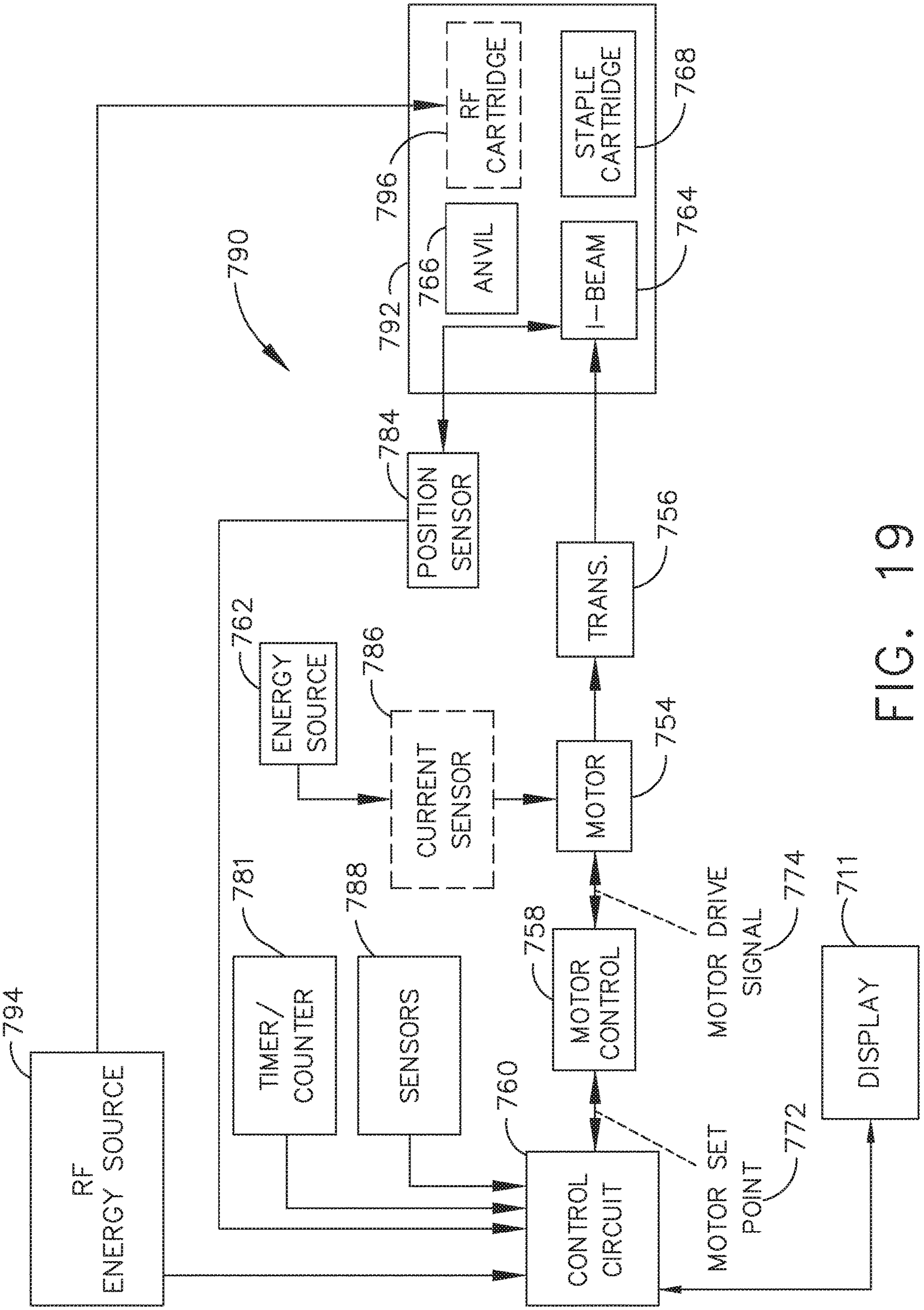

790
792
RF CARTRIDGE
796
STAPLE CARTRIDGE
768
ANVIL
766
I–BEAM
764
POSITION SENSOR
784
TRANS.
756
ENERGY SOURCE
762
CURRENT SENSOR
786
MOTOR
754
TIMER/ COUNTER
781
SENSORS
788
MOTOR CONTROL
758
MOTOR DRIVE SIGNAL
774
DISPLAY
711
RF ENERGY SOURCE
794
CONTROL CIRCUIT
760
MOTOR SET POINT
772

FIG. 19

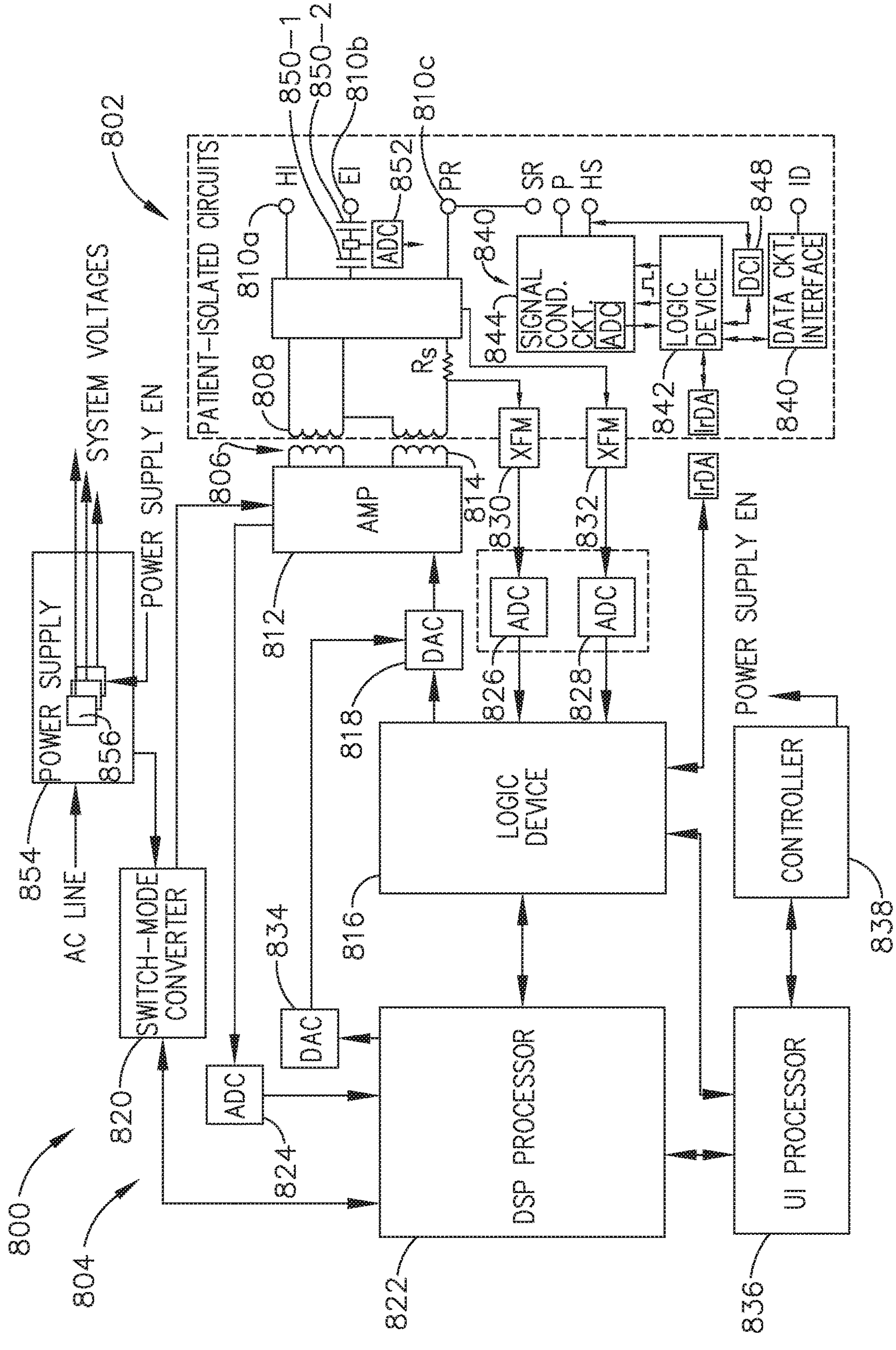

800
804
802
AC LINE
854
POWER SUPPLY
856
SYSTEM VOLTAGES
POWER SUPPLY EN
SWITCH-MODE CONVERTER
820
ADC
824
DAC
834
DSP PROCESSOR
822
LOGIC DEVICE
816
818
DAC
812
AMP
806
808
814
830
832
XFM
XFM
ADC
ADC
826
828
PATIENT-ISOLATED CIRCUITS
810a
HI
850-1
850-2
810b
EI
852
ADC
810c
PR
Rs
SR
P
HS
SIGNAL COND. CKT.
ADC
840
844
LOGIC DEVICE
842
IrDA
IrDA
DCI
848
DATA CKT. INTERFACE
ID
840
POWER SUPPLY EN
CONTROLLER
838
UI PROCESSOR
836

FIG. 20

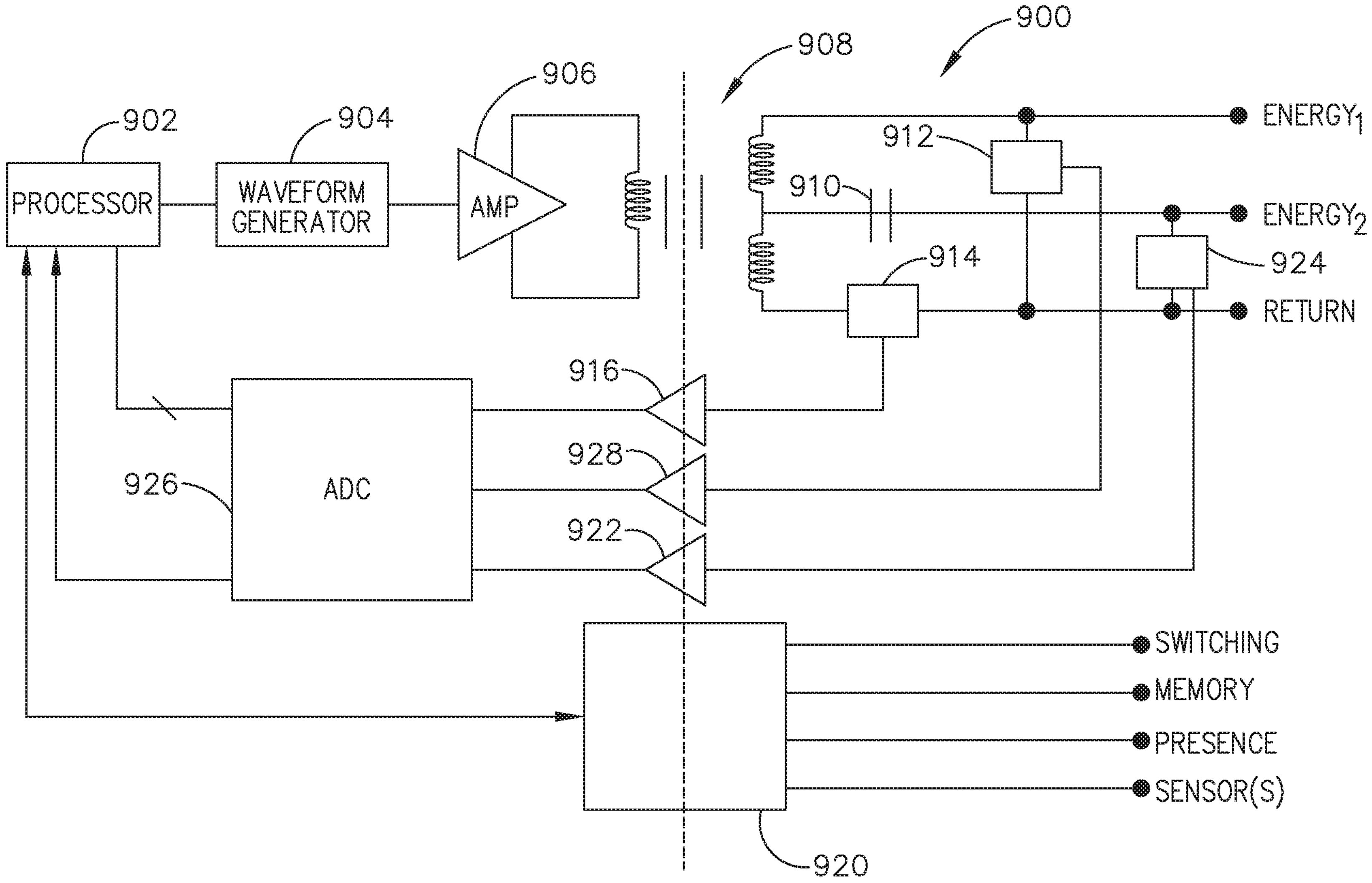

900
908
902
904
906
PROCESSOR
WAVEFORM GENERATOR
AMP
ENERGY$_1$
ENERGY$_2$
RETURN
912
910
914
924
916
928
922
926
ADC
SWITCHING
MEMORY
PRESENCE
SENSOR(S)
920

FIG. 21

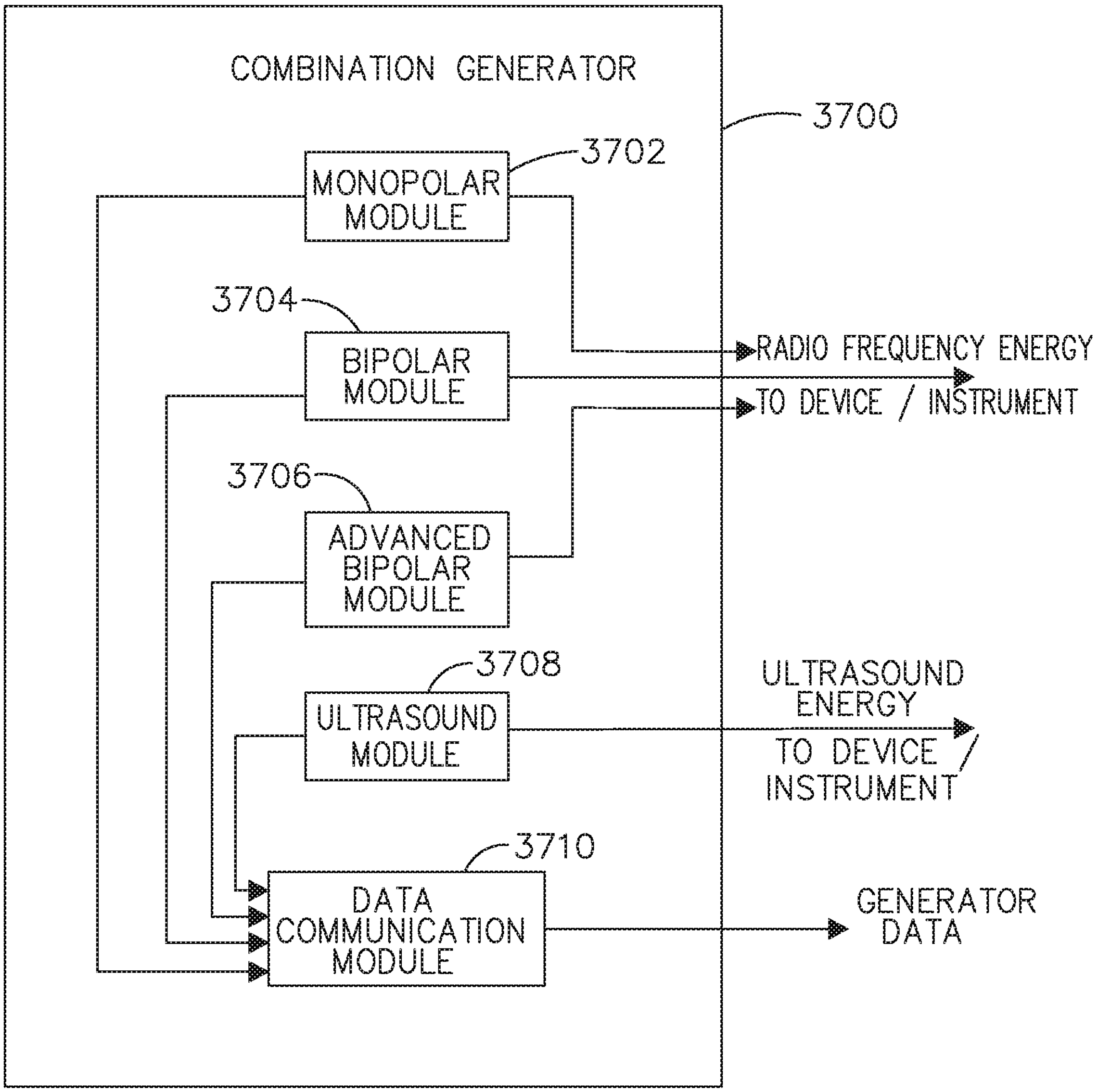

COMBINATION GENERATOR
3700
MONOPOLAR MODULE
3702
3704
BIPOLAR MODULE
3706
ADVANCED BIPOLAR MODULE
3708
ULTRASOUND MODULE
3710
DATA COMMUNICATION MODULE
RADIO FREQUENCY ENERGY
TO DEVICE / INSTRUMENT
ULTRASOUND ENERGY
TO DEVICE / INSTRUMENT
GENERATOR DATA

FIG. 22

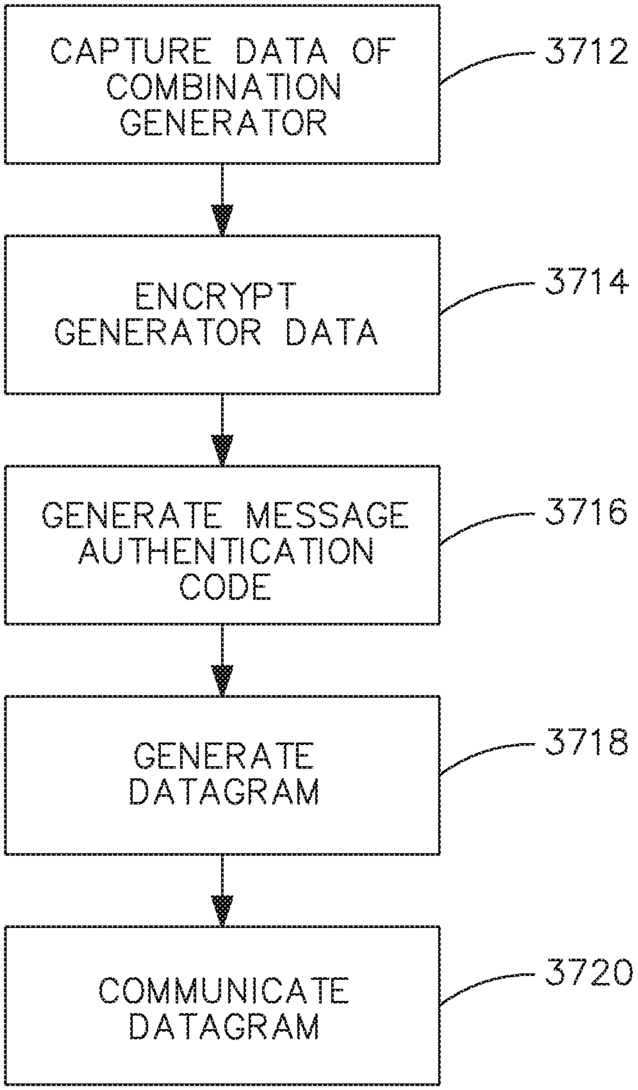

CAPTURE DATA OF COMBINATION GENERATOR
3712
ENCRYPT GENERATOR DATA
3714
GENERATE MESSAGE AUTHENTICATION CODE
3716
GENERATE DATAGRAM
3718
COMMUNICATE DATAGRAM
3720

FIG. 23

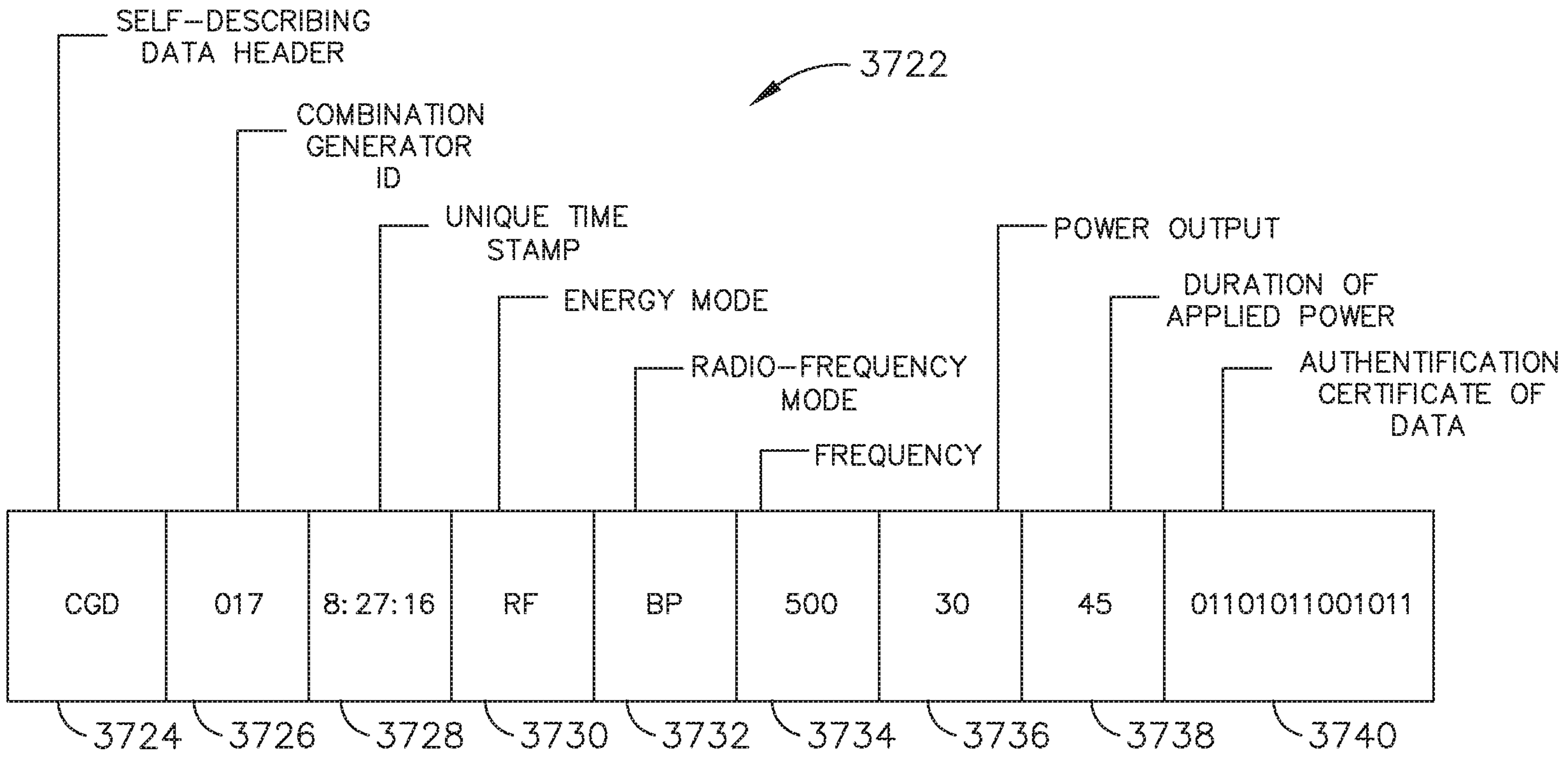

SELF-DESCRIBING DATA HEADER
3722
COMBINATION GENERATOR ID
UNIQUE TIME STAMP
ENERGY MODE
RADIO-FREQUENCY MODE
FREQUENCY
POWER OUTPUT
DURATION OF APPLIED POWER
AUTHENTIFICATION CERTIFICATE OF DATA
CGD
017
8:27:16
RF
BP
500
30
45
01101011001011
3724
3726
3728
3730
3732
3734
3736
3738
3740

FIG. 24

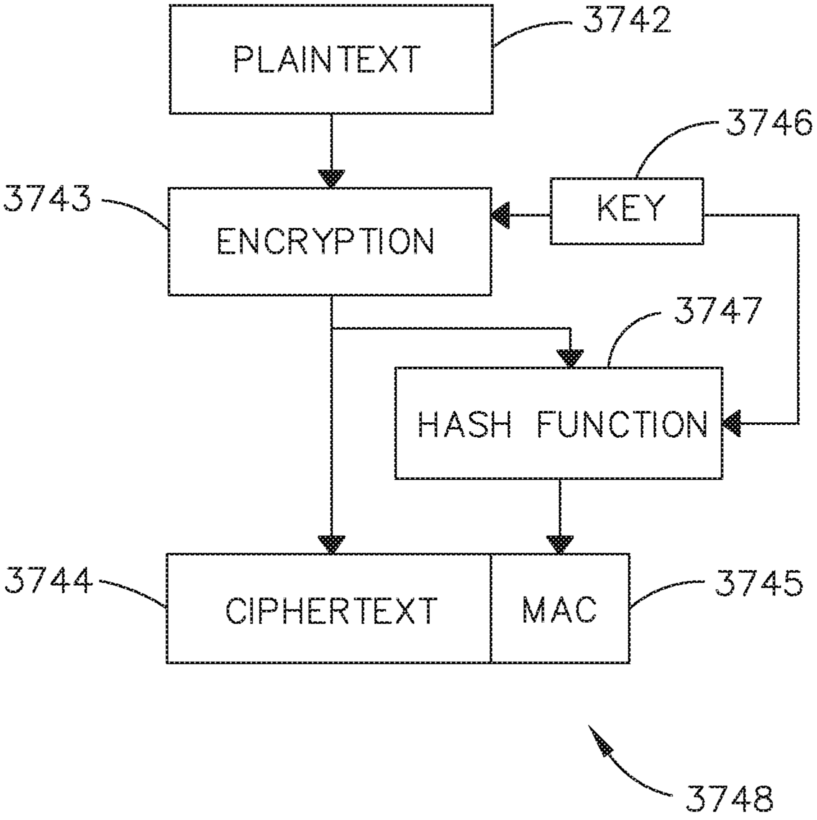

PLAINTEXT
3742
3746
3743
ENCRYPTION
KEY
3747
HASH FUNCTION
3744
CIPHERTEXT
MAC
3745
3748

FIG. 25

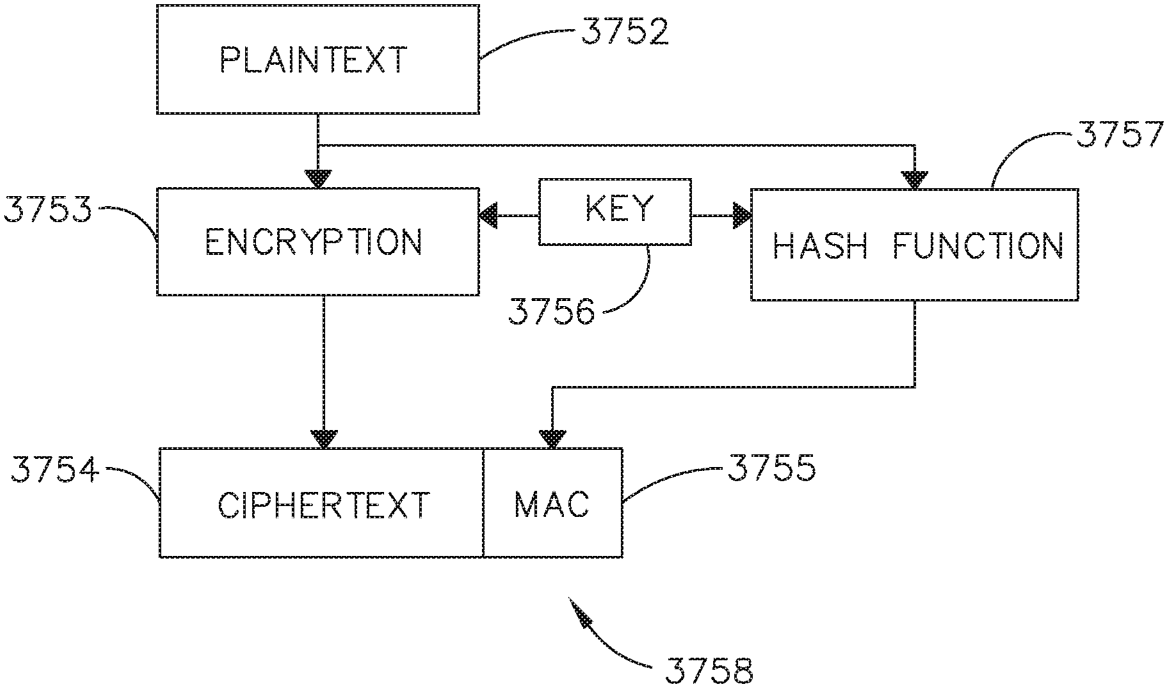

PLAINTEXT
3752
3757
3753
ENCRYPTION
KEY
HASH FUNCTION
3756
3754
CIPHERTEXT
MAC
3755
3758

FIG. 26

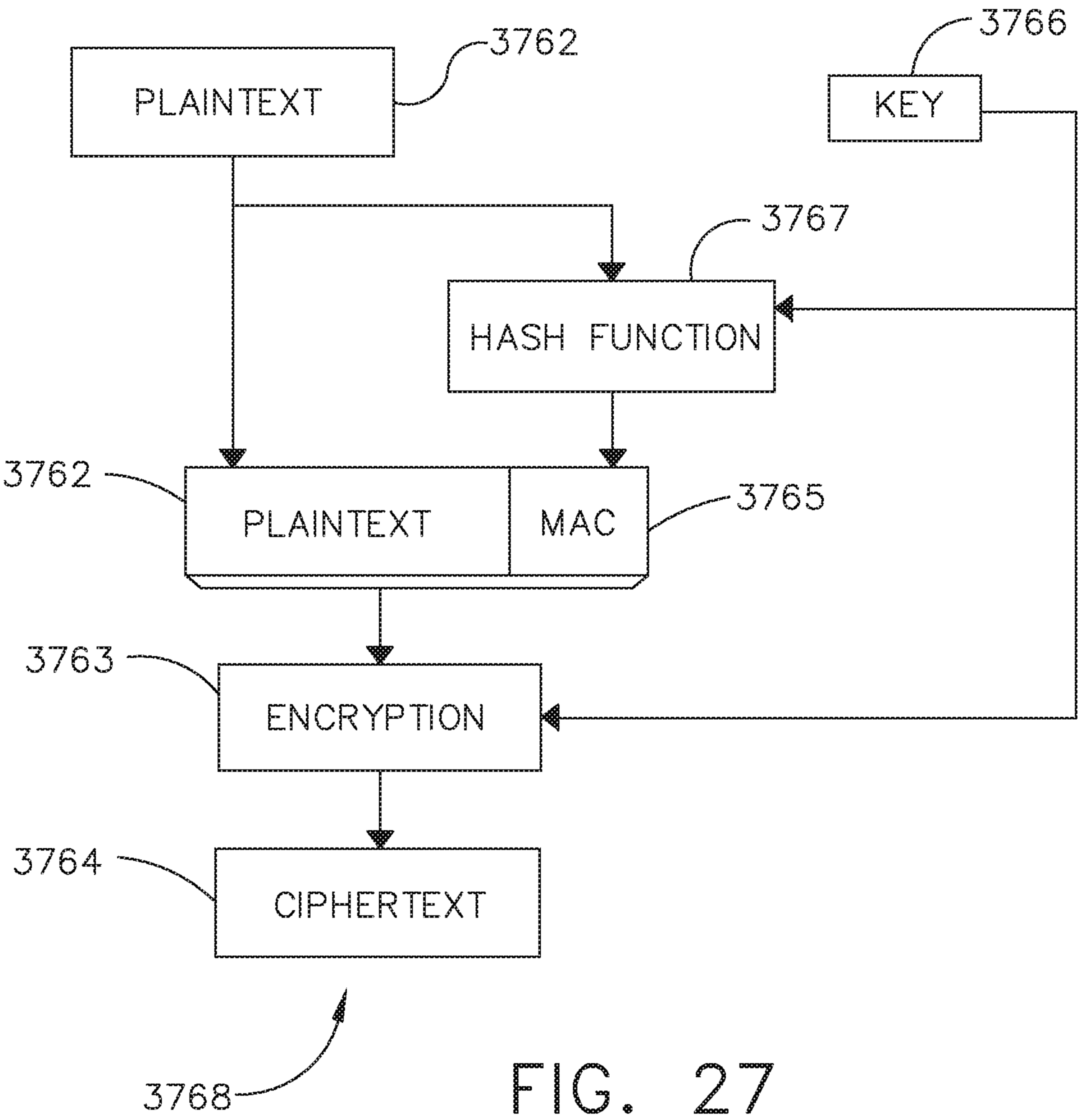

PLAINTEXT
3762
KEY
3766
3767
HASH FUNCTION
3762
PLAINTEXT
MAC
3765
3763
ENCRYPTION
3764
CIPHERTEXT
3768

FIG. 27

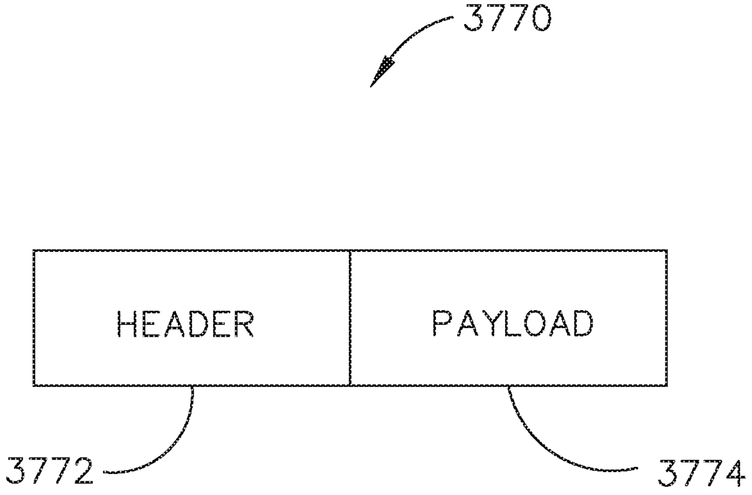


FIG. 28

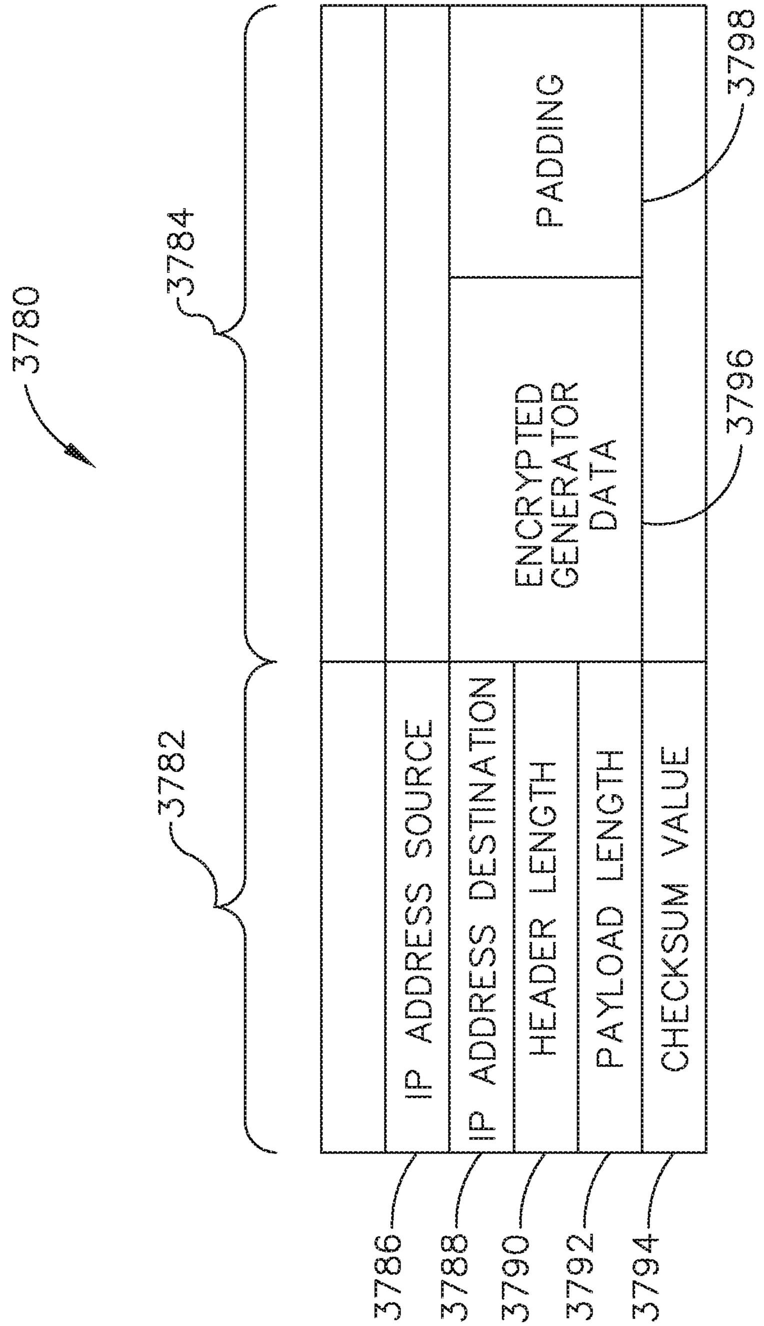

3780
3782
3784
IP ADDRESS SOURCE
IP ADDRESS DESTINATION
HEADER LENGTH
PAYLOAD LENGTH
CHECKSUM VALUE
ENCRYPTED GENERATOR DATA
PADDING
3786
3788
3790
3792
3794
3796
3798

FIG. 29

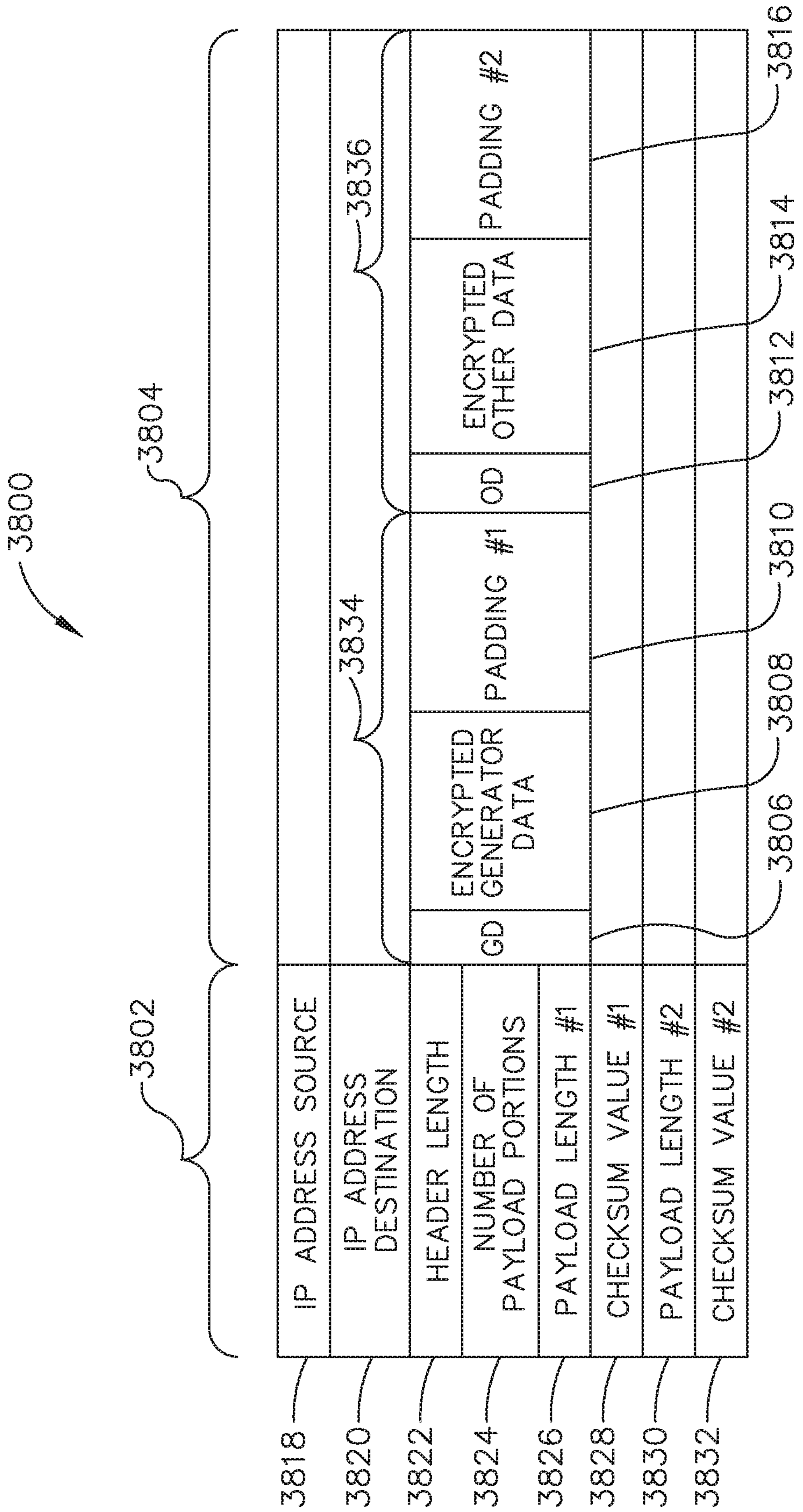

3800
3802
3804
IP ADDRESS SOURCE
IP ADDRESS DESTINATION
HEADER LENGTH
NUMBER OF PAYLOAD PORTIONS
PAYLOAD LENGTH #1
CHECKSUM VALUE #1
PAYLOAD LENGTH #2
CHECKSUM VALUE #2
3818
3820
3822
3824
3826
3828
3830
3832
GD
ENCRYPTED GENERATOR DATA
PADDING #1
OD
ENCRYPTED OTHER DATA
PADDING #2
3834
3836
3806
3808
3810
3812
3814
3816

FIG. 30

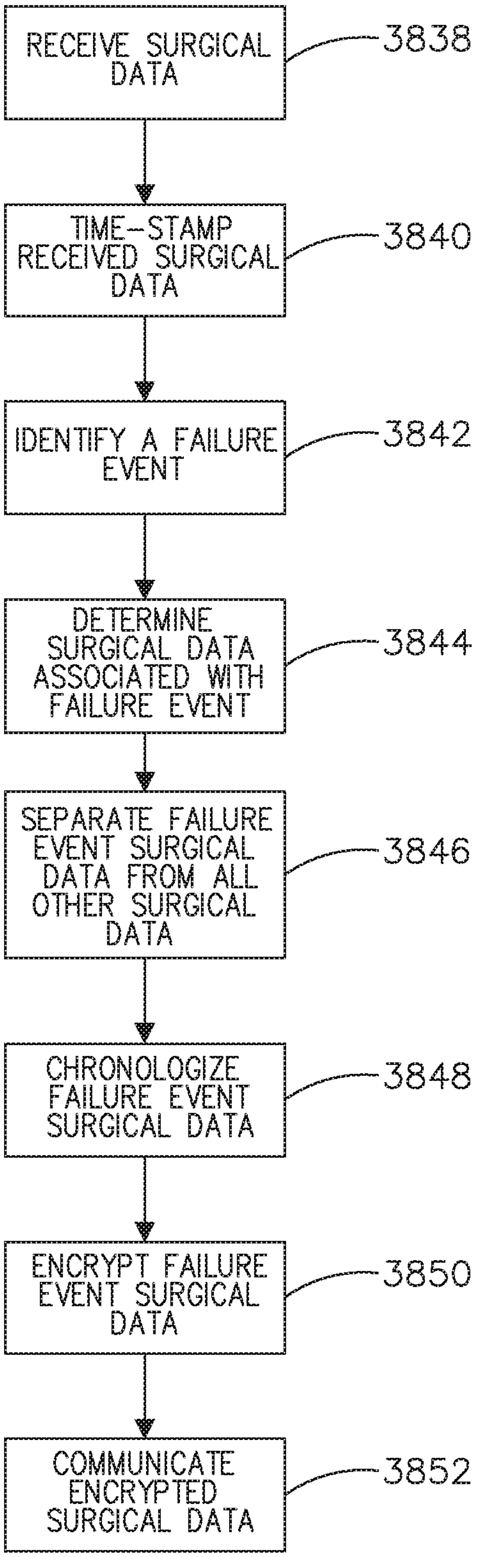

RECEIVE SURGICAL DATA
3838
TIME-STAMP RECEIVED SURGICAL DATA
3840
IDENTIFY A FAILURE EVENT
3842
DETERMINE SURGICAL DATA ASSOCIATED WITH FAILURE EVENT
3844
SEPARATE FAILURE EVENT SURGICAL DATA FROM ALL OTHER SURGICAL DATA
3846
CHRONOLOGIZE FAILURE EVENT SURGICAL DATA
3848
ENCRYPT FAILURE EVENT SURGICAL DATA
3850
COMMUNICATE ENCRYPTED SURGICAL DATA
3852

FIG. 31

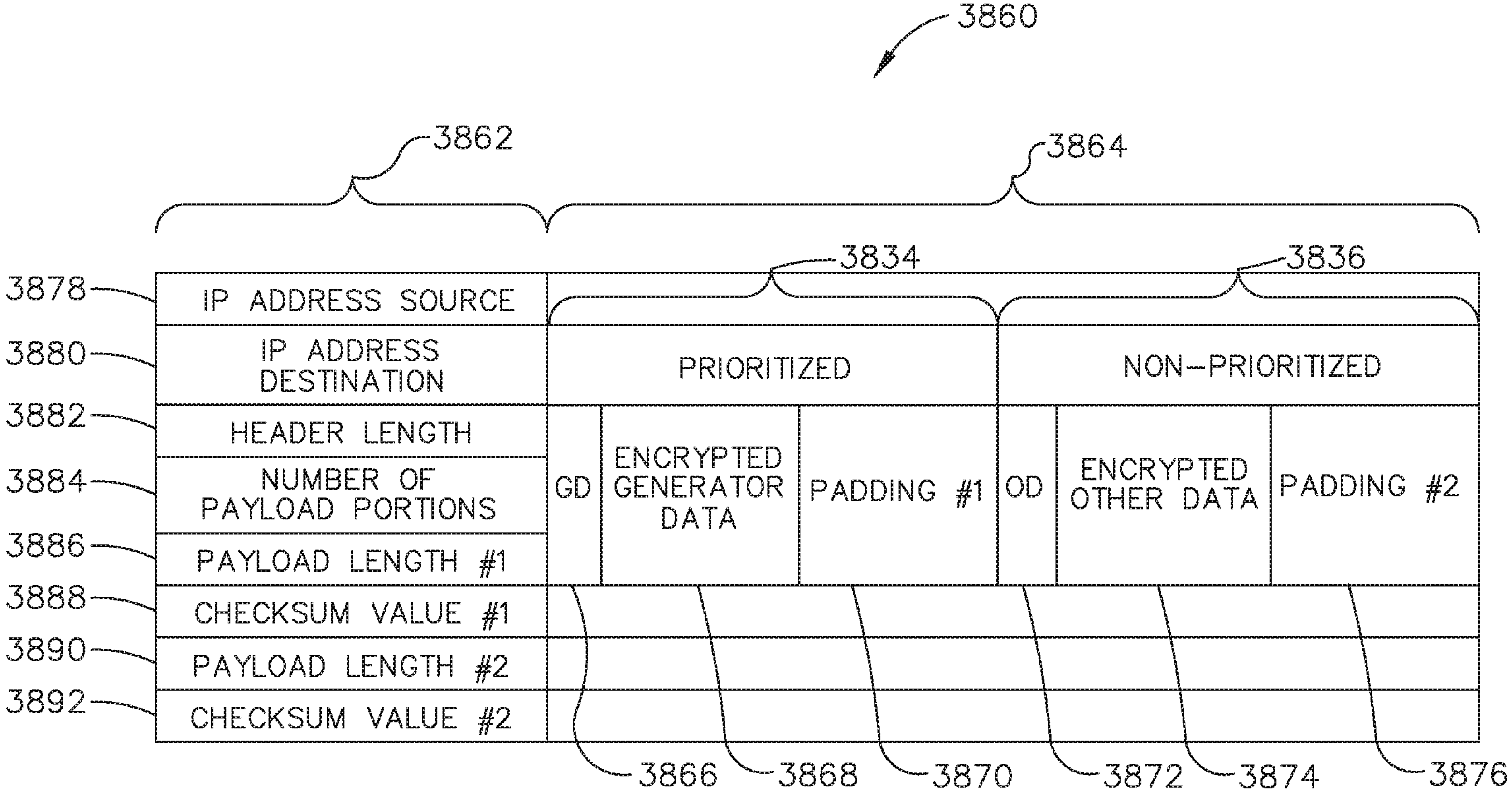

3860
3862
3864
3834
3836
3878
IP ADDRESS SOURCE
3880
IP ADDRESS DESTINATION
3882
HEADER LENGTH
3884
NUMBER OF PAYLOAD PORTIONS
3886
PAYLOAD LENGTH #1
3888
CHECKSUM VALUE #1
3890
PAYLOAD LENGTH #2
3892
CHECKSUM VALUE #2
PRIORITIZED
NON-PRIORITIZED
GD
ENCRYPTED GENERATOR DATA
PADDING #1
OD
ENCRYPTED OTHER DATA
PADDING #2
3866
3868
3870
3872
3874
3876

FIG. 32

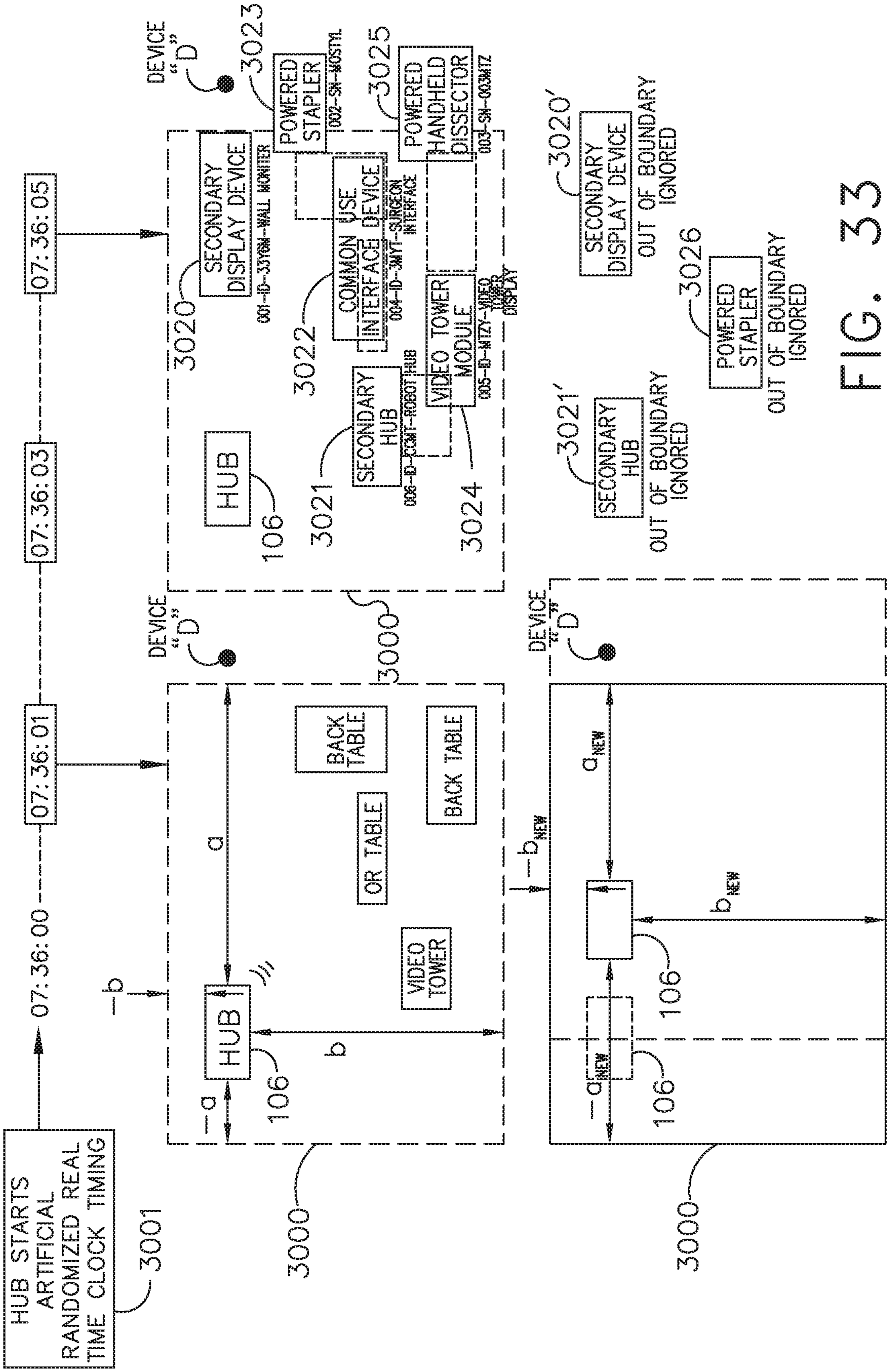

HUB STARTS ARTIFICIAL RANDOMIZED REAL TIME CLOCK TIMING
3001
07:36:00
07:36:01
07:36:03
07:36:05
—b
—a
a
b
HUB
106
BACK TABLE
BACK TABLE
OR TABLE
VIDEO TOWER
3000
DEVICE "D"
—b_NEW
a_NEW
b_NEW
—a_NEW
106
106
3000
DEVICE "D"
HUB
106
SECONDARY DISPLAY DEVICE
3020
001-ID-33YGM-WALL MONITER
COMMON USE INTERFACE DEVICE
3022
004-ID-3MYT-SURGEON INTERFACE
SECONDARY HUB
3021
006-ID-CCMT-ROBOT HUB
VIDEO TOWER MODULE
3024
005-ID-MTZY-VIDEO TOWER DISPLAY
POWERED STAPLER
3023
002-SN-MOSTYL
POWERED HANDHELD DISSECTOR
3025
003-SN-003MTZ
DEVICE "D"
3000
SECONDARY HUB
3021′
OUT OF BOUNDARY IGNORED
POWERED STAPLER
3026
OUT OF BOUNDARY IGNORED
SECONDARY DISPLAY DEVICE
3020′
OUT OF BOUNDARY IGNORED

FIG. 33

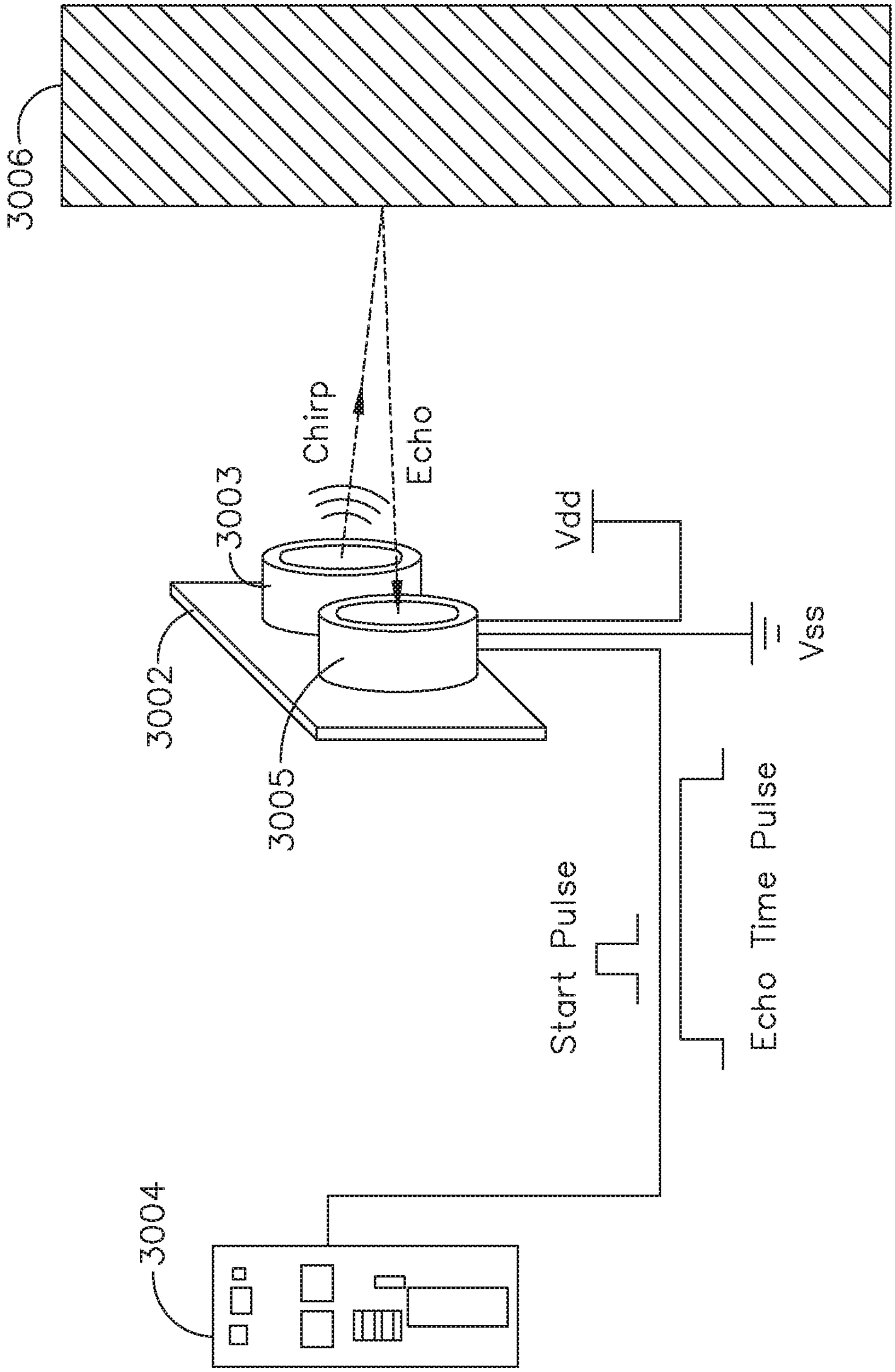

3006
Chirp
Echo
3003
Vdd
3002
Vss
3005
Start Pulse
Echo Time Pulse
3004

FIG. 34

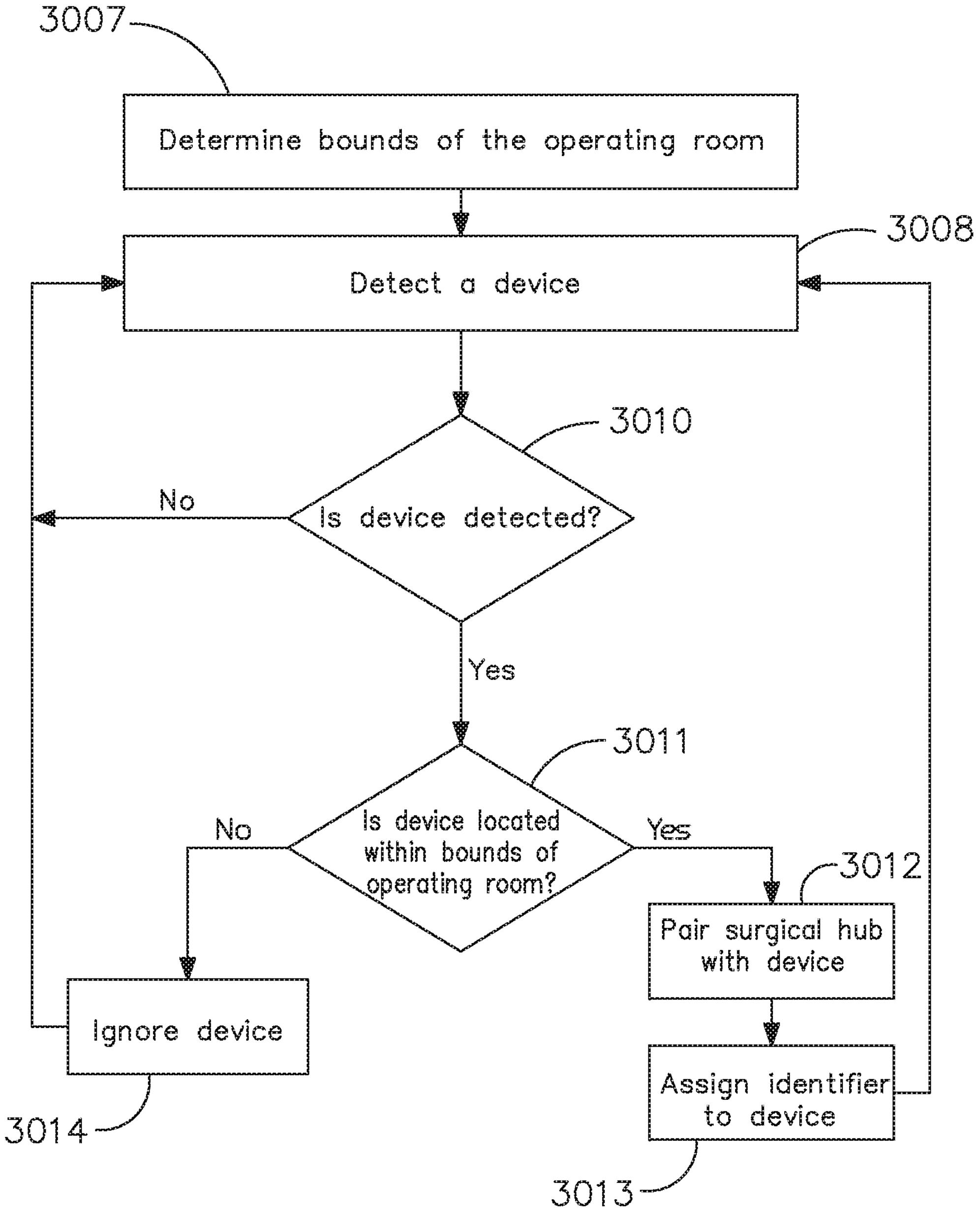

3007
Determine bounds of the operating room
3008
Detect a device
3010
No
Is device detected?
Yes
3011
No
Is device located within bounds of operating room?
Yes
3012
Pair surgical hub with device
Ignore device
Assign identifier to device
3014
3013

FIG. 35

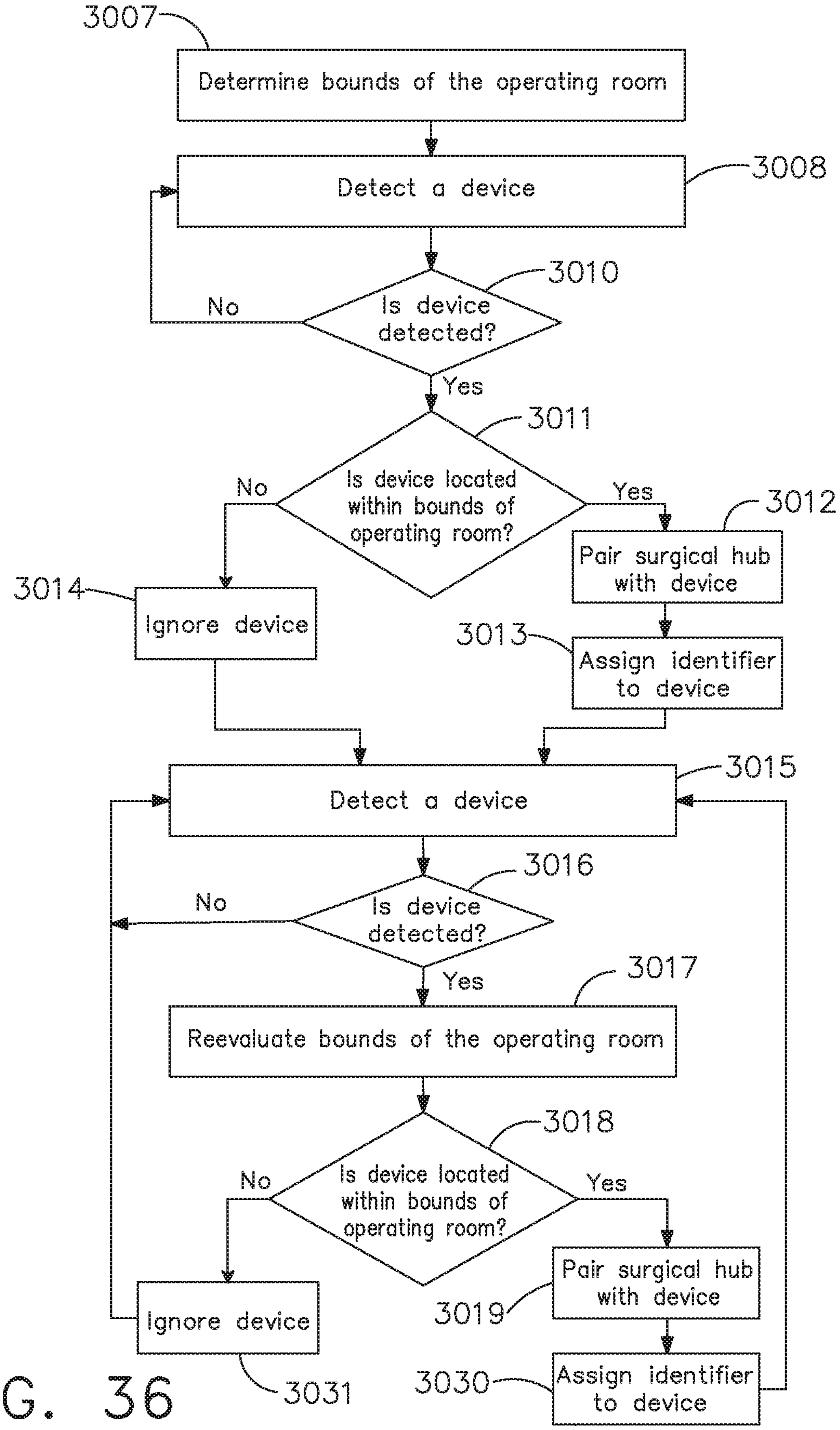

3007
Determine bounds of the operating room
3008
Detect a device
3010
Is device detected?
No
Yes
3011
Is device located within bounds of operating room?
No
Yes
3012
Pair surgical hub with device
3014
Ignore device
3013
Assign identifier to device
3015
Detect a device
3016
No
Is device detected?
Yes
3017
Reevaluate bounds of the operating room
3018
No
Is device located within bounds of operating room?
Yes
Pair surgical hub with device
3019
Ignore device
3031
3030
Assign identifier to device

FIG. 36

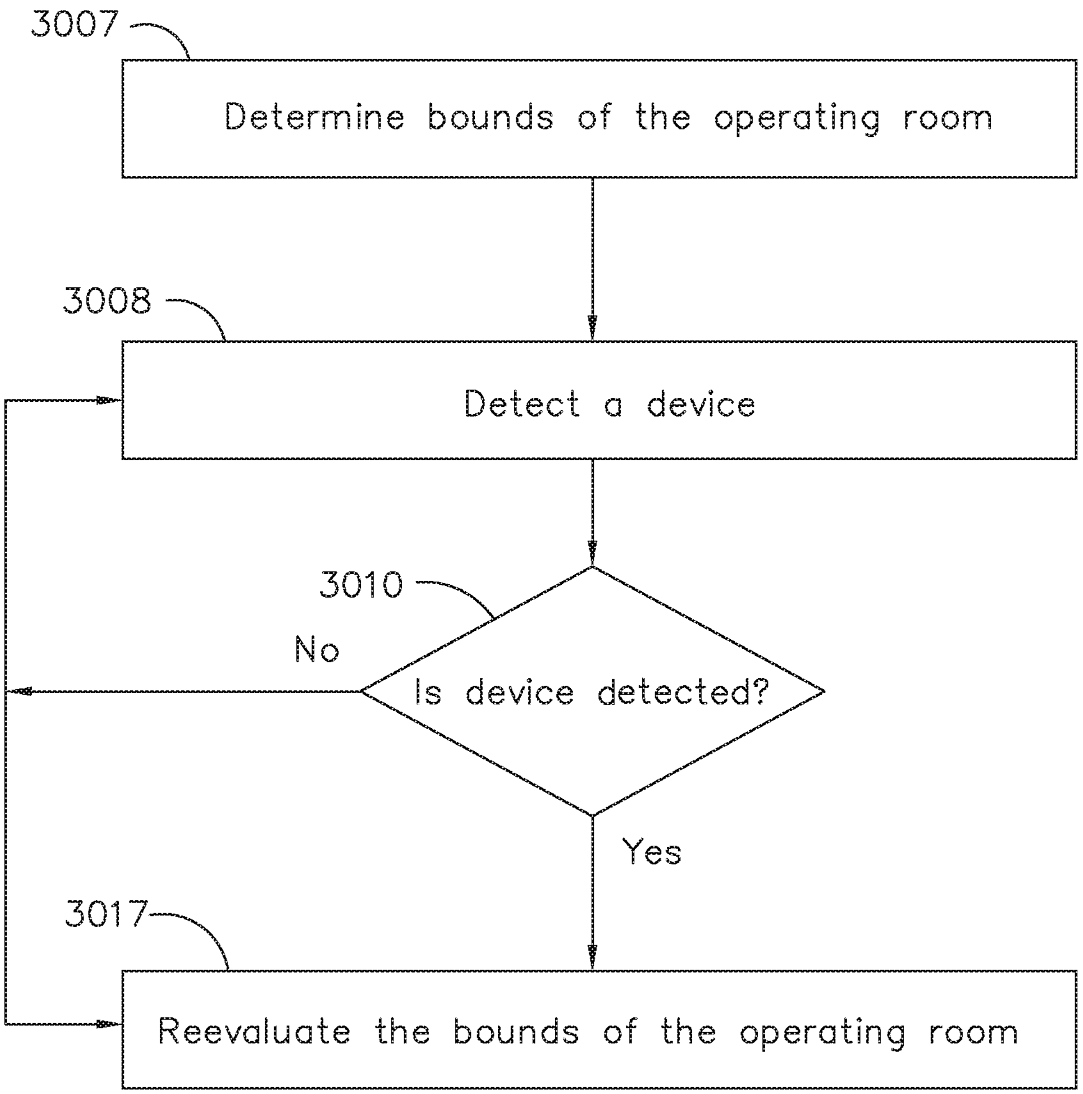

3007
Determine bounds of the operating room
3008
Detect a device
3010
Is device detected?
No
Yes
3017
Reevaluate the bounds of the operating room

FIG. 37

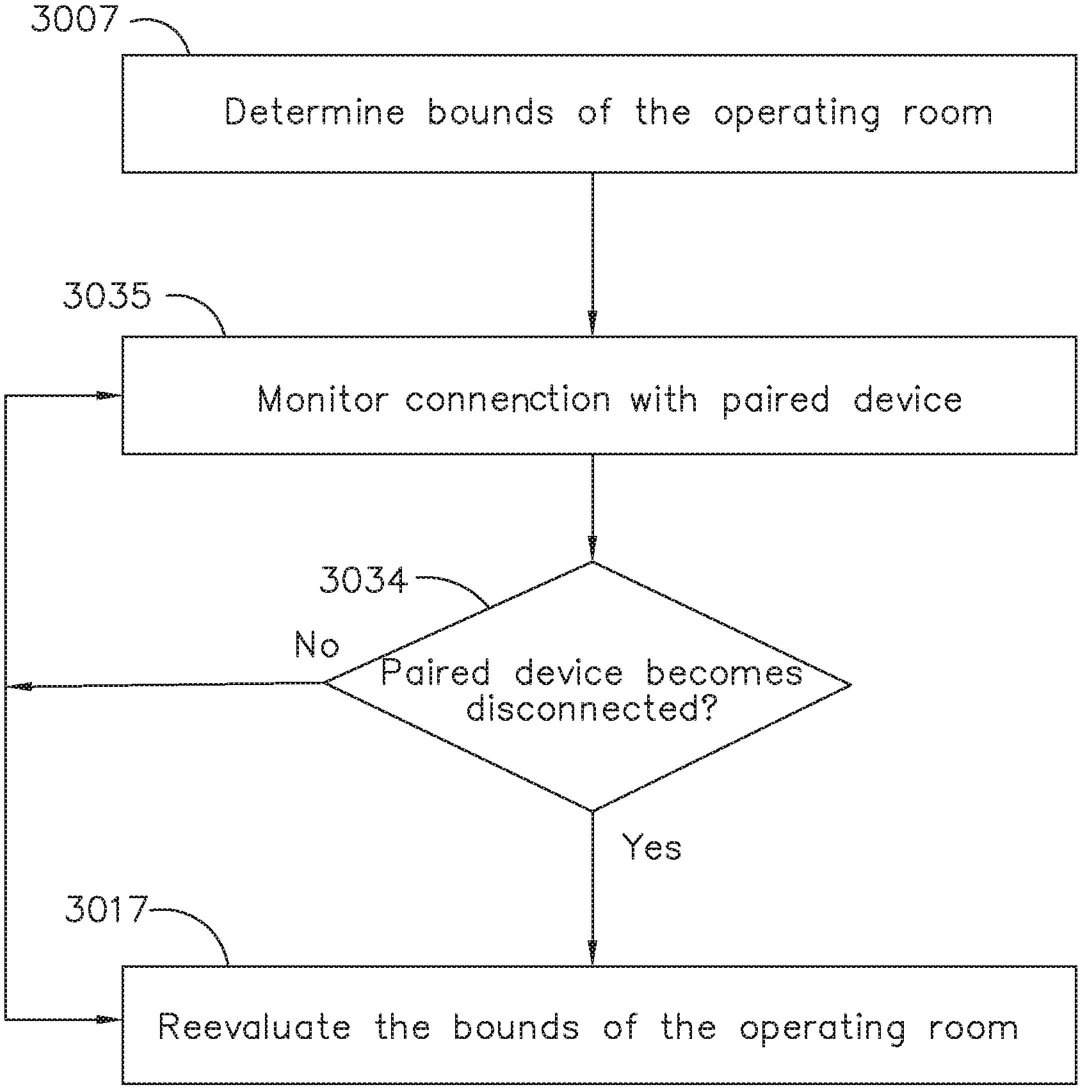

3007
Determine bounds of the operating room
3035
Monitor connenction with paired device
3034
No
Paired device becomes disconnected?
Yes
3017
Reevaluate the bounds of the operating room

FIG. 38

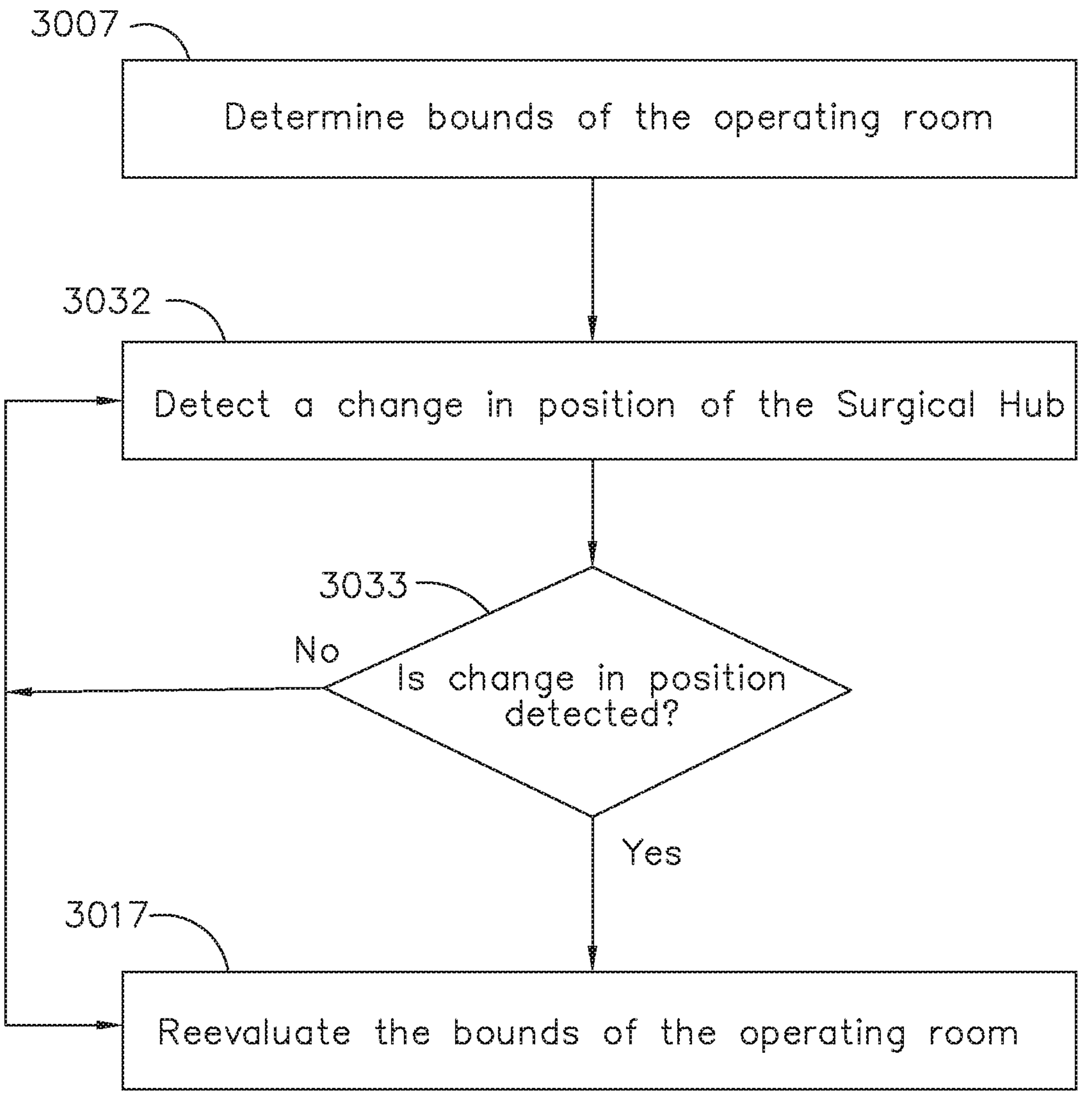

3007
Determine bounds of the operating room
3032
Detect a change in position of the Surgical Hub
3033
Is change in position detected?
No
Yes
3017
Reevaluate the bounds of the operating room

FIG. 39

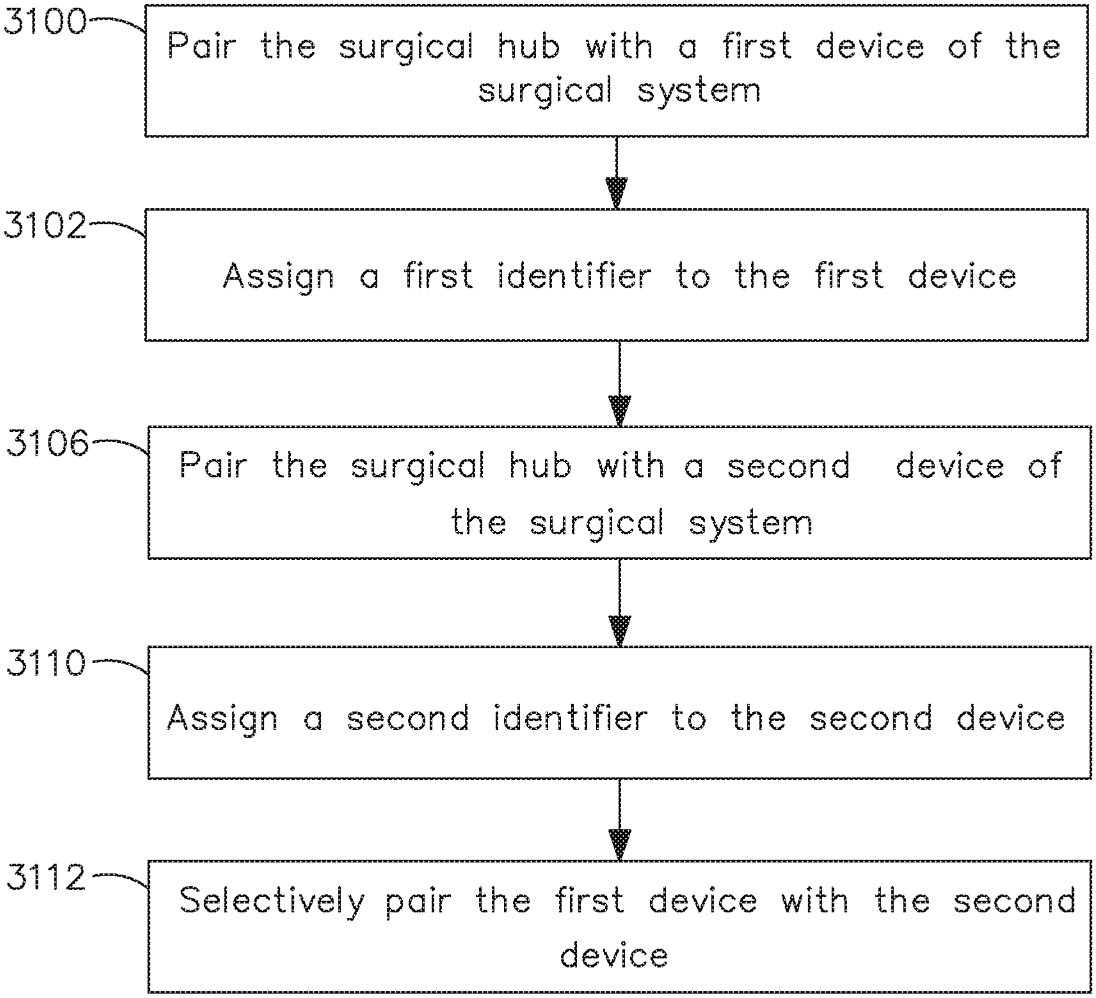

3100
Pair the surgical hub with a first device of the surgical system
3102
Assign a first identifier to the first device
3106
Pair the surgical hub with a second device of the surgical system
3110
Assign a second identifier to the second device
3112
Selectively pair the first device with the second device

FIG. 40

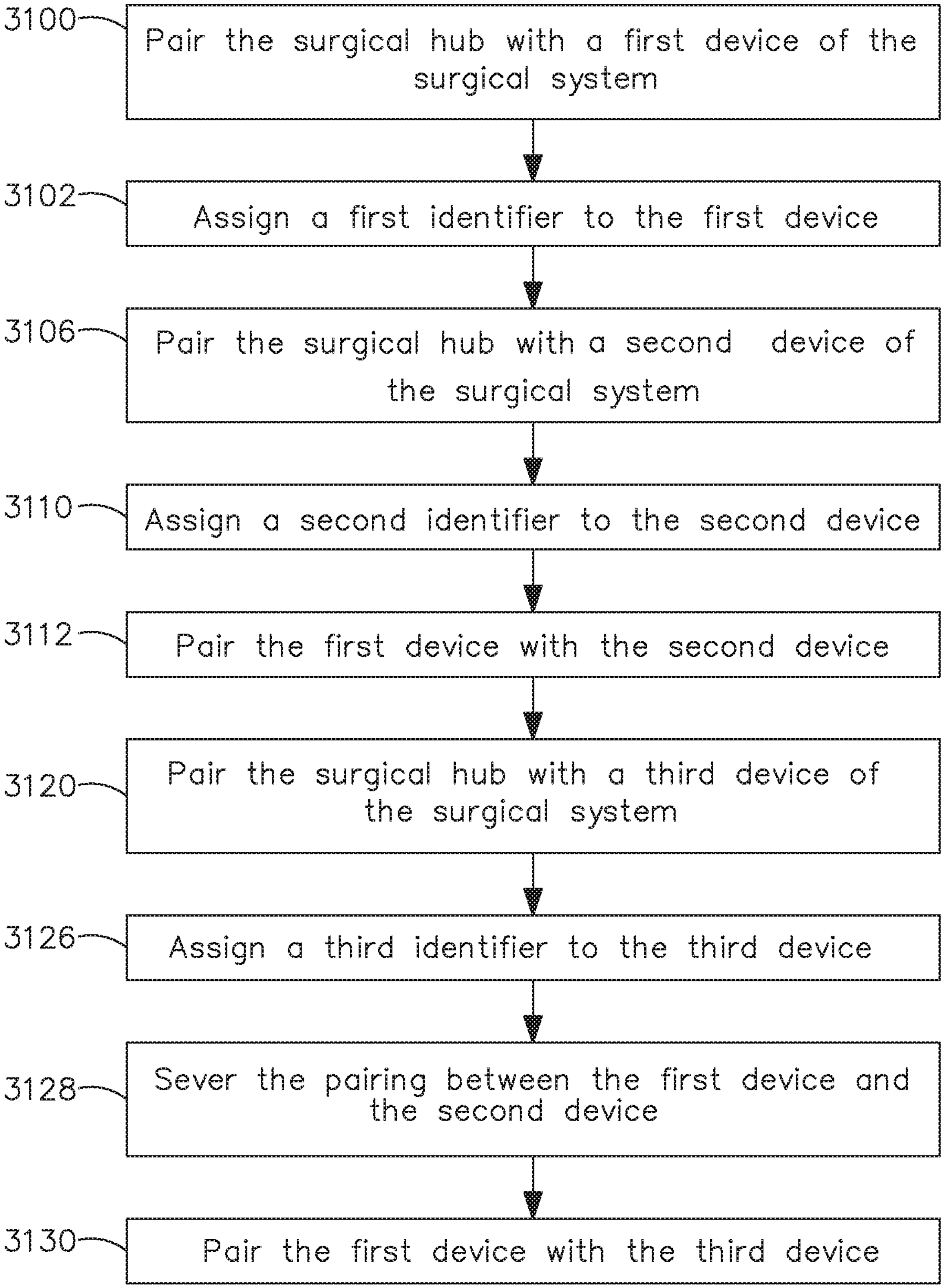

3100
Pair the surgical hub with a first device of the surgical system
3102
Assign a first identifier to the first device
3106
Pair the surgical hub with a second device of the surgical system
3110
Assign a second identifier to the second device
3112
Pair the first device with the second device
3120
Pair the surgical hub with a third device of the surgical system
3126
Assign a third identifier to the third device
3128
Sever the pairing between the first device and the second device
3130
Pair the first device with the third device

FIG. 41

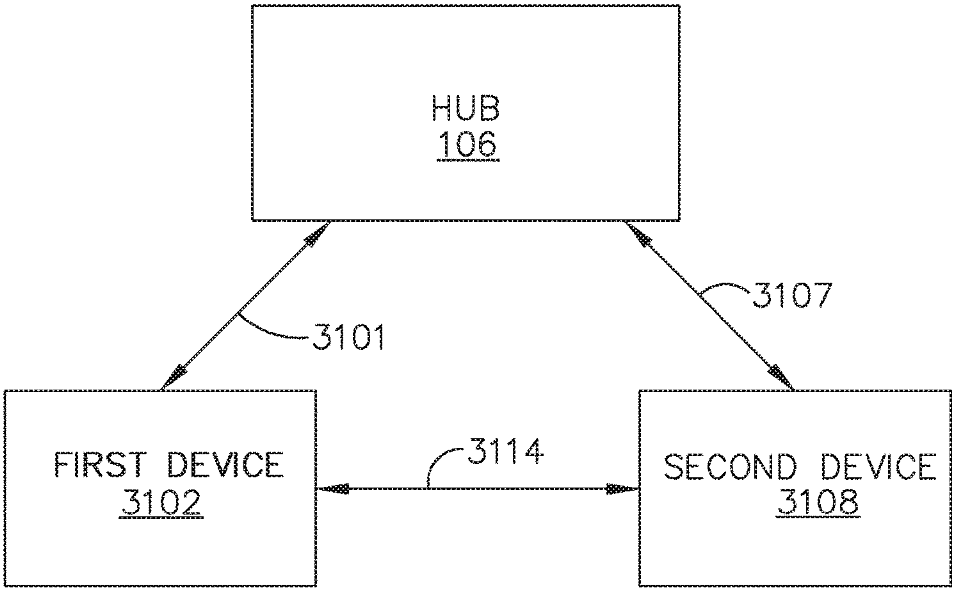

HUB
106
3101
3107
FIRST DEVICE
3102
3114
SECOND DEVICE
3108

FIG. 42

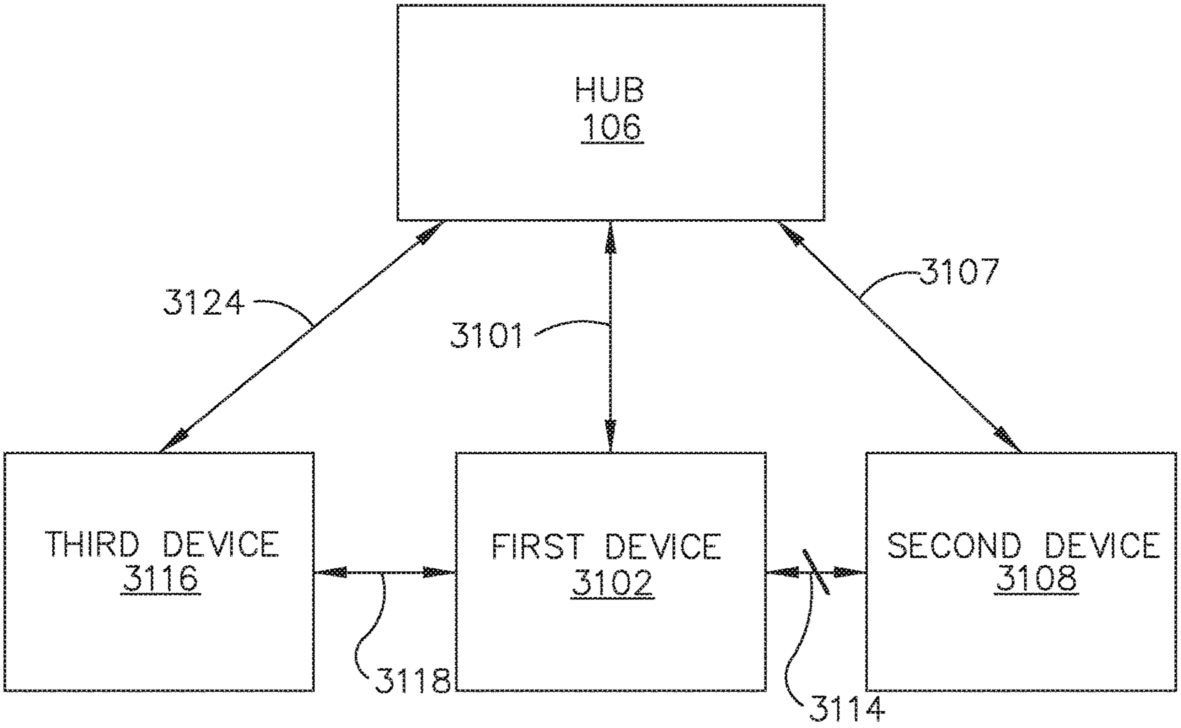

HUB
106
3124
3101
3107
THIRD DEVICE
3116
FIRST DEVICE
3102
SECOND DEVICE
3108
3118
3114

FIG. 43

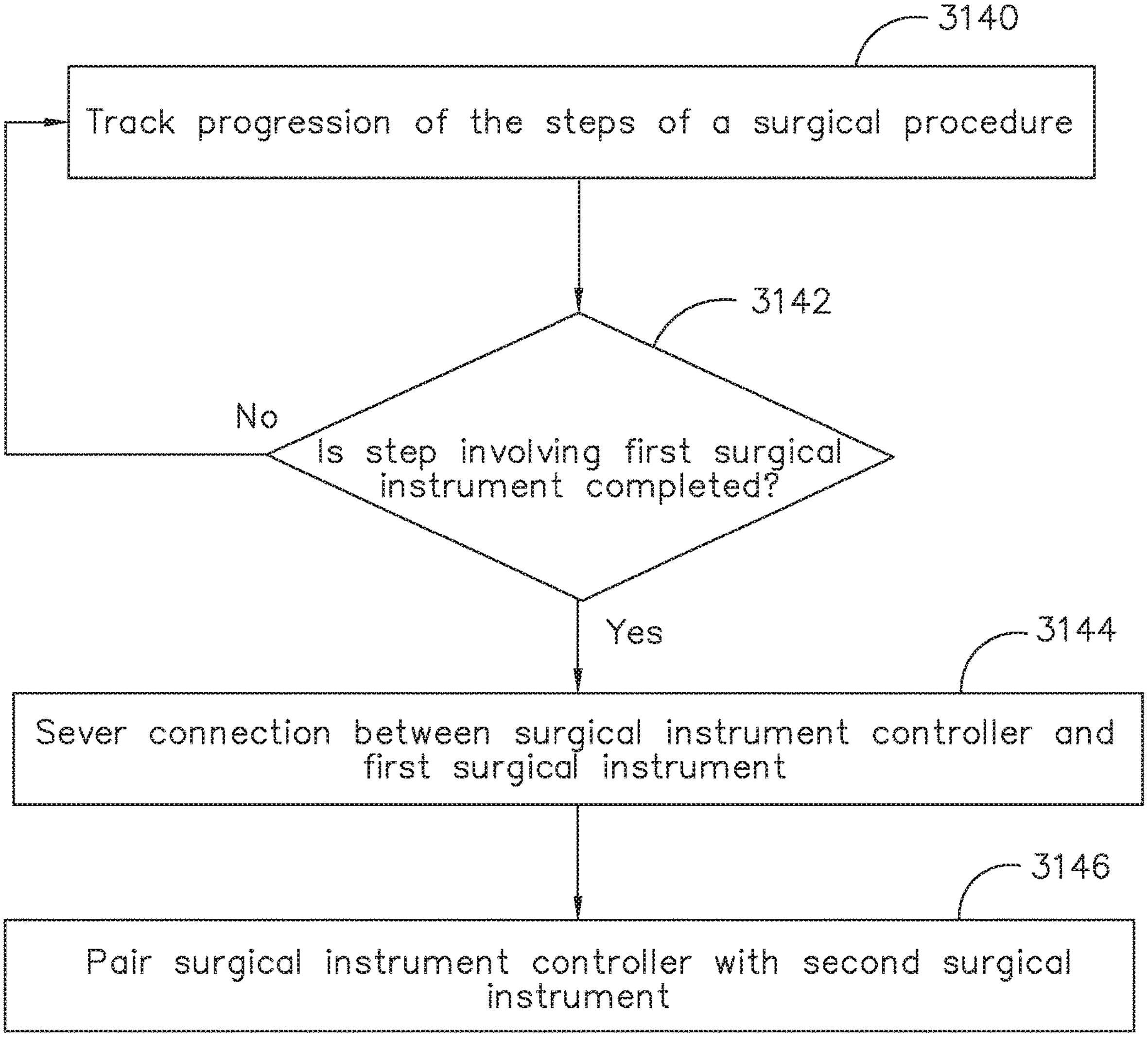

3140
Track progression of the steps of a surgical procedure
3142
No
Is step involving first surgical instrument completed?
Yes
3144
Sever connection between surgical instrument controller and first surgical instrument
3146
Pair surgical instrument controller with second surgical instrument

FIG. 44

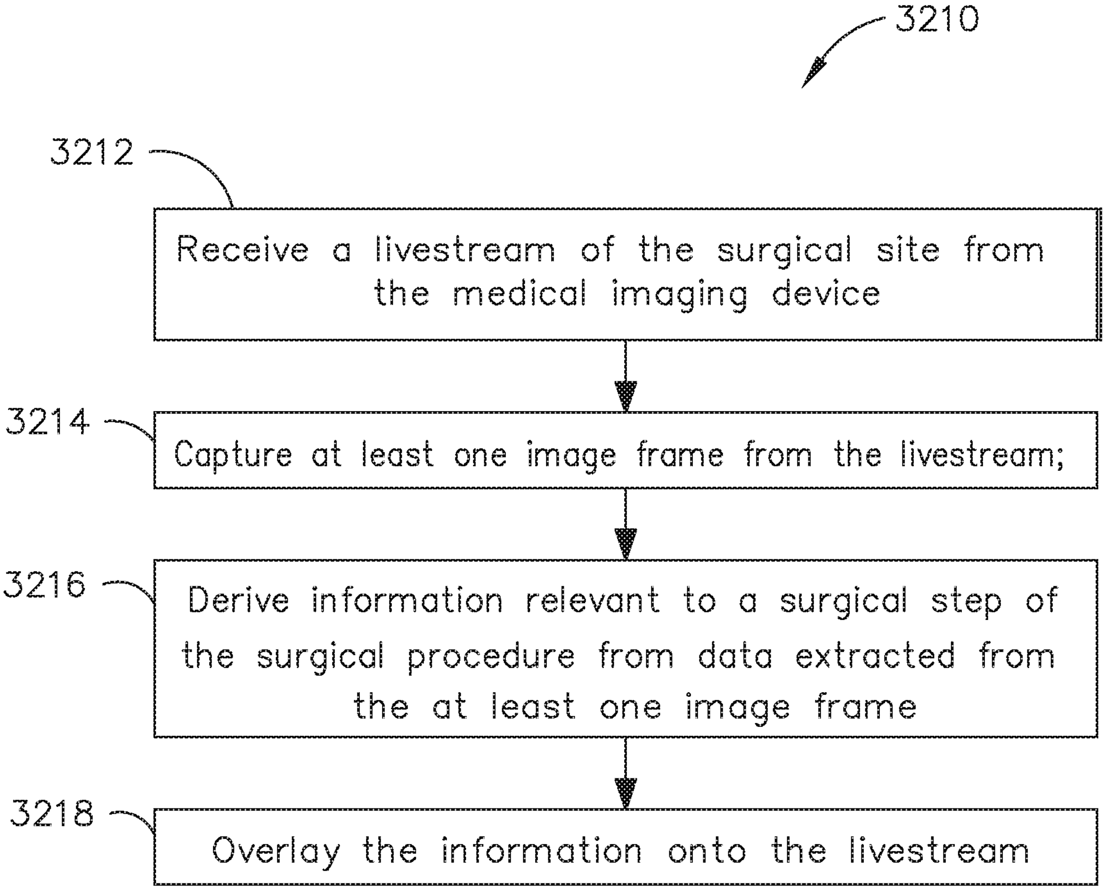

3210
3212
Receive a livestream of the surgical site from the medical imaging device
3214
Capture at least one image frame from the livestream;
3216
Derive information relevant to a surgical step of the surgical procedure from data extracted from the at least one image frame
3218
Overlay the information onto the livestream

FIG. 45

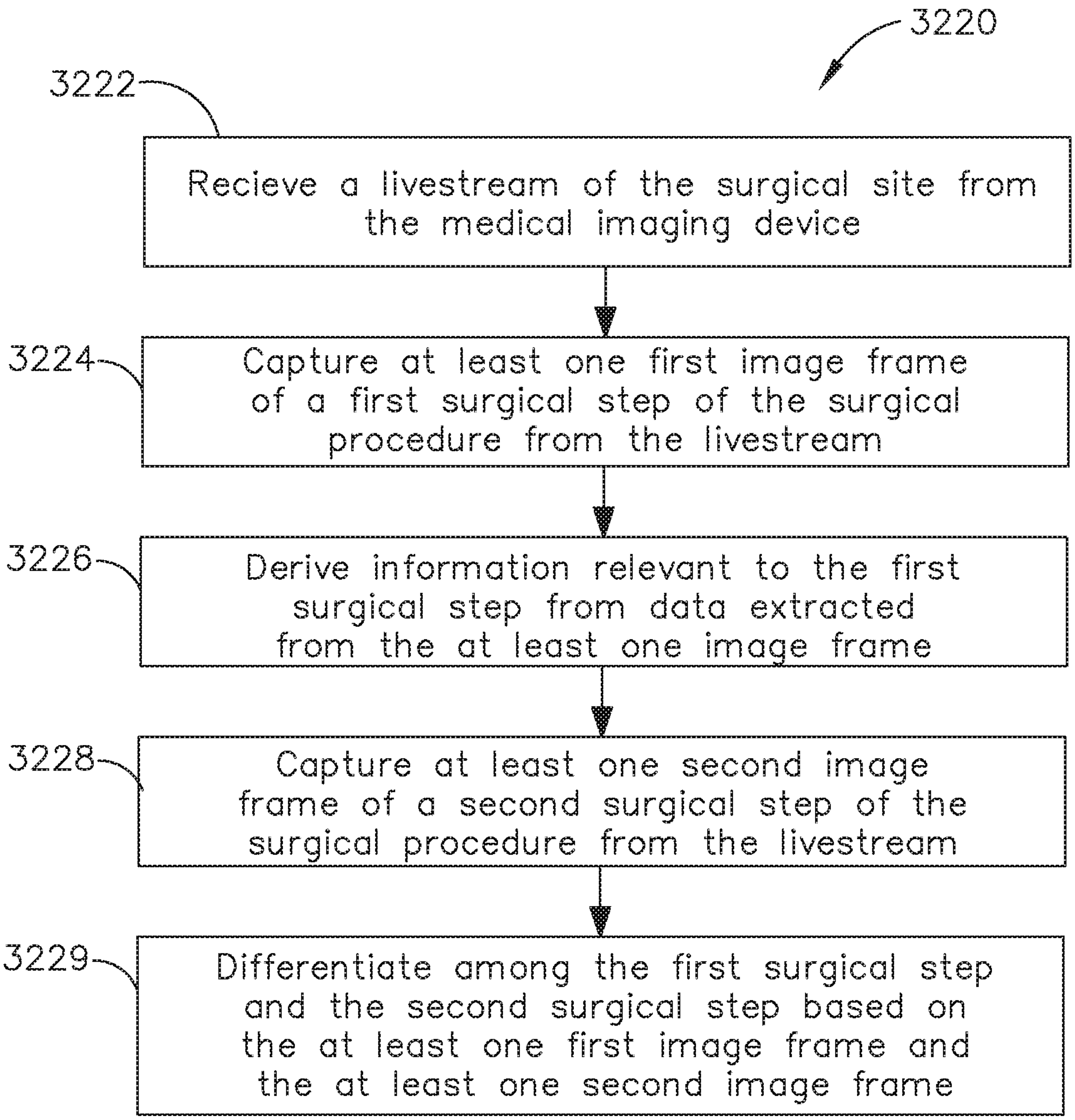

3220
3222
Recieve a livestream of the surgical site from the medical imaging device
3224
Capture at least one first image frame of a first surgical step of the surgical procedure from the livestream
3226
Derive information relevant to the first surgical step from data extracted from the at least one image frame
3228
Capture at least one second image frame of a second surgical step of the surgical procedure from the livestream
3229
Differentiate among the first surgical step and the second surgical step based on the at least one first image frame and the at least one second image frame

FIG. 46

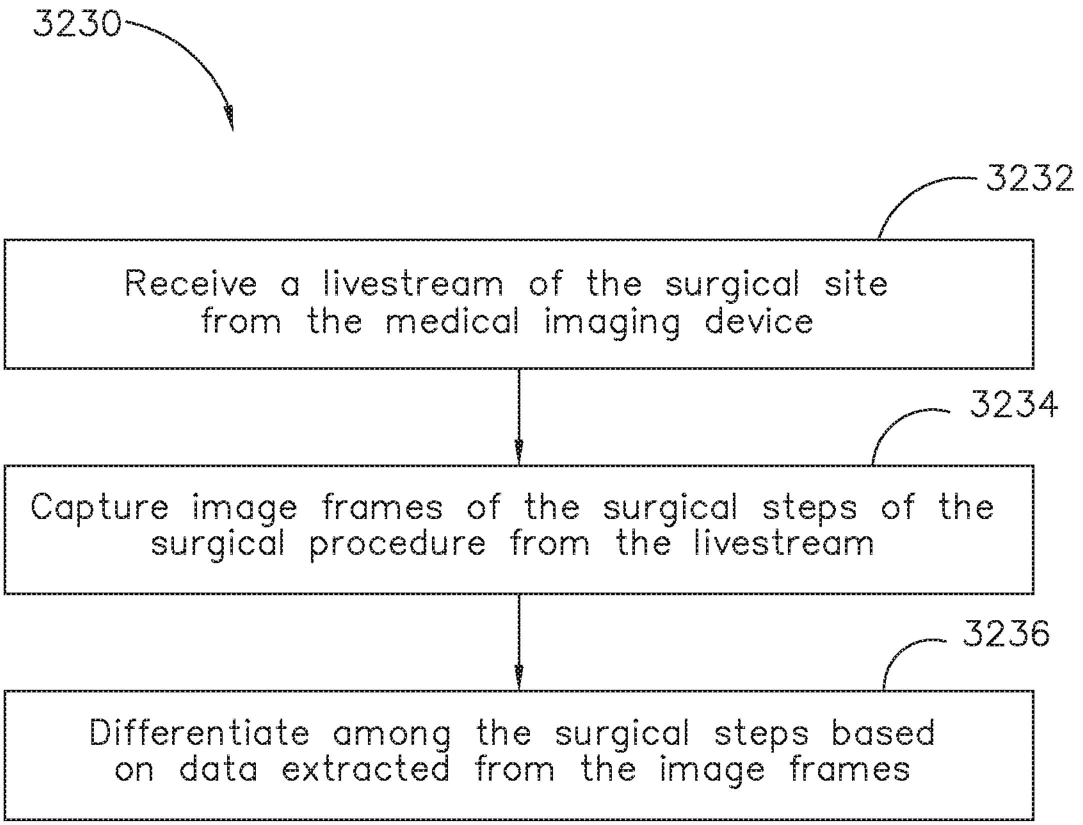

3230
3232
Receive a livestream of the surgical site from the medical imaging device
3234
Capture image frames of the surgical steps of the surgical procedure from the livestream
3236
Differentiate among the surgical steps based on data extracted from the image frames

FIG. 47

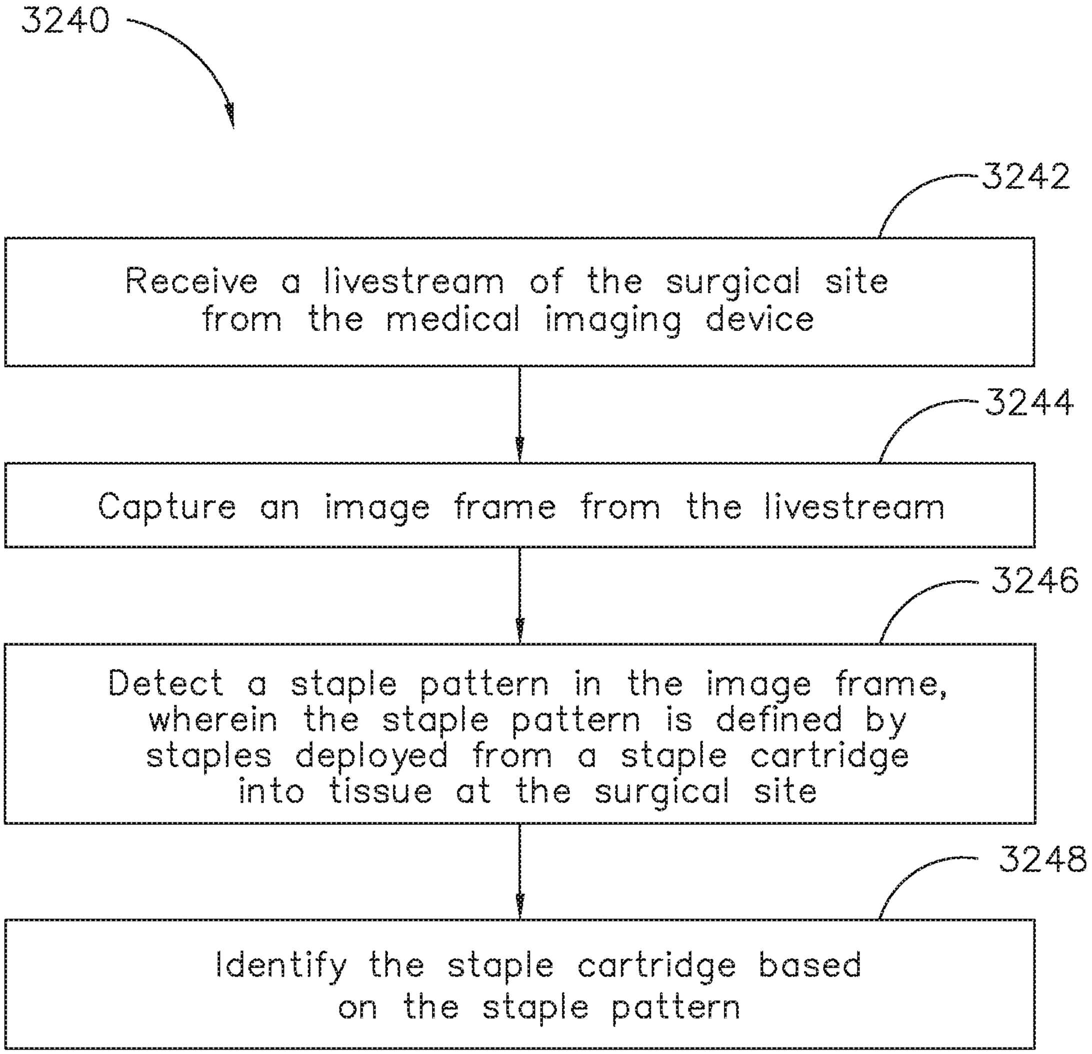

3240
3242
Receive a livestream of the surgical site from the medical imaging device
3244
Capture an image frame from the livestream
3246
Detect a staple pattern in the image frame, wherein the staple pattern is defined by staples deployed from a staple cartridge into tissue at the surgical site
3248
Identify the staple cartridge based on the staple pattern

FIG. 48

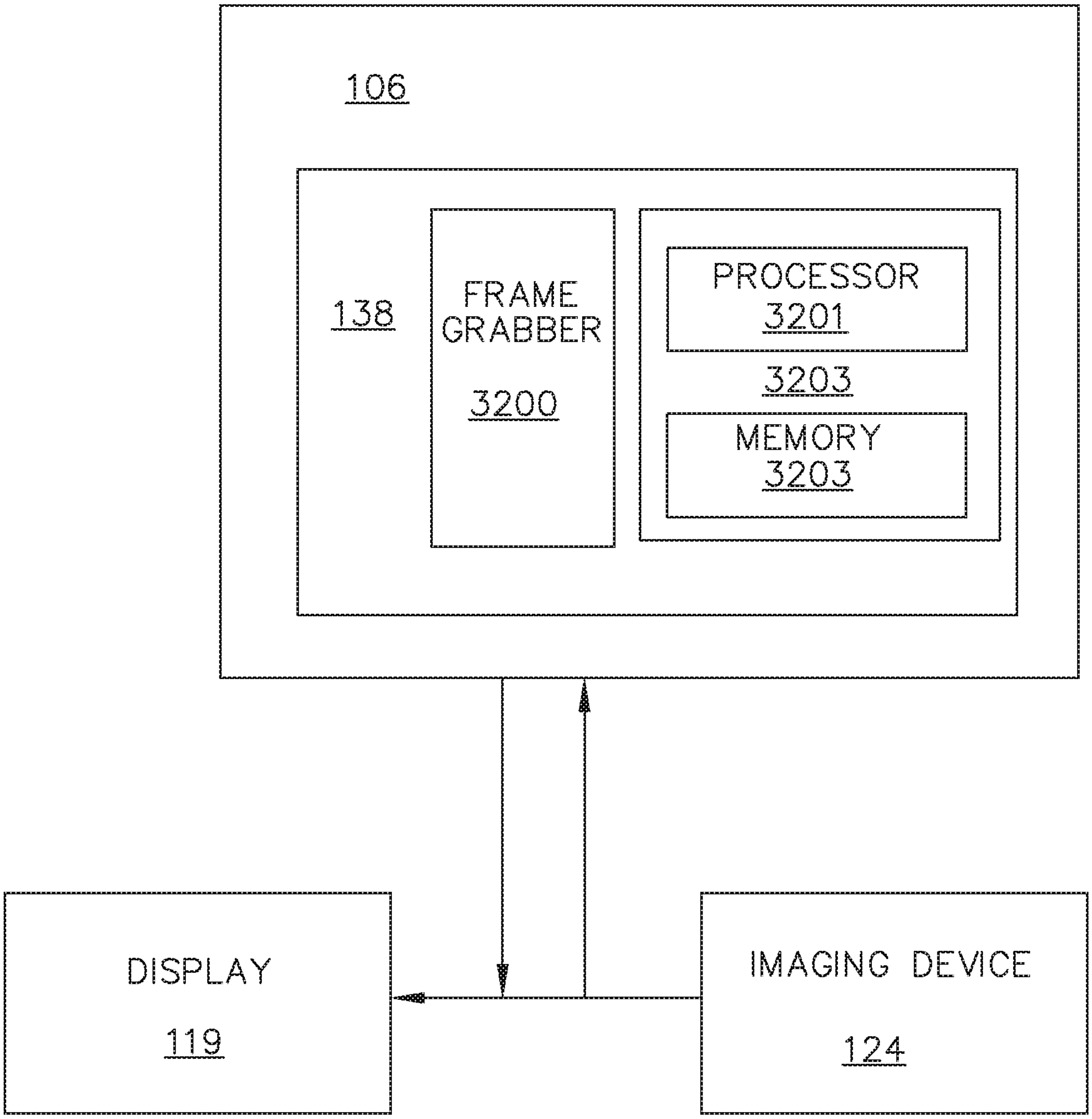

106
138
FRAME GRABBER
3200
PROCESSOR
3201
3203
MEMORY
3203
DISPLAY
119
IMAGING DEVICE
124

FIG. 49

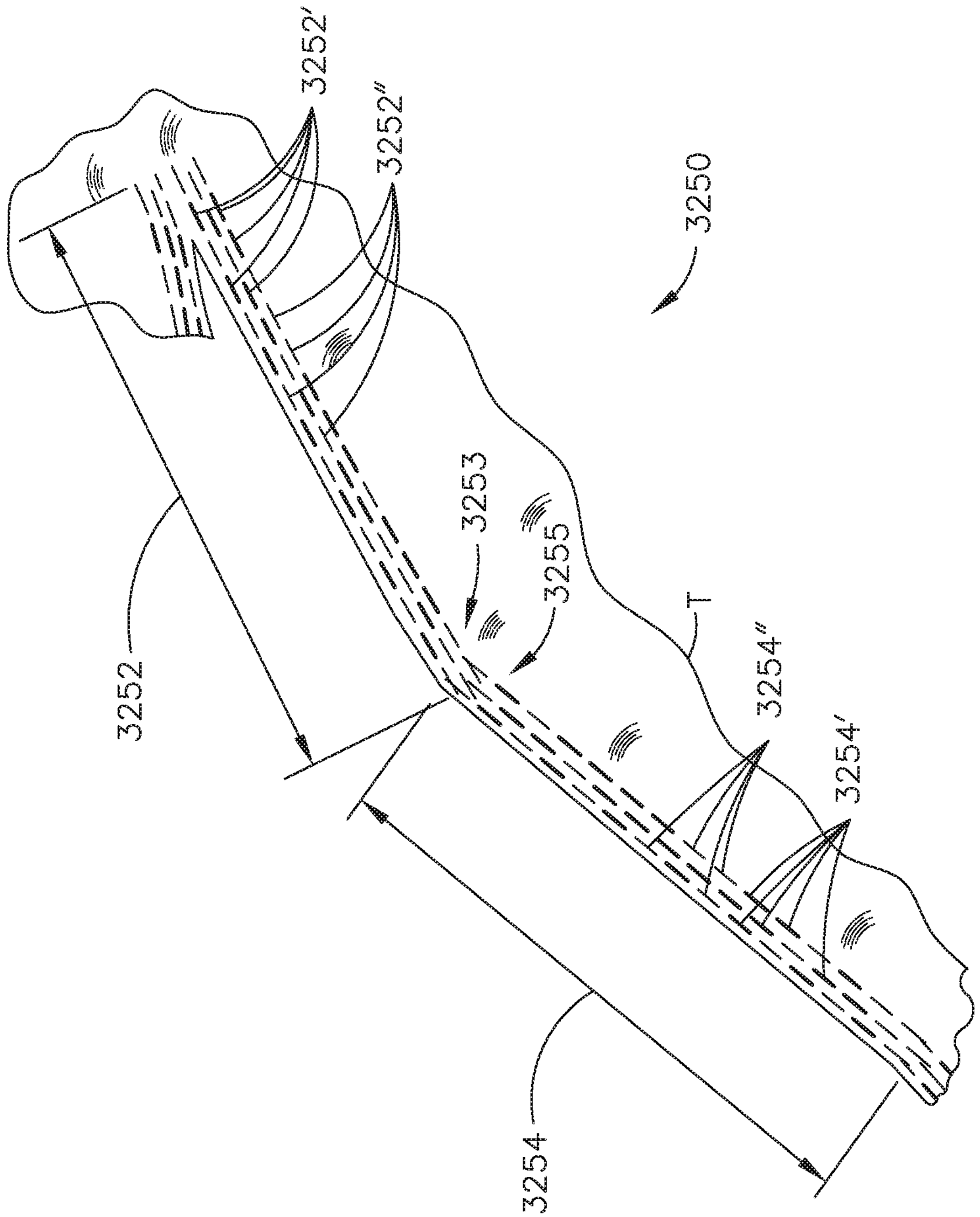


FIG. 50

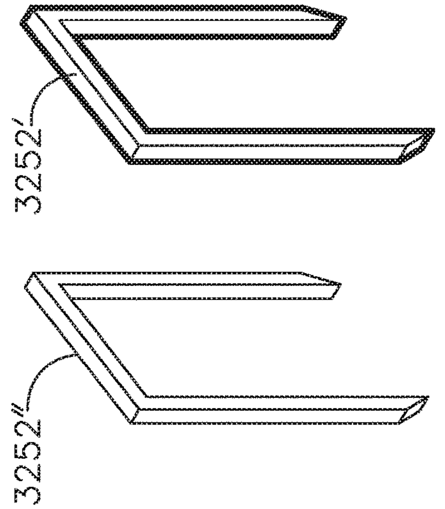


FIG. 52

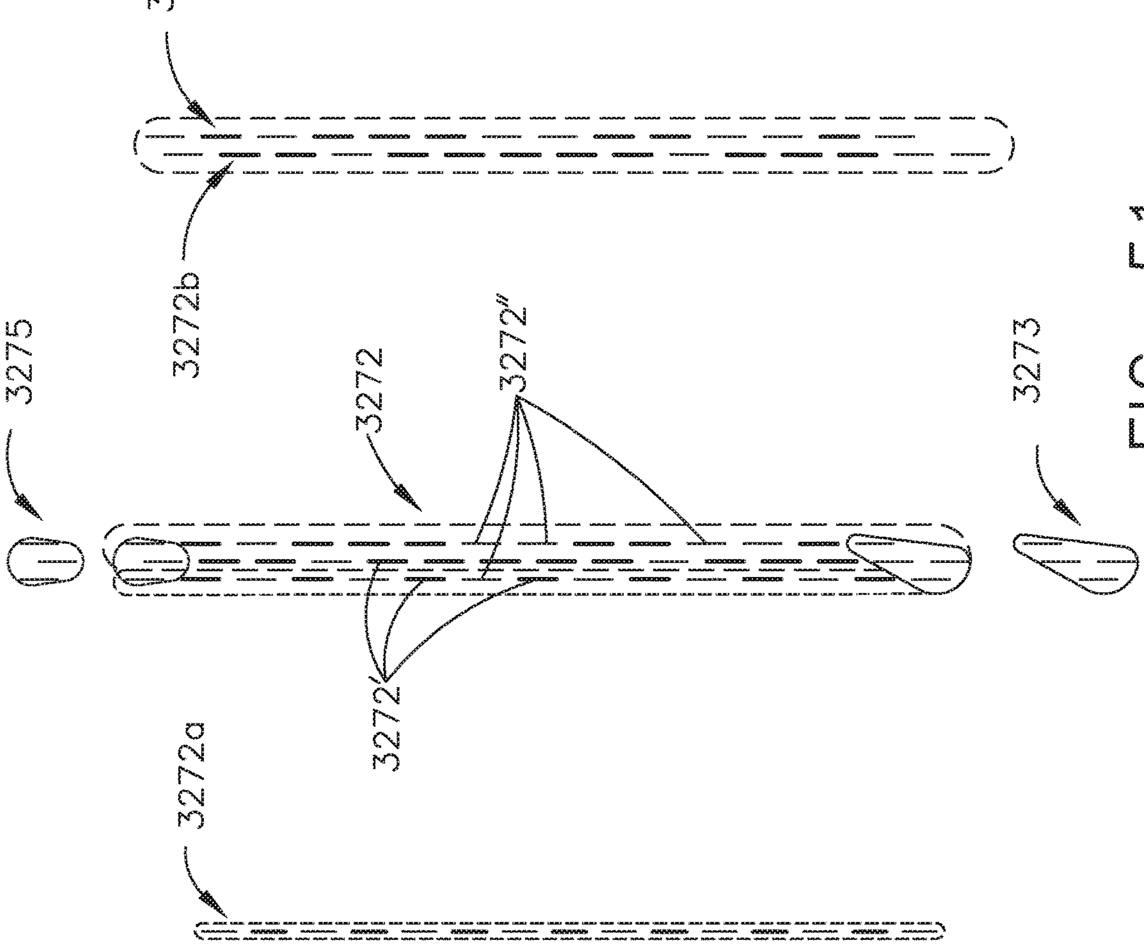


FIG. 51

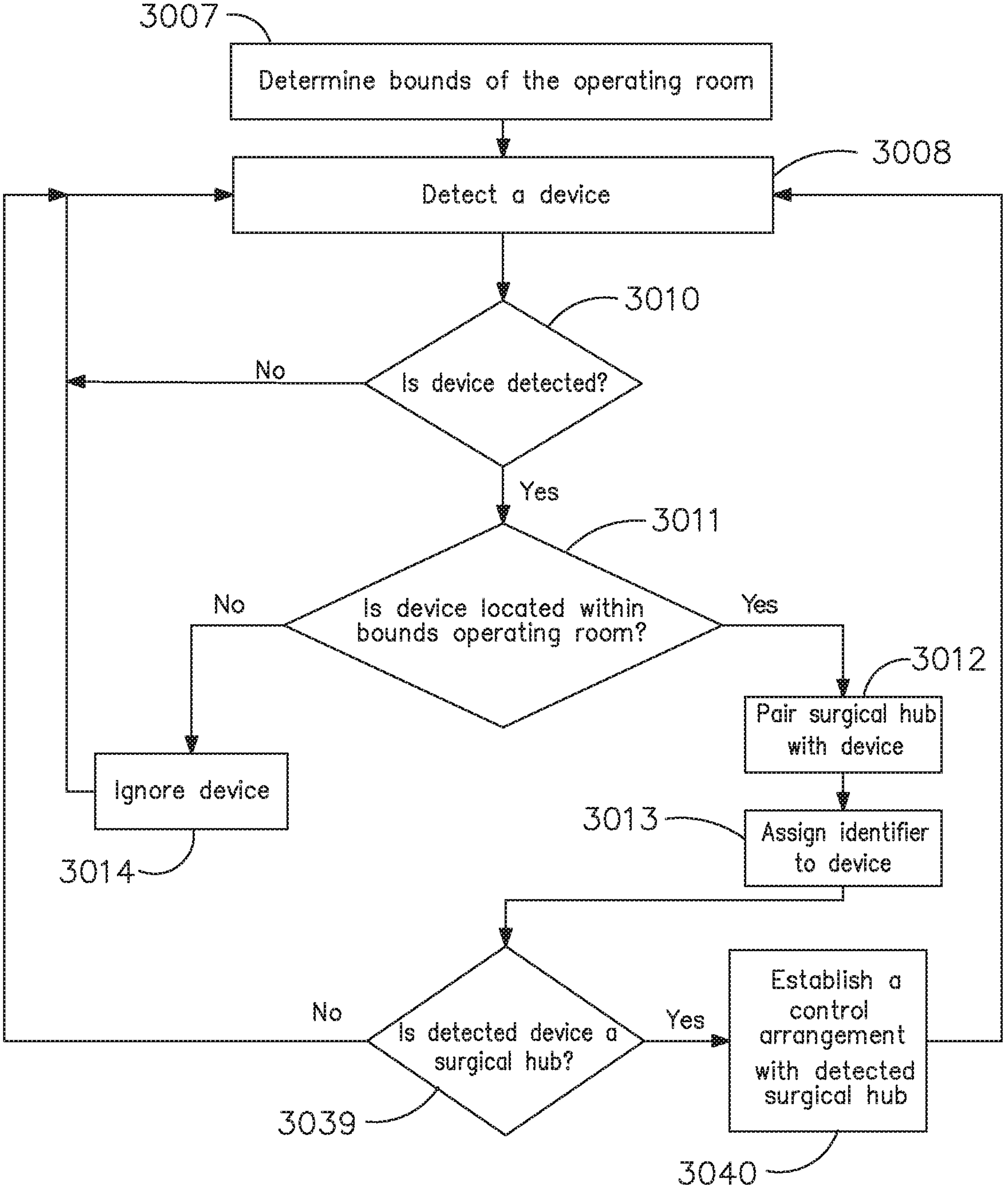

3007
Determine bounds of the operating room
3008
Detect a device
3010
Is device detected?
No
Yes
3011
Is device located within bounds operating room?
No
Yes
3012
Pair surgical hub with device
3013
Assign identifier to device
Ignore device
3014
No
Is detected device a surgical hub?
Yes
Establish a control arrangement with detected surgical hub
3039
3040

FIG. 53

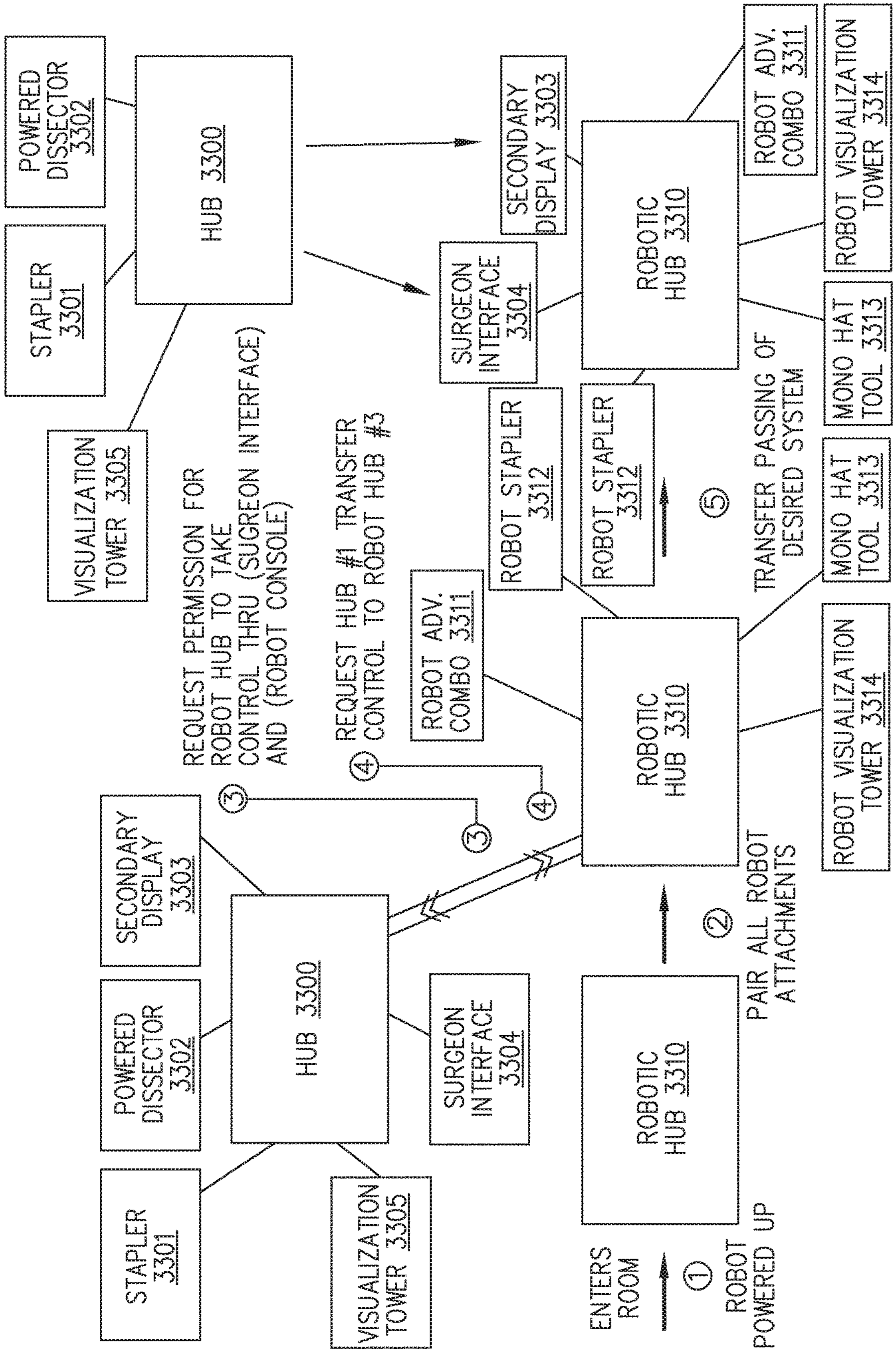

STAPLER 3301
POWERED DISSECTOR 3302
SECONDARY DISPLAY 3303
HUB 3300
SURGEON INTERFACE 3304
VISUALIZATION TOWER 3305
ROBOTIC HUB 3310
ENTERS ROOM
①
ROBOT POWERED UP
②
PAIR ALL ROBOT ATTACHMENTS
ROBOTIC HUB 3310
③
③
REQUEST PERMISSION FOR ROBOT HUB TO TAKE CONTROL THRU (SUGREON INTERFACE) AND (ROBOT CONSOLE)
④
④
REQUEST HUB #1 TRANSFER CONTROL TO ROBOT HUB #3
ROBOT ADV. COMBO 3311
ROBOT STAPLER 3312
MONO HAT TOOL 3313
ROBOT VISUALIZATION TOWER 3314
ROBOT STAPLER 3312
⑤
TRANSFER PASSING OF DESIRED SYSTEM
STAPLER 3301
POWERED DISSECTOR 3302
HUB 3300
VISUALIZATION TOWER 3305
SURGEON INTERFACE 3304
SECONDARY DISPLAY 3303
ROBOTIC HUB 3310
ROBOT ADV. COMBO 3311
ROBOT VISUALIZATION TOWER 3314
MONO HAT TOOL 3313

FIG. 54

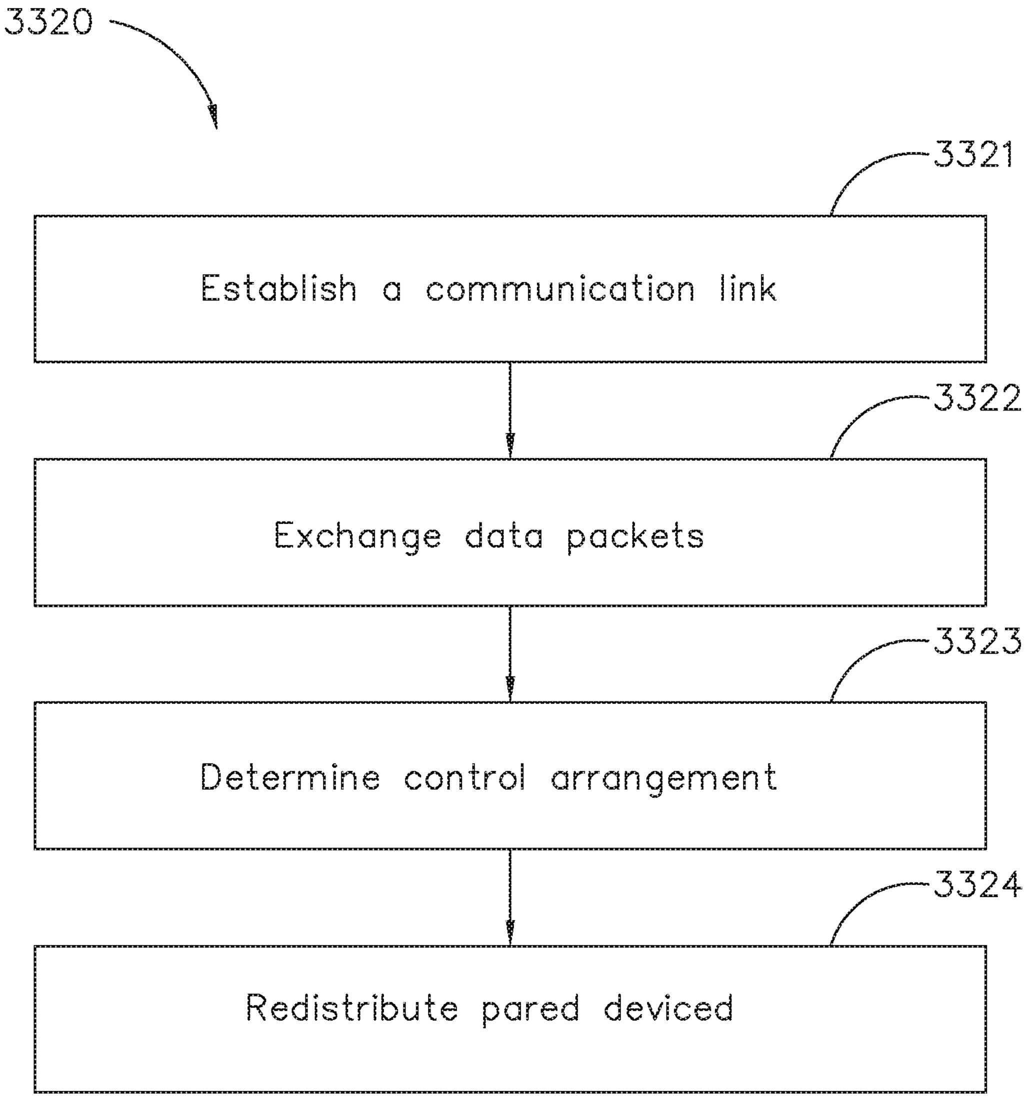
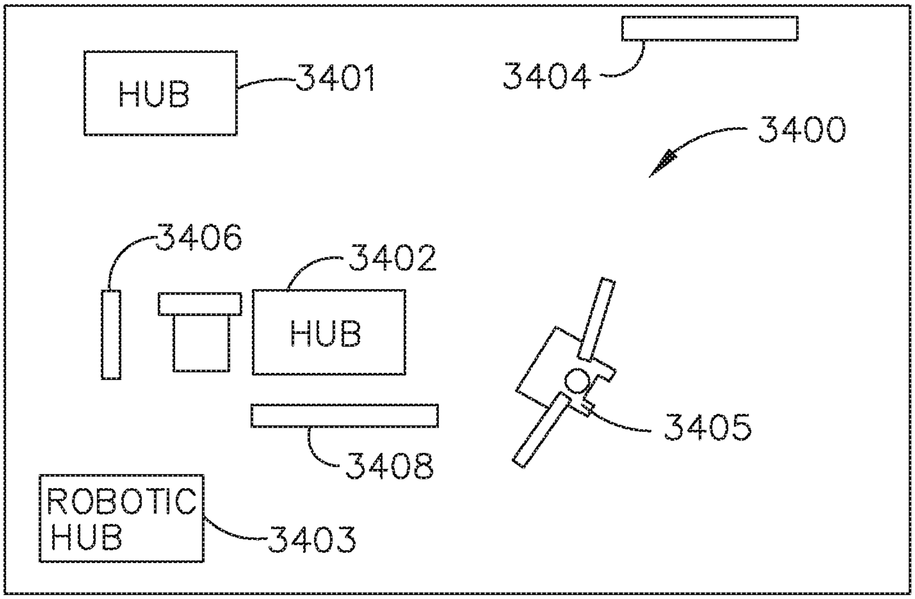
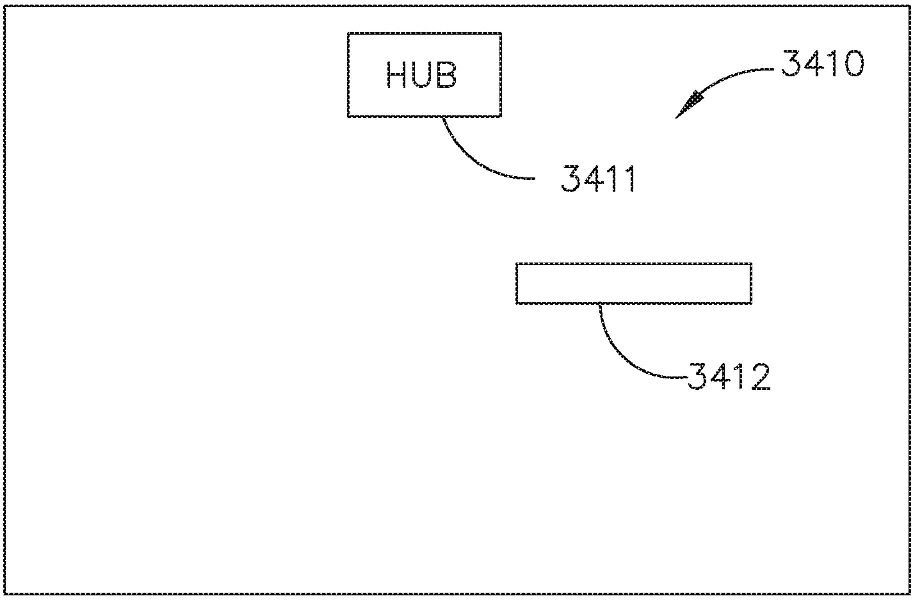

3320
3321
Establish a communication link
3322
Exchange data packets
3323
Determine control arrangement
3324
Redistribute pared deviced

FIG. 55



OR 1 THORACIC SEGMENTECTOMY



OR 3 COLORECTAL

FIG. 56

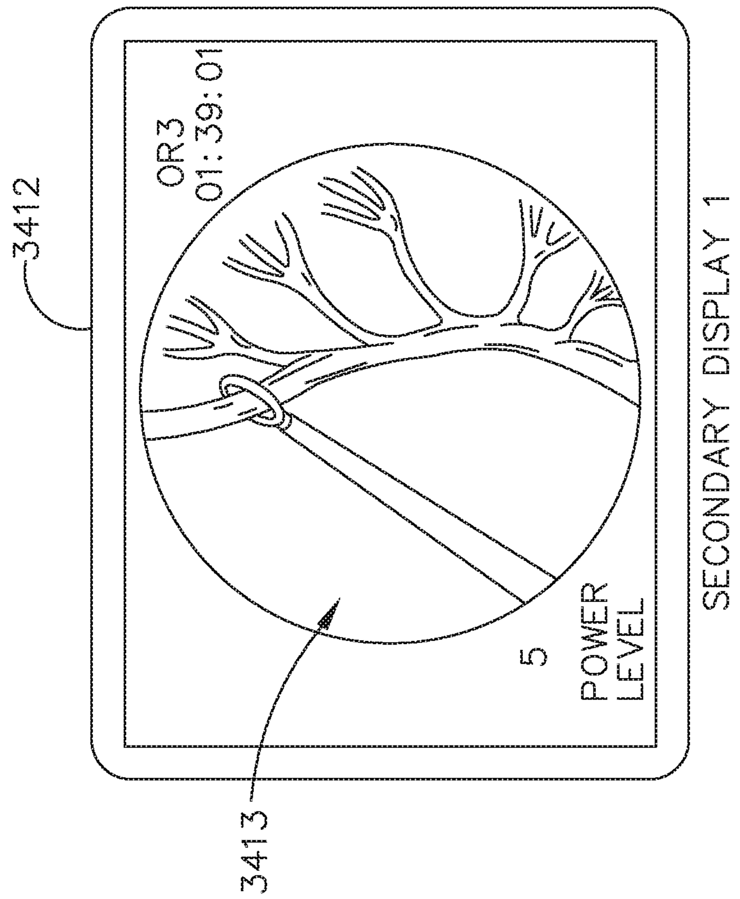


FIG. 57

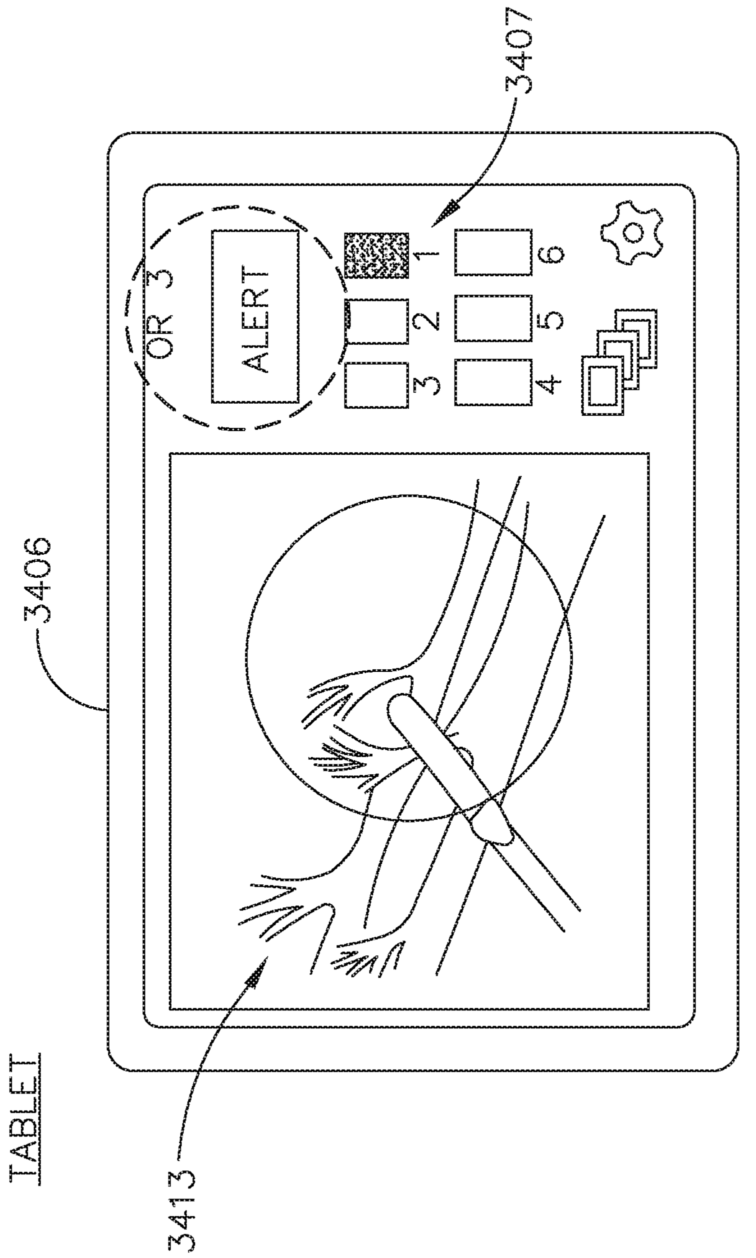


FIG. 58

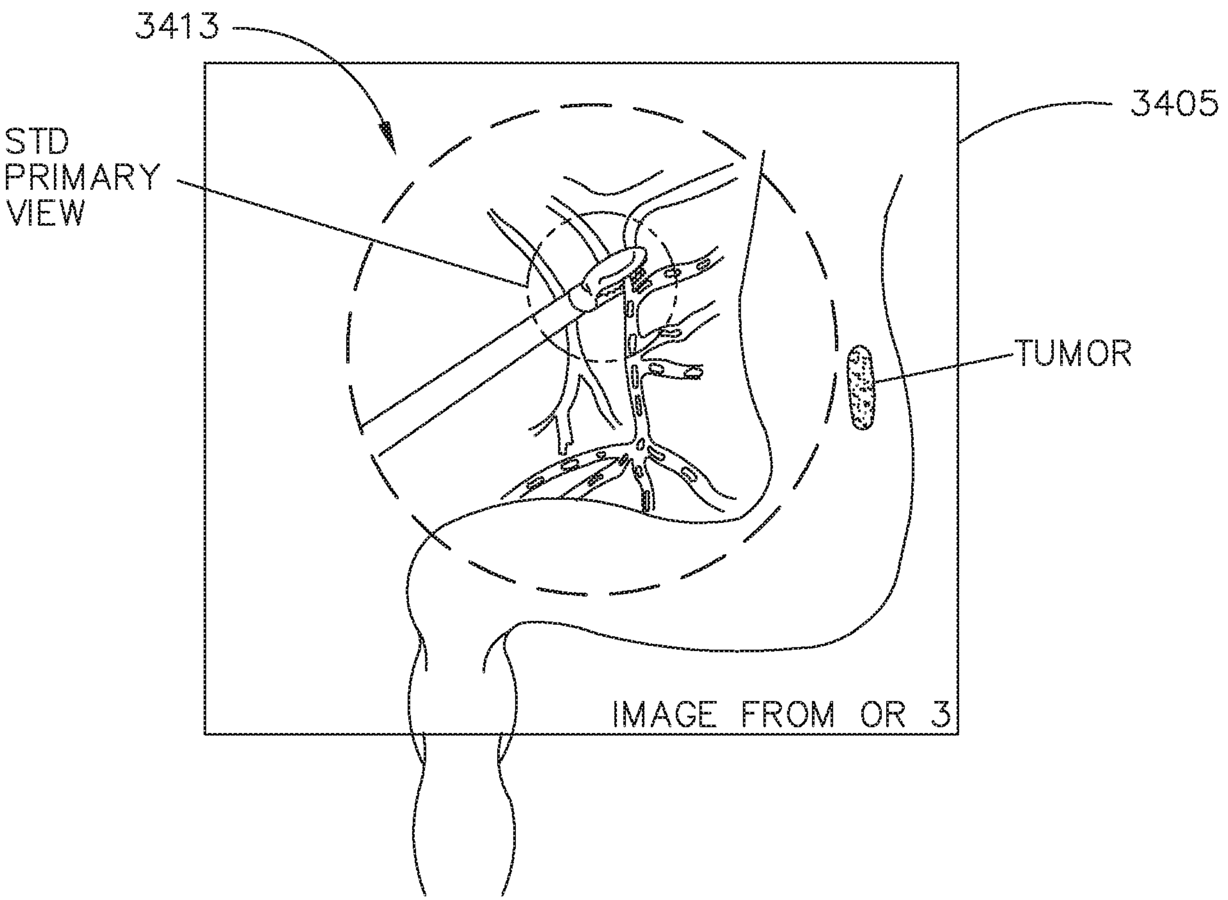


FIG. 59

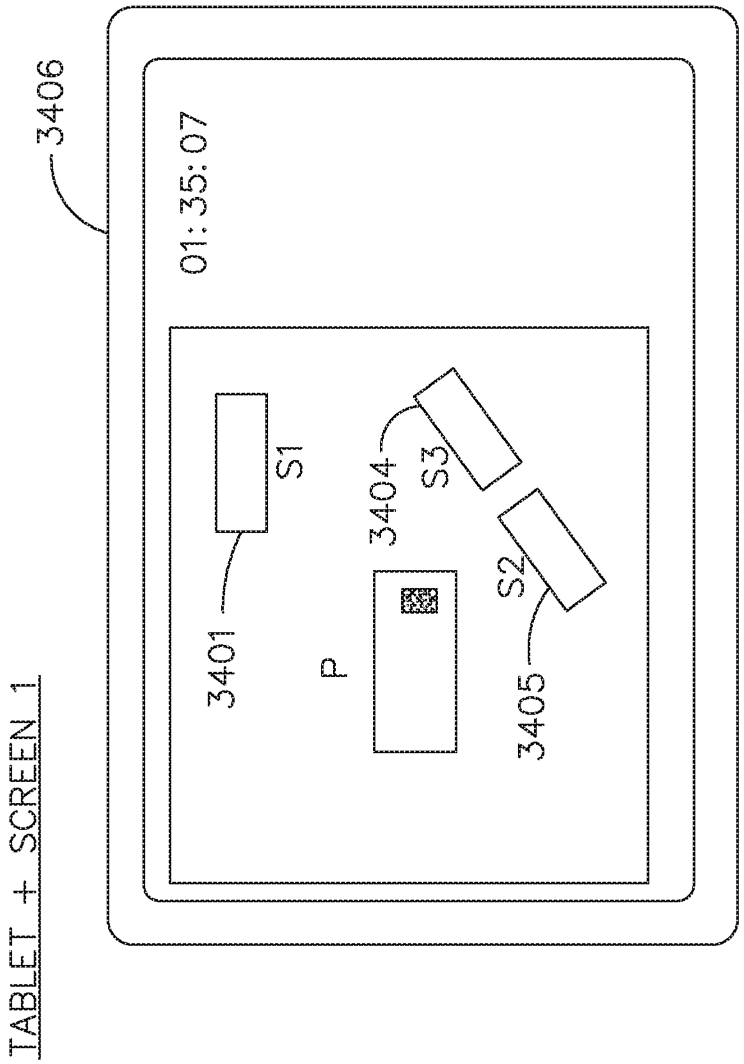


FIG. 60

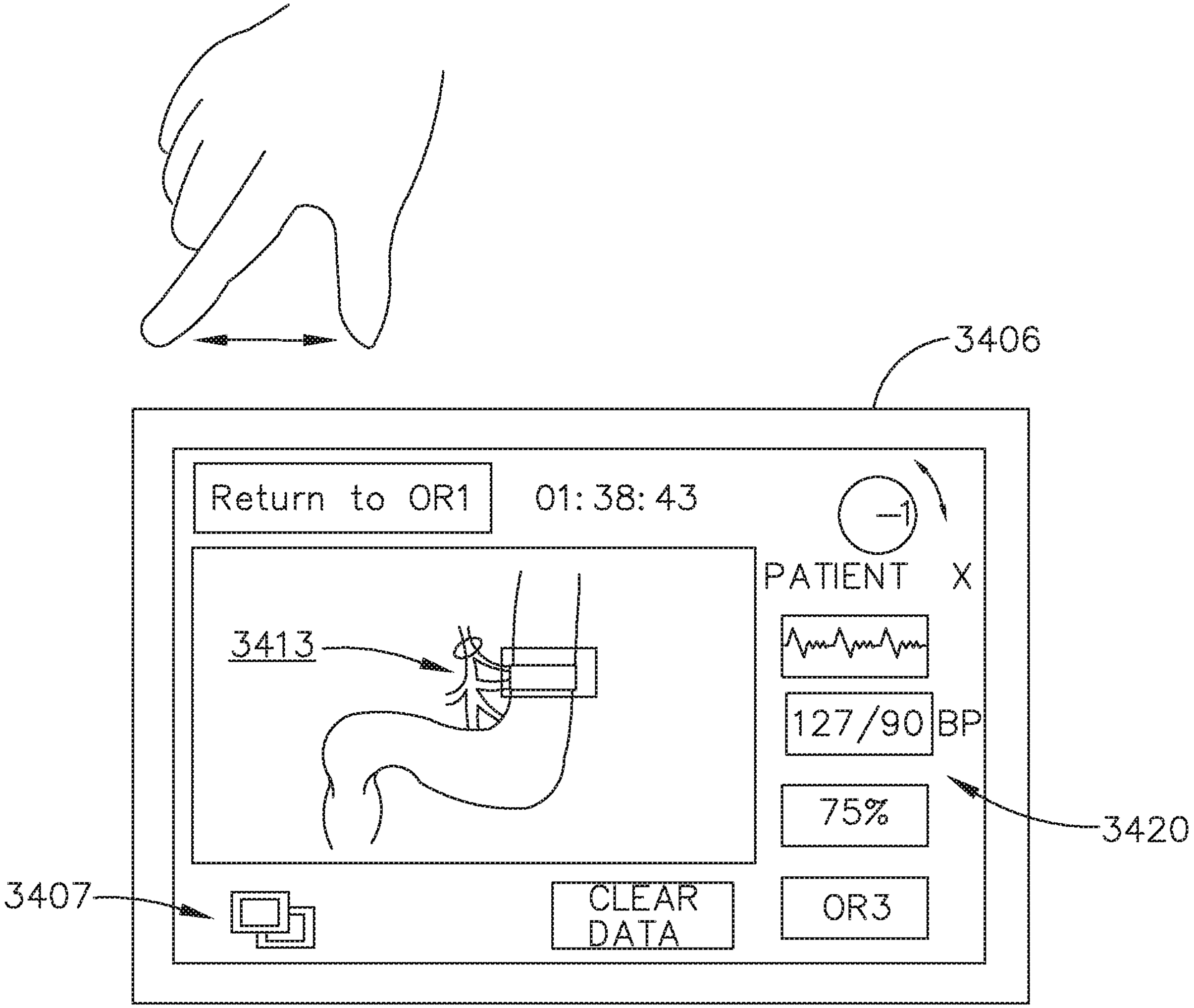

3406
Return to OR1
01:38:43
−1
PATIENT X
3413
127/90 BP
75%
3420
3407
CLEAR DATA
OR3

FIG. 61

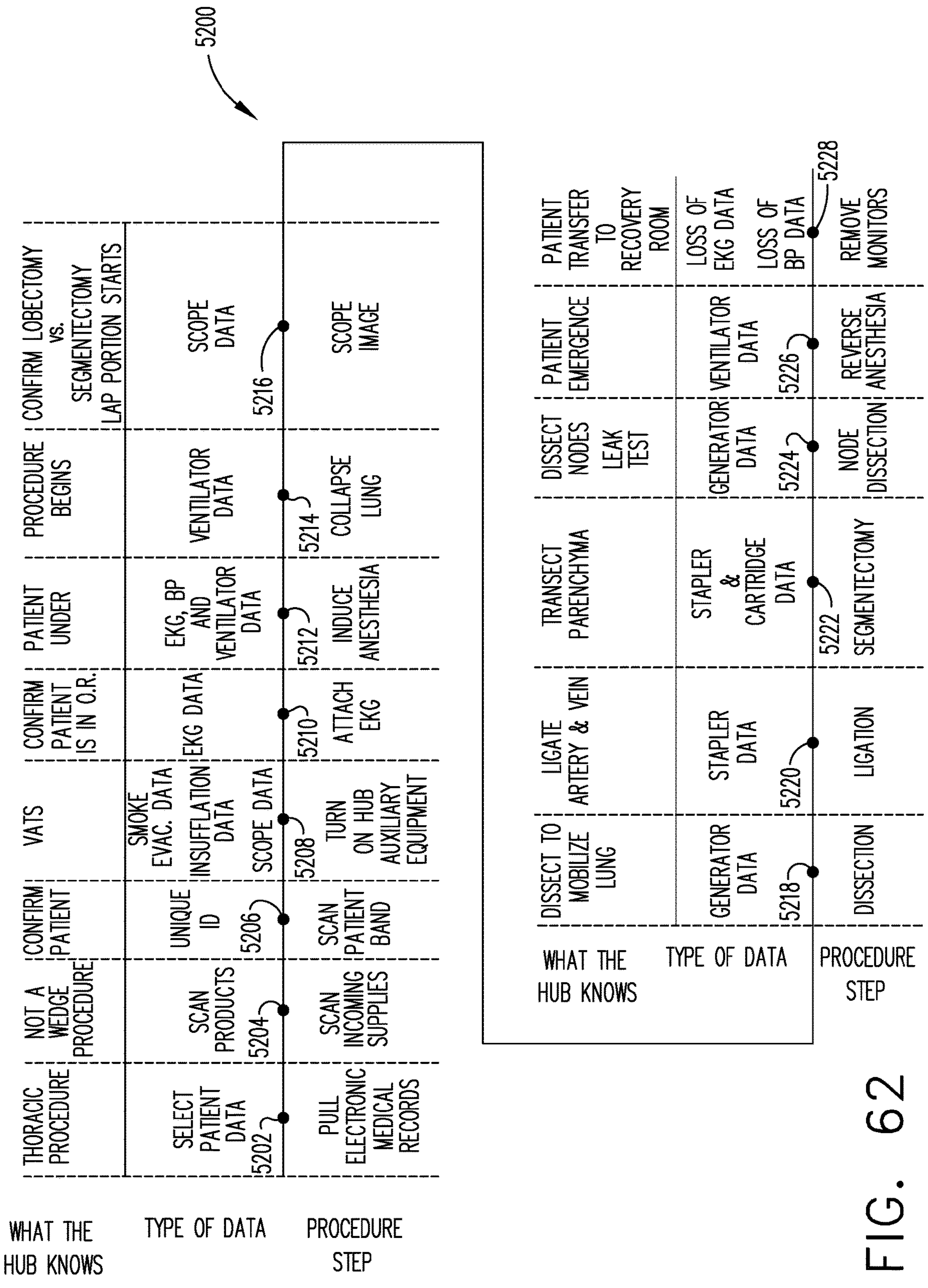

5200
WHAT THE HUB KNOWS
TYPE OF DATA
PROCEDURE STEP
THORACIC PROCEDURE
SELECT PATIENT DATA
5202
PULL ELECTRONIC MEDICAL RECORDS
NOT A WEDGE PROCEDURE
SCAN PRODUCTS
5204
SCAN INCOMING SUPPLIES
CONFIRM PATIENT
UNIQUE ID
5206
SCAN PATIENT BAND
VATS
SMOKE EVAC. DATA
INSUFFLATION DATA
SCOPE DATA
5208
TURN ON HUB AUXILIARY EQUIPMENT
CONFIRM PATIENT IS IN O.R.
EKG DATA
5210
ATTACH EKG
PATIENT UNDER
EKG, BP AND VENTILATOR DATA
5212
INDUCE ANESTHESIA
PROCEDURE BEGINS
VENTILATOR DATA
5214
COLLAPSE LUNG
CONFIRM LOBECTOMY vs. SEGMENTECTOMY LAP PORTION STARTS
SCOPE DATA
5216
SCOPE IMAGE
WHAT THE HUB KNOWS
TYPE OF DATA
PROCEDURE STEP
DISSECT TO MOBILIZE LUNG
GENERATOR DATA
5218
DISSECTION
LIGATE ARTERY & VEIN
STAPLER DATA
5220
LIGATION
TRANSECT PARENCHYMA
STAPLER & CARTRIDGE DATA
5222
SEGMENTECTOMY
DISSECT NODES LEAK TEST
GENERATOR DATA
5224
NODE DISSECTION
PATIENT EMERGENCE
VENTILATOR DATA
5226
REVERSE ANESTHESIA
PATIENT TRANSFER TO RECOVERY ROOM
LOSS OF EKG DATA
LOSS OF BP DATA
5228
REMOVE MONITORS

FIG. 62

INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority under 35 U.S.C. 119(e) to U.S. Provisional Patent Application Ser. No. 62/649,302, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES, filed on Mar. 28, 2018, the disclosure of which is herein incorporated by reference in its entirety.

This application also claims the benefit of priority under 35 U.S.C. 119(e) to U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, of U.S. Provisional Patent Application Ser. No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed Dec. 28, 2017, of U.S. Provisional Patent Application Ser. No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of each of which is herein incorporated by reference in its entirety.

BACKGROUND

The present disclosure relates to various surgical systems. Surgical procedures are typically performed in surgical operating theaters or rooms in a healthcare facility such as, for example, a hospital. A sterile field is typically created around the patient. The sterile field may include the scrubbed team members, who are properly attired, and all furniture and fixtures in the area. Various surgical devices and systems are utilized in performance of a surgical procedure.

SUMMARY

In one general aspect, a surgical hub is provided. The surgical hub is configured to transmit generator data associated with a surgical procedure from a generator of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs. The surgical hub comprises a processor and a memory coupled to the processor. The memory stores instructions executable by the processor to: receive generator data from the generator; encrypt the generator data; generate a message authentication code based on the generator data; generate a datagram comprising the encrypted generator data, the generated message authentication code, a source identifier and a destination identifier; and transmit the datagram to a cloud-based system. The datagram allows for the cloud-based system to: decrypt the encrypted generator data of the transmitted datagram; verify the integrity of the generator data based on the message authentication code; authenticate the surgical hub as the source of the datagram; and validate a transmission path followed by the datagram between the surgical hub and the cloud based system. The generator data is structured into a data packet comprising at least two of the following fields: a field that indicates a source of the data; a unique time stamp; a field indicating an energy mode of the generator; a field indicating a power output of the generator; and a field indicating a duration of the power output of the generator.

In another general aspect, another surgical hub is provided. The surgical hub is configured to transmit generator data associated with a surgical procedure from a generator of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs. The surgical hub comprises a control circuit configured to: receive generator data from the generator; encrypt the generator data; generate a message authentication code based on the generator data; generate a datagram comprising the encrypted generator data, the generated message authentication code, a source identifier and a destination identifier; and transmit the datagram to a cloud-based system. The generator data is structured into a data packet comprising at least two of the following fields: a field that indicates a source of the data; a unique time stamp; a field indicating an energy mode of the generator; a field indicating a power output of the generator; and a field indicating a duration of the power output of the generator. The datagram allows for the cloud-based system to: decrypt the encrypted generator data of the transmitted datagram; verify the integrity of the generator data based on the message authentication code; authenticate the surgical hub as the source of the datagram; and validate a transmission path followed by the datagram between the surgical hub and the cloud-based system.

In yet another general aspect, another surgical hub is provided. The surgical hub is configured to prioritize surgical data associated with a surgical procedure from a surgical device of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs. The surgical hub comprises a processor and a memory coupled to the processor. The memory stores instructions executable by the processor to: capture surgical data, comprising data associated with the surgical device; time-stamp the captured surgical data; identify a failure event; identify a time period associated with the failure event; isolate failure event surgical data from surgical data not associated with the failure event based on the identified time period; chronologize the failure event surgical data by time-stamp; encrypt the chronologized failure event surgical data; and generate a datagram comprising the encrypted failure event surgical data. The datagram is structured to include a field which includes a flag that prioritizes the encrypted failure event surgical data over other encrypted data of the datagram. The memory stores instructions executable by the processor to also transmit the datagram to the cloud-based system. The datagram allows for the cloud-based system to: decrypt the encrypted failure event surgical data; focus analysis on the failure event surgical data rather than surgical data not associated with the failure event; and flag the surgical device associated with the failure event for at least one of: removal from an operating room; return to a manufacturer; future inoperability in the cloud-based system; or a download update to prevent failure events.

FIGURES

The features of various aspects are set forth with particularity in the appended claims. The various aspects, however, both as to organization and methods of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings as follows.

FIG. **1** is a block diagram of a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

FIG. **2** is a surgical system being used to perform a surgical procedure in an operating room, in accordance with at least one aspect of the present disclosure.

FIG. **3** is a surgical hub paired with a visualization system, a robotic system, and an intelligent instrument, in accordance with at least one aspect of the present disclosure.

FIG. **4** is a partial perspective view of a surgical hub enclosure, and of a combo generator module slidably receivable in a drawer of the surgical hub enclosure, in accordance with at least one aspect of the present disclosure.

FIG. **5** is a perspective view of a combo generator module with bipolar, ultrasonic, and monopolar contacts and a smoke evacuation component, in accordance with at least one aspect of the present disclosure.

FIG. **6** illustrates individual power bus attachments for a plurality of lateral docking ports of a lateral modular housing configured to receive a plurality of modules, in accordance with at least one aspect of the present disclosure.

FIG. **7** illustrates a vertical modular housing configured to receive a plurality of modules, in accordance with at least one aspect of the present disclosure.

FIG. **8** illustrates a surgical data network comprising a modular communication hub configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to the cloud, in accordance with at least one aspect of the present disclosure.

FIG. **9** illustrates a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

FIG. **10** illustrates a surgical hub comprising a plurality of modules coupled to the modular control tower, in accordance with at least one aspect of the present disclosure.

FIG. **11** illustrates one aspect of a Universal Serial Bus (USB) network hub device, in accordance with at least one aspect of the present disclosure.

FIG. **12** illustrates a logic diagram of a control system of a surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

FIG. **13** illustrates a control circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

FIG. **14** illustrates a combinational logic circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

FIG. **15** illustrates a sequential logic circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

FIG. **16** illustrates a surgical instrument or tool comprising a plurality of motors which can be activated to perform various functions, in accordance with at least one aspect of the present disclosure.

FIG. **17** is a schematic diagram of a robotic surgical instrument configured to operate a surgical tool described herein, in accordance with at least one aspect of the present disclosure.

FIG. **18** illustrates a block diagram of a surgical instrument programmed to control the distal translation of a displacement member, in accordance with at least one aspect of the present disclosure.

FIG. **19** is a schematic diagram of a surgical instrument configured to control various functions, in accordance with at least one aspect of the present disclosure.

FIG. **20** is a simplified block diagram of a generator configured to provide inductorless tuning, among other benefits, in accordance with at least one aspect of the present disclosure.

FIG. **21** illustrates an example of a generator, which is one form of the generator of FIG. **20**, in accordance with at least one aspect of the present disclosure.

FIG. **22** illustrates a combination generator, in accordance with at least one aspect of the present disclosure.

FIG. **23** illustrates a method of capturing data from a combination generator and communicating the captured generator data to a cloud-based system, in accordance with at least one aspect of the present disclosure.

FIG. **24** illustrates a data packet of combination generator data, in accordance with at least one aspect of the present disclosure.

FIG. **25** illustrates an encryption algorithm, in accordance with at least one aspect of the present disclosure.

FIG. **26** illustrates another encryption algorithm, in accordance with at least one aspect of the present disclosure.

FIG. **27** illustrates yet another encryption algorithm, in accordance with at least one aspect of the present disclosure.

FIG. **28** illustrates a high-level representation of a datagram, in accordance with at least one aspect of the present disclosure.

FIG. **29** illustrates a more detailed representation of the datagram of FIG. **28**, in accordance with at least one aspect of the present disclosure.

FIG. **30** illustrates another representation of the datagram of FIG. **28**, in accordance with at least one aspect of the present disclosure.

FIG. **31** illustrates a method of identifying surgical data associated with a failure event and communicating the identified surgical data to a cloud-based system on a prioritized basis, in accordance with at least one aspect of the present disclosure.

FIG. **32** illustrates yet another representation of the datagram of FIG. **28**, in accordance with at least one aspect of the present disclosure.

FIG. **33** illustrates a partial artificial timeline of a surgical procedure performed in an operating room via a surgical system, in accordance with at least one aspect of the present disclosure.

FIG. **34** illustrates ultrasonic pinging of an operating room wall to determine a distance between a surgical hub and the operating room wall, in accordance with at least one aspect of the present disclosure.

FIG. **35** is a logic flow diagram of a process depicting a control program or a logic configuration for surgical hub pairing with surgical devices of a surgical system that are located within the bounds of an operating room, in accordance with at least one aspect of the present disclosure.

FIG. **36** is a logic flow diagram of a process depicting a control program or a logic configuration for selectively forming and severing connections between devices of a surgical system, in accordance with at least one aspect of the present disclosure.

FIG. **37** is a logic flow diagram of a process depicting a control program or a logic configuration for selectively reevaluating the bounds of an operating room after detecting a new device, in accordance with at least one aspect of the present disclosure.

FIG. **38** is a logic flow diagram of a process depicting a control program or a logic configuration for selectively reevaluating the bounds of an operating room after disconnection of a paired device, in accordance with at least one aspect of the present disclosure.

FIG. **39** is a logic flow diagram of a process depicting a control program or a logic configuration for reevaluating the bounds of an operating room by a surgical hub after detecting a change in the position of the surgical hub, in accordance with at least one aspect of the present disclosure.

FIG. **40** is a logic flow diagram of a process depicting a control program or a logic configuration for selectively forming connections between devices of a surgical system, in accordance with at least one aspect of the present disclosure.

FIG. **41** is a logic flow diagram of a process depicting a control program or a logic configuration for selectively forming and severing connections between devices of a surgical system, in accordance with at least one aspect of the present disclosure.

FIG. **42** illustrates a surgical hub pairing a first device and a second device of a surgical system in an operating room, in accordance with at least one aspect of the present disclosure.

FIG. **43** illustrates a surgical hub unpairing a first device and a second device of a surgical system in an operating room, and pairing the first device with a third device in the operating room, in accordance with at least one aspect of the present disclosure.

FIG. **44** is a logic flow diagram of a process depicting a control program or a logic configuration for forming an severing connections between devices of a surgical system in an operating room during a surgical procedure based on progression of the steps of the surgical procedure, in accordance with at least one aspect of the present disclosure.

FIG. **45** is a logic flow diagram of a process depicting a control program or a logic configuration for overlaying information derived from one or more still frames of a livestream of a remote surgical site onto the livestream, in accordance with at least one aspect of the present disclosure.

FIG. **46** is a logic flow diagram of a process depicting a control program or a logic configuration for differentiating among surgical steps of a surgical procedure, in accordance with at least one aspect of the present disclosure.

FIG. **47** is a logic flow diagram of a process **3230** depicting a control program or a logic configuration for differentiating among surgical steps of a surgical procedure, in accordance with at least one aspect of the present disclosure.

FIG. **48** is a logic flow diagram of a process **3240** depicting a control program or a logic configuration for identifying a staple cartridge from information derived from one or more still frames of staples deployed from the staple cartridge into tissue, in accordance with at least one aspect of the present disclosure.

FIG. **49** is a partial view of a surgical system in an operating room, the surgical system including a surgical hub that has an imaging module in communication with an imaging device at a remote surgical site, in accordance with at least one aspect of the present disclosure.

FIG. **50** illustrates a partial view of stapled tissue that received a first staple firing and a second staple firing arranged end-to-end, in accordance with at least one aspect of the present disclosure.

FIG. **51** illustrates three rows of staples deployed on one side of a tissue stapled and cut by a surgical stapler, in accordance with at least one aspect of the present disclosure.

FIG. **52** illustrates a non-anodized staple and an anodized staple, in accordance with at least one aspect of the present disclosure.

FIG. **53** is a logic flow diagram of a process depicting a control program or a logic configuration for coordinating a control arrangement between surgical hubs, in accordance with at least one aspect of the present disclosure.

FIG. **54** illustrates an interaction between two surgical hubs in an operating room, in accordance with at least one aspect of the present disclosure.

FIG. **55** is a logic flow diagram of a process depicting a control program or a logic configuration for coordinating a control arrangement between surgical hubs, in accordance with at least one aspect of the present disclosure.

FIG. **56** illustrates an interaction between two surgical hubs in different operating rooms ("OR**1**" and "OR**3**"), in accordance with at least one aspect of the present disclosure.

FIG. **57** illustrates a secondary display in an operating room ("OR**3**") showing a surgical site in a colorectal procedure, in accordance with at least one aspect of the present disclosure.

FIG. **58** illustrates a personal interface or tablet in OR**1** displaying the surgical site of OR**3**, in accordance with at least one aspect of the present disclosure.

FIG. **59** illustrates an expanded view of the surgical site of OR**3** displayed on a primary display of OR**1**, in accordance with at least one aspect of the present disclosure.

FIG. **60** illustrates a personal interface or tablet displaying a layout of OR**1** that shows available displays, in accordance with at least one aspect of the present disclosure.

FIG. **61** illustrates a recommendation of a transection location of a surgical site of OR**3** made by a surgical operator in OR**1** via a personal interface or tablet in OR**1**, in accordance with at least one aspect of the present disclosure.

FIG. **62** illustrates a timeline depicting situational awareness of a surgical hub, in accordance with at least one aspect of the present disclosure.

DESCRIPTION

Applicant of the present application owns the following U.S. Provisional patent applications, filed on Mar. 28, 2018, each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Ser. No. 62/649,302, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES;
- U.S. Provisional Patent Application Ser. No. 62/649,294, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD;
- U.S. Provisional Patent Application Ser. No. 62/649,300, titled SURGICAL HUB SITUATIONAL AWARENESS;
- U.S. Provisional Patent Application Ser. No. 62/649,309, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER;
- U.S. Provisional Patent Application Ser. No. 62/649,310, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS;
- U.S. Provisional Patent Application Ser. No. 62/649,291, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT;
- U.S. Provisional Patent Application Ser. No. 62/649,296, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES;
- U.S. Provisional Patent Application Ser. No. 62/649,333, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER;
- U.S. Provisional Patent Application Ser. No. 62/649,327, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES;
- U.S. Provisional Patent Application Ser. No. 62/649,315, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK;

- U.S. Provisional Patent Application Ser. No. 62/649,313, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES;
- U.S. Provisional Patent Application Ser. No. 62/649,320, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Provisional Patent Application Ser. No. 62/649,307, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and
- U.S. Provisional Patent Application Ser. No. 62/649,323, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS.

Applicant of the present application owns the following U.S. Patent Applications, filed on Mar. 29, 2018, each of which is herein incorporated by reference in its entirety:

- U.S. patent application Ser. No. 15/940,648, titled INTERACTIVE SURGICAL SYSTEMS WITH CONDITION HANDLING OF DEVICES AND DATA CAPABILITIES; now U.S. Patent Application Publication No. 2019/0206004;
- U.S. patent application Ser. No. 15/940,656, titled SURGICAL HUB COORDINATION OF CONTROL AND COMMUNICATION OF OPERATING ROOM DEVICES; now U.S. Patent Application Publication No. 2019/0201141;
- U.S. patent application Ser. No. 15/940,666, titled SPATIAL AWARENESS OF SURGICAL HUBS IN OPERATING ROOMS; now U.S. Patent Application Publication No. 2019/0206551;
- U.S. patent application Ser. No. 15/940,670, titled COOPERATIVE UTILIZATION OF DATA DERIVED FROM SECONDARY SOURCES BY INTELLIGENT SURGICAL HUBS; now U.S. Patent Application Publication No. 2019/0201116;
- U.S. patent application Ser. No. 15/940,677, titled SURGICAL HUB CONTROL ARRANGEMENTS; now U.S. Patent Application Publication No. 2019/0201143;
- U.S. patent application Ser. No. 15/940,632, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD; now U.S. Patent Application Publication No. 2019/0205566;
- U.S. patent application Ser. No. 15/940,640, titled COMMUNICATION HUB AND STORAGE DEVICE FOR STORING PARAMETERS AND STATUS OF A SURGICAL DEVICE TO BE SHARED WITH CLOUD BASED ANALYTICS SYSTEMS; now U.S. Patent Application Publication No. 2019/0200863;
- U.S. patent application Ser. No. 15/940,645, titled SELF DESCRIBING DATA PACKETS GENERATED AT AN ISSUING INSTRUMENT; now U.S. Patent Application Publication No. 2019/0207773;
- U.S. patent application Ser. No. 15/940,649, titled DATA PAIRING TO INTERCONNECT A DEVICE MEASURED PARAMETER WITH AN OUTCOME; now U.S. Patent Application Publication No. 2019/0205567;
- U.S. patent application Ser. No. 15/940,654, titled SURGICAL HUB SITUATIONAL AWARENESS; now U.S. Patent Application Publication No. 2019/0201140;
- U.S. patent application Ser. No. 15/940,663, titled SURGICAL SYSTEM DISTRIBUTED PROCESSING; now U.S. Patent Application Publication No. 2019/0201033;

- U.S. patent application Ser. No. 15/940,668, titled AGGREGATION AND REPORTING OF SURGICAL HUB DATA; now U.S. Patent Application Publication No. 2019/0201115;
- U.S. patent application Ser. No. 15/940,671, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER; now U.S. Patent Application Publication No. 2019/0201104;
- U.S. patent application Ser. No. 15/940,686, titled DISPLAY OF ALIGNMENT OF STAPLE CARTRIDGE TO PRIOR LINEAR STAPLE LINE; now U.S. Patent Application Publication No. 2019/0201105;
- U.S. patent application Ser. No. 15/940,700, titled STERILE FIELD INTERACTIVE CONTROL DISPLAYS; now U.S. Patent Application Publication No. 2019/0205001;
- U.S. patent application Ser. No. 15/940,629, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS; now U.S. Patent Application Publication No. 2019/0201112;
- U.S. patent application Ser. No. 15/940,704, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT; now U.S. Patent Application Publication No. 2019/0206050;
- U.S. patent application Ser. No. 14/940,722, titled CHARACTERIZATION OF TISSUE IRREGULARITIES THROUGH THE USE OF MONO-CHROMATIC LIGHT REFRACTIVITY; now U.S. Patent Application Publication No. 2019/0200905; and
- U.S. patent application Ser. No. 15/940,742, titled DUAL CMOS ARRAY IMAGING; now U.S. Patent Application Publication No. 2019/0200906.

Applicant of the present application owns the following U.S. Patent Applications, filed on Mar. 29, 2018, each of which is herein incorporated by reference in its entirety:

- U.S. patent application Ser. No. 15/940,636, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES; now U.S. Patent Application Publication No. 2019/0206003;
- U.S. patent application Ser. No. 15/940,653, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES; now U.S. Patent Application Publication No. 2019/0201114;
- U.S. patent application Ser. No. 15/940,660, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER; now U.S. Patent Application Publication No. 2019/0206555;
- U.S. patent application Ser. No. 15/940,679, titled CLOUD-BASED MEDICAL ANALYTICS FOR LINKING OF LOCAL USAGE TRENDS WITH THE RESOURCE ACQUISITION BEHAVIORS OF LARGER DATA SET; now U.S. Patent Application Publication No. 2019/0201144;
- U.S. patent application Ser. No. 15/940,694, titled CLOUD-BASED MEDICAL ANALYTICS FOR MEDICAL FACILITY SEGMENTED INDIVIDUALIZATION OF INSTRUMENT FUNCTION; now U.S. Patent Application Publication No. 2019/0201119;
- U.S. patent application Ser. No. 15/940,634, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES; now U.S. Patent Application Publication No. 2019/0201138;
- U.S. patent application Ser. No. 15/940,706, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD

- ANALYTICS NETWORK; now U.S. Patent Application Publication No. 2019/0206561; and
- U.S. patent application Ser. No. 15/940,675, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES; now U.S. Patent Application Publication No. 2019/0201117.

Applicant of the present application owns the following U.S. Patent Applications, filed on Mar. 29, 2018, each of which is herein incorporated by reference in its entirety:

- U.S. patent application Ser. No. 15/940,627, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; now U.S. Patent Application Publication No. 2019/0201111;
- U.S. patent application Ser. No. 15/940,637, titled COMMUNICATION ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; now U.S. Patent Application Publication No. 2019/0201139;
- U.S. patent application Ser. No. 15/940,642, titled CONTROLS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; now U.S. Patent Application Publication No. 2019/0201113;
- U.S. patent application Ser. No. 15/940,676, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; now U.S. Patent Application Publication No. 2019/0201142;
- U.S. patent application Ser. No. 15/940,680, titled CONTROLLERS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; now U.S. Patent Application Publication No. 2019/0201135;
- U.S. patent application Ser. No. 15/940,683, titled COOPERATIVE SURGICAL ACTIONS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; now U.S. Patent Application Publication No. 2019/0201145;
- U.S. patent application Ser. No. 15/940,690, titled DISPLAY ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; now U.S. Patent Application Publication No. 2019/0201118; and
- U.S. patent application Ser. No. 14/940,711, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; now U.S. Patent Application Publication No. 2019/0201120.

Before explaining various aspects of surgical devices and generators in detail, it should be noted that the illustrative examples are not limited in application or use to the details of construction and arrangement of parts illustrated in the accompanying drawings and description. The illustrative examples may be implemented or incorporated in other aspects, variations and modifications, and may be practiced or carried out in various ways. Further, unless otherwise indicated, the terms and expressions employed herein have been chosen for the purpose of describing the illustrative examples for the convenience of the reader and are not for the purpose of limitation thereof. Also, it will be appreciated that one or more of the following-described aspects, expressions of aspects, and/or examples, can be combined with any one or more of the other following-described aspects, expressions of aspects and/or examples.

Referring to FIG. **1**, a computer-implemented interactive surgical system **100** includes one or more surgical systems **102** and a cloud-based system (e.g., the cloud **104** that may include a remote server **113** coupled to a storage device **105**). Each surgical system **102** includes at least one surgical hub **106** in communication with the cloud **104** that may include a remote server **113**. In one example, as illustrated in FIG. **1**, the surgical system **102** includes a visualization system **108**, a robotic system **110**, and a handheld intelligent surgical instrument **112**, which are configured to communicate with one another and/or the hub **106**. In some aspects, a surgical system **102** may include an M number of hubs **106**, an N number of visualization systems **108**, an O number of robotic systems **110**, and a P number of handheld intelligent surgical instruments **112**, where M, N, O, and P are integers greater than or equal to one.

FIG. **3** depicts an example of a surgical system **102** being used to perform a surgical procedure on a patient who is lying down on an operating table **114** in a surgical operating room **116**. A robotic system **110** is used in the surgical procedure as a part of the surgical system **102**. The robotic system **110** includes a surgeon's console **118**, a patient side cart **120** (surgical robot), and a surgical robotic hub **122**. The patient side cart **120** can manipulate at least one removably coupled surgical tool **117** through a minimally invasive incision in the body of the patient while the surgeon views the surgical site through the surgeon's console **118**. An image of the surgical site can be obtained by a medical imaging device **124**, which can be manipulated by the patient side cart **120** to orient the imaging device **124**. The robotic hub **122** can be used to process the images of the surgical site for subsequent display to the surgeon through the surgeon's console **118**.

Other types of robotic systems can be readily adapted for use with the surgical system **102**. Various examples of robotic systems and surgical tools that are suitable for use with the present disclosure are described in U.S. Provisional Patent Application Ser. No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

Various examples of cloud-based analytics that are performed by the cloud **104**, and are suitable for use with the present disclosure, are described in U.S. Provisional Patent Application Ser. No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

In various aspects, the imaging device **124** includes at least one image sensor and one or more optical components. Suitable image sensors include, but are not limited to, Charge-Coupled Device (CCD) sensors and Complementary Metal-Oxide Semiconductor (CMOS) sensors.

The optical components of the imaging device **124** may include one or more illumination sources and/or one or more lenses. The one or more illumination sources may be directed to illuminate portions of the surgical field. The one or more image sensors may receive light reflected or refracted from the surgical field, including light reflected or refracted from tissue and/or surgical instruments.

The one or more illumination sources may be configured to radiate electromagnetic energy in the visible spectrum as well as the invisible spectrum. The visible spectrum, sometimes referred to as the optical spectrum or luminous spectrum, is that portion of the electromagnetic spectrum that is visible to (i.e., can be detected by) the human eye and may be referred to as visible light or simply light. A typical human eye will respond to wavelengths in air that are from about 380 nm to about 750 nm.

The invisible spectrum (i.e., the non-luminous spectrum) is that portion of the electromagnetic spectrum that lies below and above the visible spectrum (i.e., wavelengths below about 380 nm and above about 750 nm). The invisible spectrum is not detectable by the human eye. Wavelengths greater than about 750 nm are longer than the red visible spectrum, and they become invisible infrared (IR), microwave, and radio electromagnetic radiation. Wavelengths less than about 380 nm are shorter than the violet spectrum, and they become invisible ultraviolet, x-ray, and gamma ray electromagnetic radiation.

In various aspects, the imaging device **124** is configured for use in a minimally invasive procedure. Examples of imaging devices suitable for use with the present disclosure include, but not limited to, an arthroscope, angioscope, bronchoscope, choledochoscope, colonoscope, cytoscope, duodenoscope, enteroscope, esophagogastro-duodenoscope (gastroscope), endoscope, laryngoscope, nasopharyngo-neproscope, sigmoidoscope, thoracoscope, and ureteroscope.

In one aspect, the imaging device employs multi-spectrum monitoring to discriminate topography and underlying structures. A multi-spectral image is one that captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, e.g., IR and ultraviolet. Spectral imaging can allow extraction of additional information the human eye fails to capture with its receptors for red, green, and blue. The use of multi-spectral imaging is described in greater detail under the heading "Advanced Imaging Acquisition Module" in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. Multi-spectrum monitoring can be a useful tool in relocating a surgical field after a surgical task is completed to perform one or more of the previously described tests on the treated tissue.

It is axiomatic that strict sterilization of the operating room and surgical equipment is required during any surgery. The strict hygiene and sterilization conditions required in a "surgical theater," i.e., an operating or treatment room, necessitate the highest possible sterility of all medical devices and equipment. Part of that sterilization process is the need to sterilize anything that comes in contact with the patient or penetrates the sterile field, including the imaging device **124** and its attachments and components. It will be appreciated that the sterile field may be considered a specified area, such as within a tray or on a sterile towel, that is considered free of microorganisms, or the sterile field may be considered an area, immediately around a patient, who has been prepared for a surgical procedure. The sterile field may include the scrubbed team members, who are properly attired, and all furniture and fixtures in the area.

In various aspects, the visualization system **108** includes one or more imaging sensors, one or more image-processing units, one or more storage arrays, and one or more displays that are strategically arranged with respect to the sterile field, as illustrated in FIG. **2**. In one aspect, the visualization system **108** includes an interface for HL7, PACS, and EMR. Various components of the visualization system **108** are described under the heading "Advanced Imaging Acquisition Module" in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

As illustrated in FIG. **2**, a primary display **119** is positioned in the sterile field to be visible to an operator at the operating table **114**. In addition, a visualization tower **111** is positioned outside the sterile field. The visualization tower **111** includes a first non-sterile display **107** and a second non-sterile display **109**, which face away from each other. The visualization system **108**, guided by the hub **106**, is configured to utilize the displays **107**, **109**, and **119** to coordinate information flow to operators inside and outside the sterile field. For example, the hub **106** may cause the visualization system **108** to display a snapshot of a surgical site, as recorded by an imaging device **124**, on a non-sterile display **107** or **109**, while maintaining a live feed of the surgical site on the primary display **119**. The snapshot on the non-sterile display **107** or **109** can permit a non-sterile operator to perform a diagnostic step relevant to the surgical procedure, for example.

In one aspect, the hub **106** is also configured to route a diagnostic input or feedback entered by a non-sterile operator at the visualization tower **111** to the primary display **119** within the sterile field, where it can be viewed by a sterile operator at the operating table. In one example, the input can be in the form of a modification to the snapshot displayed on the non-sterile display **107** or **109**, which can be routed to the primary display **119** by the hub **106**.

Referring to FIG. **2**, a surgical instrument **112** is being used in the surgical procedure as part of the surgical system **102**. The hub **106** is also configured to coordinate information flow to a display of the surgical instrument **112**. For example, in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. A diagnostic input or feedback entered by a non-sterile operator at the visualization tower **111** can be routed by the hub **106** to the surgical instrument display **115** within the sterile field, where it can be viewed by the operator of the surgical instrument **112**. Example surgical instruments that are suitable for use with the surgical system **102** are described under the heading "Surgical Instrument Hardware" and in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety, for example.

Referring now to FIG. **3**, a hub **106** is depicted in communication with a visualization system **108**, a robotic system **110**, and a handheld intelligent surgical instrument **112**. The hub **106** includes a hub display **135**, an imaging module **138**, a generator module **140**, a communication module **130**, a processor module **132**, and a storage array **134**. In certain aspects, as illustrated in FIG. **3**, the hub **106** further includes a smoke evacuation module **126** and/or a suction/irrigation module **128**.

During a surgical procedure, energy application to tissue, for sealing and/or cutting, is generally associated with smoke evacuation, suction of excess fluid, and/or irrigation of the tissue. Fluid, power, and/or data lines from different sources are often entangled during the surgical procedure. Valuable time can be lost addressing this issue during a surgical procedure. Detangling the lines may necessitate disconnecting the lines from their respective modules, which may require resetting the modules. The hub modular enclosure **136** offers a unified environment for managing the power, data, and fluid lines, which reduces the frequency of entanglement between such lines.

Aspects of the present disclosure present a surgical hub for use in a surgical procedure that involves energy application to tissue at a surgical site. The surgical hub includes a hub enclosure and a combo generator module slidably receivable in a docking station of the hub enclosure. The docking station includes data and power contacts. The combo generator module includes two or more of an ultrasonic energy generator component, a bipolar RF energy generator component, and a monopolar RF energy generator component that are housed in a single unit. In one aspect, the combo generator module also includes a smoke evacuation component, at least one energy delivery cable for connecting the combo generator module to a surgical instrument, at least one smoke evacuation component configured to evacuate smoke, fluid, and/or particulates generated by the application of therapeutic energy to the tissue, and a fluid line extending from the remote surgical site to the smoke evacuation component.

In one aspect, the fluid line is a first fluid line and a second fluid line extends from the remote surgical site to a suction and irrigation module slidably received in the hub enclosure. In one aspect, the hub enclosure comprises a fluid interface.

Certain surgical procedures may require the application of more than one energy type to the tissue. One energy type may be more beneficial for cutting the tissue, while another different energy type may be more beneficial for sealing the tissue. For example, a bipolar generator can be used to seal the tissue while an ultrasonic generator can be used to cut the sealed tissue. Aspects of the present disclosure present a solution where a hub modular enclosure **136** is configured to accommodate different generators, and facilitate an interactive communication therebetween. One of the advantages of the hub modular enclosure **136** is enabling the quick removal and/or replacement of various modules.

Aspects of the present disclosure present a modular surgical enclosure for use in a surgical procedure that involves energy application to tissue. The modular surgical enclosure includes a first energy-generator module, configured to generate a first energy for application to the tissue, and a first docking station comprising a first docking port that includes first data and power contacts, wherein the first energy-generator module is slidably movable into an electrical engagement with the power and data contacts and wherein the first energy-generator module is slidably movable out of the electrical engagement with the first power and data contacts,

Further to the above, the modular surgical enclosure also includes a second energy-generator module configured to generate a second energy, different than the first energy, for application to the tissue, and a second docking station comprising a second docking port that includes second data and power contacts, wherein the second energy-generator module is slidably movable into an electrical engagement with the power and data contacts, and wherein the second energy-generator module is slidably movable out of the electrical engagement with the second power and data contacts.

In addition, the modular surgical enclosure also includes a communication bus between the first docking port and the second docking port, configured to facilitate communication between the first energy-generator module and the second energy-generator module.

Referring to FIGS. **3**-**7**, aspects of the present disclosure are presented for a hub modular enclosure **136** that allows the modular integration of a generator module **140**, a smoke evacuation module **126**, and a suction/irrigation module **128**. The hub modular enclosure **136** further facilitates interactive communication between the modules **140**, **126**, **128**. As illustrated in FIG. **5**, the generator module **140** can be a generator module with integrated monopolar, bipolar, and ultrasonic components supported in a single housing unit **139** slidably insertable into the hub modular enclosure **136**. As illustrated in FIG. **5**, the generator module **140** can be configured to connect to a monopolar device **146**, a bipolar device **147**, and an ultrasonic device **148**. Alternatively, the generator module **140** may comprise a series of monopolar, bipolar, and/or ultrasonic generator modules that interact through the hub modular enclosure **136**. The hub modular enclosure **136** can be configured to facilitate the insertion of multiple generators and interactive communication between the generators docked into the hub modular enclosure **136** so that the generators would act as a single generator.

In one aspect, the hub modular enclosure **136** comprises a modular power and communication backplane **149** with external and wireless communication headers to enable the removable attachment of the modules **140**, **126**, **128** and interactive communication therebetween.

In one aspect, the hub modular enclosure **136** includes docking stations, or drawers, **151**, herein also referred to as drawers, which are configured to slidably receive the modules **140**, **126**, **128**. FIG. **4** illustrates a partial perspective view of a surgical hub enclosure **136**, and a combo generator module **145** slidably receivable in a docking station **151** of the surgical hub enclosure **136**. A docking port **152** with power and data contacts on a rear side of the combo generator module **145** is configured to engage a corresponding docking port **150** with power and data contacts of a corresponding docking station **151** of the hub modular enclosure **136** as the combo generator module **145** is slid into position within the corresponding docking station **151** of the hub module enclosure **136**. In one aspect, the combo generator module **145** includes a bipolar, ultrasonic, and monopolar module and a smoke evacuation module integrated together into a single housing unit **139**, as illustrated in FIG. **5**.

In various aspects, the smoke evacuation module **126** includes a fluid line **154** that conveys captured/collected smoke and/or fluid away from a surgical site and to, for example, the smoke evacuation module **126**. Vacuum suction originating from the smoke evacuation module **126** can draw the smoke into an opening of a utility conduit at the surgical site. The utility conduit, coupled to the fluid line, can be in the form of a flexible tube terminating at the smoke evacuation module **126**. The utility conduit and the fluid line define a fluid path extending toward the smoke evacuation module **126** that is received in the hub enclosure **136**.

In various aspects, the suction/irrigation module **128** is coupled to a surgical tool comprising an aspiration fluid line and a suction fluid line. In one example, the aspiration and suction fluid lines are in the form of flexible tubes extending from the surgical site toward the suction/irrigation module **128**. One or more drive systems can be configured to cause irrigation and aspiration of fluids to and from the surgical site.

In one aspect, the surgical tool includes a shaft having an end effector at a distal end thereof and at least one energy treatment associated with the end effector, an aspiration tube, and an irrigation tube. The aspiration tube can have an inlet port at a distal end thereof and the aspiration tube extends through the shaft. Similarly, an irrigation tube can extend through the shaft and can have an inlet port in proximity to the energy deliver implement. The energy deliver implement is configured to deliver ultrasonic and/or RF energy to the surgical site and is coupled to the generator module **140** by a cable extending initially through the shaft.

The irrigation tube can be in fluid communication with a fluid source, and the aspiration tube can be in fluid communication with a vacuum source. The fluid source and/or the vacuum source can be housed in the suction/irrigation module **128**. In one example, the fluid source and/or the vacuum source can be housed in the hub enclosure **136** separately from the suction/irrigation module **128**. In such example, a fluid interface can be configured to connect the suction/irrigation module **128** to the fluid source and/or the vacuum source.

In one aspect, the modules **140**, **126**, **128** and/or their corresponding docking stations on the hub modular enclosure **136** may include alignment features that are configured to align the docking ports of the modules into engagement with their counterparts in the docking stations of the hub modular enclosure **136**. For example, as illustrated in FIG. **4**, the combo generator module **145** includes side brackets **155** that are configured to slidably engage with corresponding brackets **156** of the corresponding docking station **151** of the hub modular enclosure **136**. The brackets cooperate to guide the docking port contacts of the combo generator module **145** into an electrical engagement with the docking port contacts of the hub modular enclosure **136**.

In some aspects, the drawers **151** of the hub modular enclosure **136** are the same, or substantially the same size, and the modules are adjusted in size to be received in the drawers **151**. For example, the side brackets **155** and/or **156** can be larger or smaller depending on the size of the module. In other aspects, the drawers **151** are different in size and are each designed to accommodate a particular module.

Furthermore, the contacts of a particular module can be keyed for engagement with the contacts of a particular drawer to avoid inserting a module into a drawer with mismatching contacts.

As illustrated in FIG. **4**, the docking port **150** of one drawer **151** can be coupled to the docking port **150** of another drawer **151** through a communications link **157** to facilitate an interactive communication between the modules housed in the hub modular enclosure **136**. The docking ports **150** of the hub modular enclosure **136** may alternatively, or additionally, facilitate a wireless interactive communication between the modules housed in the hub modular enclosure **136**. Any suitable wireless communication can be employed, such as for example Air Titan-Bluetooth.

FIG. **6** illustrates individual power bus attachments for a plurality of lateral docking ports of a lateral modular housing **160** configured to receive a plurality of modules of a surgical hub **206**. The lateral modular housing **160** is configured to laterally receive and interconnect the modules **161**. The modules **161** are slidably inserted into docking stations **162** of lateral modular housing **160**, which includes a backplane for interconnecting the modules **161**. As illustrated in FIG. **6**, the modules **161** are arranged laterally in the lateral modular housing **160**. Alternatively, the modules **161** may be arranged vertically in a lateral modular housing.

FIG. **7** illustrates a vertical modular housing **164** configured to receive a plurality of modules **165** of the surgical hub **106**. The modules **165** are slidably inserted into docking stations, or drawers, **167** of vertical modular housing **164**, which includes a backplane for interconnecting the modules **165**. Although the drawers **167** of the vertical modular housing **164** are arranged vertically, in certain instances, a vertical modular housing **164** may include drawers that are arranged laterally. Furthermore, the modules **165** may interact with one another through the docking ports of the vertical modular housing **164**. In the example of FIG. **7**, a display **177** is provided for displaying data relevant to the operation of the modules **165**. In addition, the vertical modular housing **164** includes a master module **178** housing a plurality of sub-modules that are slidably received in the master module **178**.

In various aspects, the imaging module **138** comprises an integrated video processor and a modular light source and is adapted for use with various imaging devices. In one aspect, the imaging device is comprised of a modular housing that can be assembled with a light source module and a camera module. The housing can be a disposable housing. In at least one example, the disposable housing is removably coupled to a reusable controller, a light source module, and a camera module. The light source module and/or the camera module can be selectively chosen depending on the type of surgical procedure. In one aspect, the camera module comprises a CCD sensor. In another aspect, the camera module comprises a CMOS sensor. In another aspect, the camera module is configured for scanned beam imaging. Likewise, the light source module can be configured to deliver a white light or a different light, depending on the surgical procedure.

During a surgical procedure, removing a surgical device from the surgical field and replacing it with another surgical device that includes a different camera or a different light source can be inefficient. Temporarily losing sight of the surgical field may lead to undesirable consequences. The module imaging device of the present disclosure is configured to permit the replacement of a light source module or a camera module midstream during a surgical procedure, without having to remove the imaging device from the surgical field.

In one aspect, the imaging device comprises a tubular housing that includes a plurality of channels. A first channel is configured to slidably receive the camera module, which can be configured for a snap-fit engagement with the first channel. A second channel is configured to slidably receive the light source module, which can be configured for a snap-fit engagement with the second channel. In another example, the camera module and/or the light source module can be rotated into a final position within their respective channels. A threaded engagement can be employed in lieu of the snap-fit engagement.

In various examples, multiple imaging devices are placed at different positions in the surgical field to provide multiple views. The imaging module **138** can be configured to switch between the imaging devices to provide an optimal view. In various aspects, the imaging module **138** can be configured to integrate the images from the different imaging device.

Various image processors and imaging devices suitable for use with the present disclosure are described in U.S. Pat. No. 7,995,045, titled COMBINED SBI AND CONVENTIONAL IMAGE PROCESSOR, which issued on Aug. 9, 2011, which is herein incorporated by reference in its entirety. In addition, U.S. Pat. No. 7,982,776, titled SBI MOTION ARTIFACT REMOVAL APPARATUS AND METHOD, which issued on Jul. 19, 2011, which is herein incorporated by reference in its entirety, describes various systems for removing motion artifacts from image data. Such systems can be integrated with the imaging module **138**. Furthermore, U.S. Patent Application Publication No. 2011/0306840, titled CONTROLLABLE MAGNETIC SOURCE TO FIXTURE INTRACORPOREAL APPARATUS, which published on Dec. 15, 2011, and U.S. Patent Application Publication No. 2014/0243597, titled SYSTEM FOR PERFORMING A MINIMALLY INVASIVE SURGICAL PROCEDURE, which published on Aug. 28, 2014, each of which is herein incorporated by reference in its entirety.

FIG. **8** illustrates a surgical data network **201** comprising a modular communication hub **203** configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to a cloud-based system (e.g., the cloud **204** that may include a remote server **213** coupled to a storage device **205**). In one aspect, the modular communication hub **203** comprises a network hub **207** and/or a network switch **209** in communication with a network router. The modular communication hub **203** also can be coupled to a local computer system **210** to provide local computer processing and data manipulation. The surgical data network **201** may be configured as passive, intelligent, or switching. A passive surgical data network serves as a conduit for the data, enabling it to go from one device (or segment) to another and to the cloud computing resources. An intelligent surgical data network includes additional features to enable the traffic passing through the surgical data network to be monitored and to configure each port in the network hub **207** or network switch **209**. An intelligent surgical data network may be referred to as a manageable hub or switch. A switching hub reads the destination address of each packet and then forwards the packet to the correct port.

Modular devices **1***a*-**1***n* located in the operating theater may be coupled to the modular communication hub **203**. The network hub **207** and/or the network switch **209** may be coupled to a network router **211** to connect the devices **1***a*-**1***n* to the cloud **204** or the local computer system **210**. Data associated with the devices **1***a*-**1***n* may be transferred to cloud-based computers via the router for remote data processing and manipulation. Data associated with the devices **1***a*-**1***n* may also be transferred to the local computer system **210** for local data processing and manipulation. Modular devices **2***a*-**2***m* located in the same operating theater also may be coupled to a network switch **209**. The network switch **209** may be coupled to the network hub **207** and/or the network router **211** to connect to the devices **2***a*-**2***m* to the cloud **204**. Data associated with the devices **2***a*-**2***n* may be transferred to the cloud **204** via the network router **211** for data processing and manipulation. Data associated with the devices **2***a*-**2***m* may also be transferred to the local computer system **210** for local data processing and manipulation.

It will be appreciated that the surgical data network **201** may be expanded by interconnecting multiple network hubs **207** and/or multiple network switches **209** with multiple network routers **211**. The modular communication hub **203** may be contained in a modular control tower configured to receive multiple devices **1***a*-**1***n*/**2***a*-**2***m*. The local computer system **210** also may be contained in a modular control tower. The modular communication hub **203** is connected to a display **212** to display images obtained by some of the devices **1***a*-**1***n*/**2***a*-**2***m*, for example during surgical procedures. In various aspects, the devices **1***a*-**1***n*/**2***a*-**2***m* may include, for example, various modules such as an imaging module **138** coupled to an endoscope, a generator module **140** coupled to an energy-based surgical device, a smoke evacuation module **126**, a suction/irrigation module **128**, a communication module **130**, a processor module **132**, a storage array **134**, a surgical device coupled to a display, and/or a non-contact sensor module, among other modular devices that may be connected to the modular communication hub **203** of the surgical data network **201**.

In one aspect, the surgical data network **201** may comprise a combination of network hub(s), network switch(es), and network router(s) connecting the devices **1***a*-**1***n*/**2***a*-**2***m* to the cloud. Any one of or all of the devices **1***a*-**1***n*/**2***a*-**2***m* coupled to the network hub or network switch may collect data in real time and transfer the data to cloud computers for data processing and manipulation. It will be appreciated that cloud computing relies on sharing computing resources rather than having local servers or personal devices to handle software applications. The word "cloud" may be used as a metaphor for "the Internet," although the term is not limited as such. Accordingly, the term "cloud computing" may be used herein to refer to "a type of Internet-based computing," where different services—such as servers, storage, and applications—are delivered to the modular communication hub **203** and/or computer system **210** located in the surgical theater (e.g., a fixed, mobile, temporary, or field operating room or space) and to devices connected to the modular communication hub **203** and/or computer system **210** through the Internet. The cloud infrastructure may be maintained by a cloud service provider. In this context, the cloud service provider may be the entity that coordinates the usage and control of the devices **1***a*-**1***n*/**2***a*-**2***m* located in one or more operating theaters. The cloud computing services can perform a large number of calculations based on the data gathered by smart surgical instruments, robots, and other computerized devices located in the operating theater. The hub hardware enables multiple devices or connections to be connected to a computer that communicates with the cloud computing resources and storage.

Applying cloud computer data processing techniques on the data collected by the devices **1***a*-**1***n*/**2***a*-**2***m*, the surgical data network provides improved surgical outcomes, reduced costs, and improved patient satisfaction. At least some of the devices **1***a*-**1***n*/**2***a*-**2***m* may be employed to view tissue states to assess leaks or perfusion of sealed tissue after a tissue sealing and cutting procedure. At least some of the devices **1***a*-**1***n*/**2***a*-**2***m* may be employed to identify pathology, such as the effects of diseases, using the cloud-based computing to examine data including images of samples of body tissue for diagnostic purposes. This includes localization and margin confirmation of tissue and phenotypes. At least some of the devices **1***a*-**1***n*/**2***a*-**2***m* may be employed to identify anatomical structures of the body using a variety of sensors integrated with imaging devices and techniques such as overlaying images captured by multiple imaging devices. The data gathered by the devices **1***a*-**1***n*/**2***a*-**2***m*, including image data, may be transferred to the cloud **204** or the local computer system **210** or both for data processing and manipulation including image processing and manipulation. The data may be analyzed to improve surgical procedure outcomes by determining if further treatment, such as the application of endoscopic intervention, emerging technologies, a targeted radiation, targeted intervention, and precise robotics to tissue-specific sites and conditions, may be pursued. Such data analysis may further employ outcome analytics processing, and using standardized approaches may provide beneficial feedback to either confirm surgical treatments and the behavior of the surgeon or suggest modifications to surgical treatments and the behavior of the surgeon.

In one implementation, the operating theater devices **1***a*-**1***n* may be connected to the modular communication hub **203** over a wired channel or a wireless channel depending on the configuration of the devices **1***a*-**1***n* to a network hub. The network hub **207** may be implemented, in one aspect, as a local network broadcast device that works on the physical layer of the Open System Interconnection (OSI) model. The network hub provides connectivity to the devices **1***a*-**1***n* located in the same operating theater network. The network hub **207** collects data in the form of packets and sends them to the router in half duplex mode. The network hub **207** does not store any media access control/Internet Protocol (MAC/IP) to transfer the device data. Only one of the devices **1***a*-**1***n* can send data at a time through the network hub **207**. The network hub **207** has no routing tables or intelligence regarding where to send information and broadcasts all network data across each connection and to a remote server

213 (FIG. **9**) over the cloud **204**. The network hub **207** can detect basic network errors such as collisions, but having all information broadcast to multiple ports can be a security risk and cause bottlenecks.

In another implementation, the operating theater devices **2***a*-**2***m* may be connected to a network switch **209** over a wired channel or a wireless channel. The network switch **209** works in the data link layer of the OSI model. The network switch **209** is a multicast device for connecting the devices **2***a*-**2***m* located in the same operating theater to the network. The network switch **209** sends data in the form of frames to the network router **211** and works in full duplex mode. Multiple devices **2***a*-**2***m* can send data at the same time through the network switch **209**. The network switch **209** stores and uses MAC addresses of the devices **2***a*-**2***m* to transfer data.

The network hub **207** and/or the network switch **209** are coupled to the network router **211** for connection to the cloud **204**. The network router **211** works in the network layer of the OSI model. The network router **211** creates a route for transmitting data packets received from the network hub **207** and/or network switch **211** to cloud-based computer resources for further processing and manipulation of the data collected by any one of or all the devices **1***a*-**1***n*/**2***a*-**2***m*. The network router **211** may be employed to connect two or more different networks located in different locations, such as, for example, different operating theaters of the same healthcare facility or different networks located in different operating theaters of different healthcare facilities. The network router **211** sends data in the form of packets to the cloud **204** and works in full duplex mode. Multiple devices can send data at the same time. The network router **211** uses IP addresses to transfer data.

In one example, the network hub **207** may be implemented as a USB hub, which allows multiple USB devices to be connected to a host computer. The USB hub may expand a single USB port into several tiers so that there are more ports available to connect devices to the host system computer. The network hub **207** may include wired or wireless capabilities to receive information over a wired channel or a wireless channel. In one aspect, a wireless USB short-range, high-bandwidth wireless radio communication protocol may be employed for communication between the devices **1***a*-**1***n* and devices **2***a*-**2***m* located in the operating theater.

In other examples, the operating theater devices **1***a*-**1***n*/**2***a*-**2***m* may communicate to the modular communication hub **203** via Bluetooth wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices and building personal area networks (PANs). In other aspects, the operating theater devices **1***a*-**1***n*/**2***a*-**2***m* may communicate to the modular communication hub **203** via a number of wireless or wired communication standards or protocols, including but not limited to W-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long-term evolution (LTE), and Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, and Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter-range wireless communications such as Wi-Fi and Bluetooth, and a second communication module may be dedicated to longer-range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

The modular communication hub **203** may serve as a central connection for one or all of the operating theater devices **1***a*-**1***n*/**2***a*-**2***m* and handles a data type known as frames. Frames carry the data generated by the devices **1***a*-**1***n*/**2***a*-**2***m*. When a frame is received by the modular communication hub **203**, it is amplified and transmitted to the network router **211**, which transfers the data to the cloud computing resources by using a number of wireless or wired communication standards or protocols, as described herein.

The modular communication hub **203** can be used as a standalone device or be connected to compatible network hubs and network switches to form a larger network. The modular communication hub **203** is generally easy to install, configure, and maintain, making it a good option for networking the operating theater devices **1***a*-**1***n*/**2***a*-**2***m*.

FIG. **9** illustrates a computer-implemented interactive surgical system **200**. The computer-implemented interactive surgical system **200** is similar in many respects to the computer-implemented interactive surgical system **100**. For example, the computer-implemented interactive surgical system **200** includes one or more surgical systems **202**, which are similar in many respects to the surgical systems **102**. Each surgical system **202** includes at least one surgical hub **206** in communication with a cloud **204** that may include a remote server **213**. In one aspect, the computer-implemented interactive surgical system **200** comprises a modular control tower **236** connected to multiple operating theater devices such as, for example, intelligent surgical instruments, robots, and other computerized devices located in the operating theater. As shown in FIG. **10**, the modular control tower **236** comprises a modular communication hub **203** coupled to a computer system **210**. As illustrated in the example of FIG. **9**, the modular control tower **236** is coupled to an imaging module **238** that is coupled to an endoscope **239**, a generator module **240** that is coupled to an energy device **241**, a smoke evacuator module **226**, a suction/irrigation module **228**, a communication module **230**, a processor module **232**, a storage array **234**, a smart device/instrument **235** optionally coupled to a display **237**, and a non-contact sensor module **242**. The operating theater devices are coupled to cloud computing resources and data storage via the modular control tower **236**. A robot hub **222** also may be connected to the modular control tower **236** and to the cloud computing resources. The devices/instruments **235**, visualization systems **208**, among others, may be coupled to the modular control tower **236** via wired or wireless communication standards or protocols, as described herein. The modular control tower **236** may be coupled to a hub display **215** (e.g., monitor, screen) to display and overlay images received from the imaging module, device/instrument display, and/or other visualization systems **208**. The hub display also may display data received from devices connected to the modular control tower in conjunction with images and overlaid images.

FIG. **10** illustrates a surgical hub **206** comprising a plurality of modules coupled to the modular control tower **236**. The modular control tower **236** comprises a modular communication hub **203**, e.g., a network connectivity device, and a computer system **210** to provide local processing, visualization, and imaging, for example. As shown in FIG. **10**, the modular communication hub **203** may be connected in a tiered configuration to expand the number of modules (e.g., devices) that may be connected to the modular communication hub **203** and transfer data associated with the modules to the computer system **210**, cloud computing resources, or both. As shown in FIG. **10**, each of the network hubs/switches in the modular communication hub **203** includes three downstream ports and one upstream port. The upstream network hub/switch is connected to a processor to provide a communication connection to the cloud computing resources and a local display **217**. Communication to the cloud **204** may be made either through a wired or a wireless communication channel.

The surgical hub **206** employs a non-contact sensor module **242** to measure the dimensions of the operating theater and generate a map of the surgical theater using either ultrasonic or laser-type non-contact measurement devices. An ultrasound-based non-contact sensor module scans the operating theater by transmitting a burst of ultrasound and receiving the echo when it bounces off the perimeter walls of an operating theater as described under the heading "Surgical Hub Spatial Awareness Within an Operating Room" in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, which is herein incorporated by reference in its entirety, in which the sensor module is configured to determine the size of the operating theater and to adjust Bluetooth-pairing distance limits. A laser-based non-contact sensor module scans the operating theater by transmitting laser light pulses, receiving laser light pulses that bounce off the perimeter walls of the operating theater, and comparing the phase of the transmitted pulse to the received pulse to determine the size of the operating theater and to adjust Bluetooth pairing distance limits, for example.

The computer system **210** comprises a processor **244** and a network interface **245**. The processor **244** is coupled to a communication module **247**, storage **248**, memory **249**, non-volatile memory **250**, and input/output interface **251** via a system bus. The system bus can be any of several types of bus structure(s) including the memory bus or memory controller, a peripheral bus or external bus, and/or a local bus using any variety of available bus architectures including, but not limited to, 9-bit bus, Industrial Standard Architecture (ISA), Micro-Charmel Architecture (MSA), Extended ISA (EISA), Intelligent Drive Electronics (IDE), VESA Local Bus (VLB), Peripheral Component Interconnect (PCI), USB, Advanced Graphics Port (AGP), Personal Computer Memory Card International Association bus (PCMCIA), Small Computer Systems Interface (SCSI), or any other proprietary bus.

The processor **244** may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), an internal read-only memory (ROM) loaded with StellarisWare® software, a 2 KB electrically erasable programmable read-only memory (EEPROM), and/or one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analogs, one or more 12-bit analog-to-digital converters (ADCs) with 12 analog input channels, details of which are available for the product datasheet.

In one aspect, the processor **244** may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

The system memory includes volatile memory and non-volatile memory. The basic input/output system (BIOS), containing the basic routines to transfer information between elements within the computer system, such as during start-up, is stored in non-volatile memory. For example, the non-volatile memory can include ROM, programmable ROM (PROM), electrically programmable ROM (EPROM), EEPROM, or flash memory. Volatile memory includes random-access memory (RAM), which acts as external cache memory. Moreover, RAM is available in many forms such as SRAM, dynamic RAM (DRAM), synchronous DRAM (SDRAM), double data rate SDRAM (DDR SDRAM), enhanced SDRAM (ESDRAM), Synchlink DRAM (SL-DRAM), and direct Rambus RAM (DRRAM).

The computer system **210** also includes removable/non-removable, volatile/non-volatile computer storage media, such as for example disk storage. The disk storage includes, but is not limited to, devices like a magnetic disk drive, floppy disk drive, tape drive, Jaz drive, Zip drive, LS-60 drive, flash memory card, or memory stick. In addition, the disk storage can include storage media separately or in combination with other storage media including, but not limited to, an optical disc drive such as a compact disc ROM device (CD-ROM), compact disc recordable drive (CD-R Drive), compact disc rewritable drive (CD-RW Drive), or a digital versatile disc ROM drive (DVD-ROM). To facilitate the connection of the disk storage devices to the system bus, a removable or non-removable interface may be employed.

It is to be appreciated that the computer system **210** includes software that acts as an intermediary between users and the basic computer resources described in a suitable operating environment. Such software includes an operating system. The operating system, which can be stored on the disk storage, acts to control and allocate resources of the computer system. System applications take advantage of the management of resources by the operating system through program modules and program data stored either in the system memory or on the disk storage. It is to be appreciated that various components described herein can be implemented with various operating systems or combinations of operating systems.

A user enters commands or information into the computer system **210** through input device(s) coupled to the I/O interface **251**. The input devices include, but are not limited to, a pointing device such as a mouse, trackball, stylus, touch pad, keyboard, microphone, joystick, game pad, satellite dish, scanner, TV tuner card, digital camera, digital video camera, web camera, and the like. These and other input devices connect to the processor through the system bus via interface port(s). The interface port(s) include, for example, a serial port, a parallel port, a game port, and a USB. The output device(s) use some of the same types of ports as input device(s). Thus, for example, a USB port may be used to provide input to the computer system and to output information from the computer system to an output device. An output adapter is provided to illustrate that there are some output devices like monitors, displays, speakers, and printers, among other output devices that require special adapters. The output adapters include, by way of illustration and not limitation, video and sound cards that provide a means of connection between the output device and the system bus.

It should be noted that other devices and/or systems of devices, such as remote computer(s), provide both input and output capabilities.

The computer system **210** can operate in a networked environment using logical connections to one or more remote computers, such as cloud computer(s), or local computers. The remote cloud computer(s) can be a personal computer, server, router, network PC, workstation, microprocessor-based appliance, peer device, or other common network node, and the like, and typically includes many or all of the elements described relative to the computer system. For purposes of brevity, only a memory storage device is illustrated with the remote computer(s). The remote computer(s) is logically connected to the computer system through a network interface and then physically connected via a communication connection. The network interface encompasses communication networks such as local area networks (LANs) and wide area networks (WANs). LAN technologies include Fiber Distributed Data Interface (FDDI), Copper Distributed Data Interface (CDDI), Ethernet/IEEE 802.3, Token Ring/IEEE 802.5 and the like. WAN technologies include, but are not limited to, point-to-point links, circuit-switching networks like Integrated Services Digital Networks (ISDN) and variations thereon, packet-switching networks, and Digital Subscriber Lines (DSL).

In various aspects, the computer system **210** of FIG. **10**, the imaging module **238** and/or visualization system **208**, and/or the processor module **232** of FIGS. **9-10**, may comprise an image processor, image-processing engine, media processor, or any specialized digital signal processor (DSP) used for the processing of digital images. The image processor may employ parallel computing with single instruction, multiple data (SIMD) or multiple instruction, multiple data (MIMD) technologies to increase speed and efficiency. The digital image-processing engine can perform a range of tasks. The image processor may be a system on a chip with multicore processor architecture.

The communication connection(s) refers to the hardware/software employed to connect the network interface to the bus. While the communication connection is shown for illustrative clarity inside the computer system, it can also be external to the computer system **210**. The hardware/software necessary for connection to the network interface includes, for illustrative purposes only, internal and external technologies such as modems, including regular telephone-grade modems, cable modems, and DSL modems, ISDN adapters, and Ethernet cards.

FIG. **11** illustrates a functional block diagram of one aspect of a USB network hub **300** device, according to one aspect of the present disclosure. In the illustrated aspect, the USB network hub device **300** employs a TUSB2036 integrated circuit hub by Texas Instruments. The USB network hub **300** is a CMOS device that provides an upstream USB transceiver port **302** and up to three downstream USB transceiver ports **304**, **306**, **308** in compliance with the USB 2.0 specification. The upstream USB transceiver port **302** is a differential root data port comprising a differential data minus (DM**0**) input paired with a differential data plus (DP**0**) input. The three downstream USB transceiver ports **304**, **306**, **308** are differential data ports where each port includes differential data plus (DP**1**-DP**3**) outputs paired with differential data minus (DM**1**-DM**3**) outputs.

The USB network hub **300** device is implemented with a digital state machine instead of a microcontroller, and no firmware programming is required. Fully compliant USB transceivers are integrated into the circuit for the upstream USB transceiver port **302** and all downstream USB transceiver ports **304**, **306**, **308**. The downstream USB transceiver ports **304**, **306**, **308** support both full-speed and low-speed devices by automatically setting the slew rate according to the speed of the device attached to the ports. The USB network hub **300** device may be configured either in bus-powered or self-powered mode and includes a hub power logic **312** to manage power.

The USB network hub **300** device includes a serial interface engine **310** (SIE). The SIE **310** is the front end of the USB network hub **300** hardware and handles most of the protocol described in chapter 8 of the USB specification. The SIE **310** typically comprehends signaling up to the transaction level. The functions that it handles could include: packet recognition, transaction sequencing, SOP, EOP, RESET, and RESUME signal detection/generation, clock/data separation, non-return-to-zero invert (NRZI) data encoding/decoding and bit-stuffing, CRC generation and checking (token and data), packet ID (PID) generation and checking/decoding, and/or serial-parallel/parallel-serial conversion. The **310** receives a clock input **314** and is coupled to a suspend/resume logic and frame timer **316** circuit and a hub repeater circuit **318** to control communication between the upstream USB transceiver port **302** and the downstream USB transceiver ports **304**, **306**, **308** through port logic circuits **320**, **322**, **324**. The SIE **310** is coupled to a command decoder **326** via interface logic to control commands from a serial EEPROM via a serial EEPROM interface **330**.

In various aspects, the USB network hub **300** can connect **127** functions configured in up to six logical layers (tiers) to a single computer. Further, the USB network hub **300** can connect to all peripherals using a standardized four-wire cable that provides both communication and power distribution. The power configurations are bus-powered and self-powered modes. The USB network hub **300** may be configured to support four modes of power management: a bus-powered hub, with either individual-port power management or ganged-port power management, and the self-powered hub, with either individual-port power management or ganged-port power management. In one aspect, using a USB cable, the USB network hub **300**, the upstream USB transceiver port **302** is plugged into a USB host controller, and the downstream USB transceiver ports **304**, **306**, **308** are exposed for connecting USB compatible devices, and so forth.

Surgical Instrument Hardware

FIG. **12** illustrates a logic diagram of a control system **470** of a surgical instrument or tool in accordance with one or more aspects of the present disclosure. The system **470** comprises a control circuit. The control circuit includes a microcontroller **461** comprising a processor **462** and a memory **468**. One or more of sensors **472**, **474**, **476**, for example, provide real-time feedback to the processor **462**. A motor **482**, driven by a motor driver **492**, operably couples a longitudinally movable displacement member to drive the I-beam knife element. A tracking system **480** is configured to determine the position of the longitudinally movable displacement member. The position information is provided to the processor **462**, which can be programmed or configured to determine the position of the longitudinally movable drive member as well as the position of a firing member, firing bar, and I-beam knife element. Additional motors may be provided at the tool driver interface to control I-beam firing, closure tube travel, shaft rotation, and articulation. A display **473** displays a variety of operating conditions of the instruments and may include touch screen functionality for data input. Information displayed on the display **473** may be overlaid with images acquired via endoscopic imaging modules.

In one aspect, the microcontroller **461** may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the main microcontroller **461** may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, and internal ROM loaded with StellarisWare® software, a 2 KB EEPROM, one or more PWM modules, one or more QEI analogs, and/or one or more 12-bit ADCs with 12 analog input channels, details of which are available for the product datasheet.

In one aspect, the microcontroller **461** may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

The microcontroller **461** may be programmed to perform various functions such as precise control over the speed and position of the knife and articulation systems. In one aspect, the microcontroller **461** includes a processor **462** and a memory **468**. The electric motor **482** may be a brushed direct current (DC) motor with a gearbox and mechanical links to an articulation or knife system. In one aspect, a motor driver **492** may be an A3941 available from Allegro Microsystems, Inc. Other motor drivers may be readily substituted for use in the tracking system **480** comprising an absolute positioning system. A detailed description of an absolute positioning system is described in U.S. Patent Application Publication No. 2017/0296213, titled SYSTEMS AND METHODS FOR CONTROLLING A SURGICAL STAPLING AND CUTTING INSTRUMENT, which published on Oct. 19, 2017, which is herein incorporated by reference in its entirety.

The microcontroller **461** may be programmed to provide precise control over the speed and position of displacement members and articulation systems. The microcontroller **461** may be configured to compute a response in the software of the microcontroller **461**. The computed response is compared to a measured response of the actual system to obtain an "observed" response, which is used for actual feedback decisions. The observed response is a favorable, tuned value that balances the smooth, continuous nature of the simulated response with the measured response, which can detect outside influences on the system.

In one aspect, the motor **482** may be controlled by the motor driver **492** and can be employed by the firing system of the surgical instrument or tool. In various forms, the motor **482** may be a brushed DC driving motor having a maximum rotational speed of approximately 25,000 RPM. In other arrangements, the motor **482** may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The motor driver **492** may comprise an H-bridge driver comprising field-effect transistors (FETs), for example. The motor **482** can be powered by a power assembly releasably mounted to the handle assembly or tool housing for supplying control power to the surgical instrument or tool. The power assembly may comprise a battery which may include a number of battery cells connected in series that can be used as the power source to power the surgical instrument or tool. In certain circumstances, the battery cells of the power assembly may be replaceable and/or rechargeable. In at least one example, the battery cells can be lithium-ion batteries which can be couplable to and separable from the power assembly.

The motor driver **492** may be an A3941 available from Allegro Microsystems, Inc. The A3941 **492** is a full-bridge controller for use with external N-channel power metal-oxide semiconductor field-effect transistors (MOSFETs) specifically designed for inductive loads, such as brush DC motors. The driver **492** comprises a unique charge pump regulator that provides full (>10 V) gate drive for battery voltages down to 7 V and allows the A3941 to operate with a reduced gate drive, down to 5.5 V. A bootstrap capacitor may be employed to provide the above battery supply voltage required for N-channel MOSFETs. An internal charge pump for the high-side drive allows DC (100% duty cycle) operation. The full bridge can be driven in fast or slow decay modes using diode or synchronous rectification. In the slow decay mode, current recirculation can be through the high-side or the lowside FETs. The power FETs are protected from shoot-through by resistor-adjustable dead time. Integrated diagnostics provide indications of undervoltage, overtemperature, and power bridge faults and can be configured to protect the power MOSFETs under most short circuit conditions. Other motor drivers may be readily substituted for use in the tracking system **480** comprising an absolute positioning system.

The tracking system **480** comprises a controlled motor drive circuit arrangement comprising a position sensor **472** according to one aspect of this disclosure. The position sensor **472** for an absolute positioning system provides a unique position signal corresponding to the location of a displacement member. In one aspect, the displacement member represents a longitudinally movable drive member comprising a rack of drive teeth for meshing engagement with a corresponding drive gear of a gear reducer assembly. In other aspects, the displacement member represents the firing member, which could be adapted and configured to include a rack of drive teeth. In yet another aspect, the displacement member represents a firing bar or the I-beam, each of which can be adapted and configured to include a rack of drive teeth. Accordingly, as used herein, the term displacement member is used generically to refer to any movable member of the surgical instrument or tool such as the drive member, the firing member, the firing bar, the I-beam, or any element that can be displaced. In one aspect, the longitudinally movable drive member is coupled to the firing member, the firing bar, and the I-beam. Accordingly, the absolute positioning system can, in effect, track the linear displacement of the I-beam by tracking the linear displacement of the longitudinally movable drive member. In various other aspects, the displacement member may be coupled to any position sensor **472** suitable for measuring linear displacement. Thus, the longitudinally movable drive member, the firing member, the firing bar, or the I-beam, or combinations thereof, may be coupled to any suitable linear displacement sensor. Linear displacement sensors may include contact or non-contact displacement sensors. Linear displacement sensors may comprise linear variable differential transformers (LVDT), differential variable reluctance transducers (DVRT), a slide potentiometer, a magnetic sensing system comprising a movable magnet and a series of linearly arranged Hall effect sensors, a magnetic sensing system comprising a fixed magnet and a series of movable, linearly arranged Hall effect sensors, an optical sensing system comprising a movable light source and a series of linearly arranged photo diodes or photo detectors, an optical sensing system comprising a fixed light source and a series of movable linearly, arranged photo diodes or photo detectors, or any combination thereof.

The electric motor **482** can include a rotatable shaft that operably interfaces with a gear assembly that is mounted in meshing engagement with a set, or rack, of drive teeth on the displacement member. A sensor element may be operably coupled to a gear assembly such that a single revolution of the position sensor **472** element corresponds to some linear longitudinal translation of the displacement member. An arrangement of gearing and sensors can be connected to the linear actuator, via a rack and pinion arrangement, or a rotary actuator, via a spur gear or other connection. A power source supplies power to the absolute positioning system and an output indicator may display the output of the absolute positioning system. The displacement member represents the longitudinally movable drive member comprising a rack of drive teeth formed thereon for meshing engagement with a corresponding drive gear of the gear reducer assembly. The displacement member represents the longitudinally movable firing member, firing bar, I-beam, or combinations thereof.

A single revolution of the sensor element associated with the position sensor **472** is equivalent to a longitudinal linear displacement d**1** of the of the displacement member, where d**1** is the longitudinal linear distance that the displacement member moves from point “a” to point “b” after a single revolution of the sensor element coupled to the displacement member. The sensor arrangement may be connected via a gear reduction that results in the position sensor **472** completing one or more revolutions for the full stroke of the displacement member. The position sensor **472** may complete multiple revolutions for the full stroke of the displacement member.

A series of switches, where n is an integer greater than one, may be employed alone or in combination with a gear reduction to provide a unique position signal for more than one revolution of the position sensor **472**. The state of the switches are fed back to the microcontroller **461** that applies logic to determine a unique position signal corresponding to the longitudinal linear displacement d**1**+d**2**+ . . . dn of the displacement member. The output of the position sensor **472** is provided to the microcontroller **461**. The position sensor **472** of the sensor arrangement may comprise a magnetic sensor, an analog rotary sensor like a potentiometer, or an array of analog Hall-effect elements, which output a unique combination of position signals or values.

The position sensor **472** may comprise any number of magnetic sensing elements, such as, for example, magnetic sensors classified according to whether they measure the total magnetic field or the vector components of the magnetic field. The techniques used to produce both types of magnetic sensors encompass many aspects of physics and electronics. The technologies used for magnetic field sensing include search coil, fluxgate, optically pumped, nuclear precession, SQUID, Hall-effect, anisotropic magnetoresistance, giant magnetoresistance, magnetic tunnel junctions, giant magnetoimpedance, magnetostrictive/piezoelectric composites, magnetodiode, magnetotransistor, fiber-optic, magneto-optic, and microelectromechanical systems-based magnetic sensors, among others.

In one aspect, the position sensor **472** for the tracking system **480** comprising an absolute positioning system comprises a magnetic rotary absolute positioning system. The position sensor **472** may be implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **472** is interfaced with the microcontroller **461** to provide an absolute positioning system. The position sensor **472** is a low-voltage and low-power component and includes four Hall-effect elements in an area of the position sensor **472** that is located above a magnet. A high-resolution ADC and a smart power management controller are also provided on the chip. A coordinate rotation digital computer (CORDIC) processor, also known as the digit-by-digit method and Volder’s algorithm, is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations. The angle position, alarm bits, and magnetic field information are transmitted over a standard serial communication interface, such as a serial peripheral interface (SPI) interface, to the microcontroller **461**. The position sensor **472** provides 12 or 14 bits of resolution. The position sensor **472** may be an AS5055 chip provided in a small QFN 16-pin 4×4×0.85 mm package.

The tracking system **480** comprising an absolute positioning system may comprise and/or be programmed to implement a feedback controller, such as a PID, state feedback, and adaptive controller. A power source converts the signal from the feedback controller into a physical input to the system: in this case the voltage. Other examples include a PWM of the voltage, current, and force. Other sensor(s) may be provided to measure physical parameters of the physical system in addition to the position measured by the position sensor **472**. In some aspects, the other sensor(s) can include sensor arrangements such as those described in U.S. Pat. No. 9,345,481, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, which issued on May 24, 2016, which is herein incorporated by reference in its entirety; U.S. Patent Application Publication No. 2014/0263552, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, which published on Sep. 18, 2014, which is herein incorporated by reference in its entirety; and U.S. patent application Ser. No. 15/628,175, titled TECHNIQUES FOR ADAPTIVE CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, filed Jun. 20, 2017, which is herein incorporated by reference in its entirety. In a digital signal processing system, an absolute positioning system is coupled to a digital data acquisition system where the output of the absolute positioning system will have a finite resolution and sampling frequency. The absolute positioning system may comprise a compare-and-combine circuit to combine a computed response with a measured response using algorithms, such as a weighted average and a theoretical control loop, that drive the computed response towards the measured response. The computed response of the physical system takes into account properties like mass, inertial, viscous friction, inductance resistance, etc., to predict what the states and outputs of the physical system will be by knowing the input.

The absolute positioning system provides an absolute position of the displacement member upon power-up of the instrument, without retracting or advancing the displacement member to a reset (zero or home) position as may be required with conventional rotary encoders that merely count the number of steps forwards or backwards that the motor **482** has taken to infer the position of a device actuator, drive bar, knife, or the like.

A sensor **474**, such as, for example, a strain gauge or a micro-strain gauge, is configured to measure one or more parameters of the end effector, such as, for example, the amplitude of the strain exerted on the anvil during a clamping operation, which can be indicative of the closure forces applied to the anvil. The measured strain is converted to a digital signal and provided to the processor **462**. Alternatively, or in addition to the sensor **474**, a sensor **476**, such as, for example, a load sensor, can measure the closure force applied by the closure drive system to the anvil. The sensor **476**, such as, for example, a load sensor, can measure the firing force applied to an I-beam in a firing stroke of the surgical instrument or tool. The I-beam is configured to engage a wedge sled, which is configured to upwardly cam staple drivers to force out staples into deforming contact with an anvil. The I-beam also includes a sharpened cutting edge that can be used to sever tissue as the I-beam is advanced distally by the firing bar. Alternatively, a current sensor **478** can be employed to measure the current drawn by the motor **482**. The force required to advance the firing member can correspond to the current drawn by the motor **482**, for example. The measured force is converted to a digital signal and provided to the processor **462**.

In one form, the strain gauge sensor **474** can be used to measure the force applied to the tissue by the end effector. A strain gauge can be coupled to the end effector to measure the force on the tissue being treated by the end effector. A system for measuring forces applied to the tissue grasped by the end effector comprises a strain gauge sensor **474**, such as, for example, a micro-strain gauge, that is configured to measure one or more parameters of the end effector, for example. In one aspect, the strain gauge sensor **474** can measure the amplitude or magnitude of the strain exerted on a jaw member of an end effector during a clamping operation, which can be indicative of the tissue compression. The measured strain is converted to a digital signal and provided to a processor **462** of the microcontroller **461**. A load sensor **476** can measure the force used to operate the knife element, for example, to cut the tissue captured between the anvil and the staple cartridge. A magnetic field sensor can be employed to measure the thickness of the captured tissue. The measurement of the magnetic field sensor also may be converted to a digital signal and provided to the processor **462**.

The measurements of the tissue compression, the tissue thickness, and/or the force required to close the end effector on the tissue, as respectively measured by the sensors **474**, **476**, can be used by the microcontroller **461** to characterize the selected position of the firing member and/or the corresponding value of the speed of the firing member. In one instance, a memory **468** may store a technique, an equation, and/or a lookup table which can be employed by the microcontroller **461** in the assessment.

The control system **470** of the surgical instrument or tool also may comprise wired or wireless communication circuits to communicate with the modular communication hub as shown in FIGS. **8-11**.

FIG. **13** illustrates a control circuit **500** configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The control circuit **500** can be configured to implement various processes described herein. The control circuit **500** may comprise a microcontroller comprising one or more processors **502** (e.g., microprocessor, microcontroller) coupled to at least one memory circuit **504**. The memory circuit **504** stores machine-executable instructions that, when executed by the processor **502**, cause the processor **502** to execute machine instructions to implement various processes described herein. The processor **502** may be any one of a number of single-core or multicore processors known in the art. The memory circuit **504** may comprise volatile and non-volatile storage media. The processor **502** may include an instruction processing unit **506** and an arithmetic unit **508**. The instruction processing unit may be configured to receive instructions from the memory circuit **504** of this disclosure.

FIG. **14** illustrates a combinational logic circuit **510** configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The combinational logic circuit **510** can be configured to implement various processes described herein. The combinational logic circuit **510** may comprise a finite state machine comprising a combinational logic **512** configured to receive data associated with the surgical instrument or tool at an input **514**, process the data by the combinational logic **512**, and provide an output **516**.

FIG. **15** illustrates a sequential logic circuit **520** configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The sequential logic circuit **520** or the combinational logic **522** can be configured to implement various processes described herein. The sequential logic circuit **520** may comprise a finite state machine. The sequential logic circuit **520** may comprise a combinational logic **522**, at least one memory circuit **524**, and a clock **529**, for example. The at least one memory circuit **524** can store a current state of the finite state machine. In certain instances, the sequential logic circuit **520** may be synchronous or asynchronous. The combinational logic **522** is configured to receive data associated with the surgical instrument or tool from an input **526**, process the data by the combinational logic **522**, and provide an output **528**. In other aspects, the circuit may comprise a combination of a processor (e.g., processor **502**, FIG. **13**) and a finite state machine to implement various processes herein. In other aspects, the finite state machine may comprise a combination of a combinational logic circuit (e.g., combinational logic circuit **510**, FIG. **14**) and the sequential logic circuit **520**.

FIG. **16** illustrates a surgical instrument or tool comprising a plurality of motors which can be activated to perform various functions. In certain instances, a first motor can be activated to perform a first function, a second motor can be activated to perform a second function, a third motor can be activated to perform a third function, a fourth motor can be activated to perform a fourth function, and so on. In certain instances, the plurality of motors of robotic surgical instrument **600** can be individually activated to cause firing, closure, and/or articulation motions in the end effector. The firing, closure, and/or articulation motions can be transmitted to the end effector through a shaft assembly, for example.

In certain instances, the surgical instrument system or tool may include a firing motor **602**. The firing motor **602** may be operably coupled to a firing motor drive assembly **604** which can be configured to transmit firing motions, generated by the motor **602** to the end effector, in particular to displace the I-beam element. In certain instances, the firing motions generated by the motor **602** may cause the staples to be deployed from the staple cartridge into tissue captured by the end effector and/or the cutting edge of the I-beam element to be advanced to cut the captured tissue, for example. The I-beam element may be retracted by reversing the direction of the motor **602**.

In certain instances, the surgical instrument or tool may include a closure motor **603**. The closure motor **603** may be operably coupled to a closure motor drive assembly **605** which can be configured to transmit closure motions, generated by the motor **603** to the end effector, in particular to displace a closure tube to close the anvil and compress tissue between the anvil and the staple cartridge. The closure motions may cause the end effector to transition from an open configuration to an approximated configuration to capture tissue, for example. The end effector may be transitioned to an open position by reversing the direction of the motor **603**.

In certain instances, the surgical instrument or tool may include one or more articulation motors **606***a*, **606***b*, for example. The motors **606***a*, **606***b* may be operably coupled to respective articulation motor drive assemblies **608***a*, **608***b*, which can be configured to transmit articulation motions generated by the motors **606***a*, **606***b* to the end effector. In certain instances, the articulation motions may cause the end effector to articulate relative to the shaft, for example.

As described above, the surgical instrument or tool may include a plurality of motors which may be configured to perform various independent functions. In certain instances, the plurality of motors of the surgical instrument or tool can be individually or separately activated to perform one or more functions while the other motors remain inactive. For example, the articulation motors **606***a*, **606***b* can be activated to cause the end effector to be articulated while the firing motor **602** remains inactive. Alternatively, the firing motor **602** can be activated to fire the plurality of staples, and/or to advance the cutting edge, while the articulation motor **606** remains inactive. Furthermore, the closure motor **603** may be activated simultaneously with the firing motor **602** to cause the closure tube and the I-beam element to advance distally as described in more detail hereinbelow.

In certain instances, the surgical instrument or tool may include a common control module **610** which can be employed with a plurality of motors of the surgical instrument or tool. In certain instances, the common control module **610** may accommodate one of the plurality of motors at a time. For example, the common control module **610** can be couplable to and separable from the plurality of motors of the robotic surgical instrument individually. In certain instances, a plurality of the motors of the surgical instrument or tool may share one or more common control modules such as the common control module **610**. In certain instances, a plurality of motors of the surgical instrument or tool can be individually and selectively engaged with the common control module **610**. In certain instances, the common control module **610** can be selectively switched from interfacing with one of a plurality of motors of the surgical instrument or tool to interfacing with another one of the plurality of motors of the surgical instrument or tool.

In at least one example, the common control module **610** can be selectively switched between operable engagement with the articulation motors **606***a*, **606***b* and operable engagement with either the firing motor **602** or the closure motor **603**. In at least one example, as illustrated in FIG. **16**, a switch **614** can be moved or transitioned between a plurality of positions and/or states. In a first position **616**, the switch **614** may electrically couple the common control module **610** to the firing motor **602**; in a second position **617**, the switch **614** may electrically couple the common control module **610** to the closure motor **603**; in a third position **618***a*, the switch **614** may electrically couple the common control module **610** to the first articulation motor **606***a*; and in a fourth position **618***b*, the switch **614** may electrically couple the common control module **610** to the second articulation motor **606***b*, for example. In certain instances, separate common control modules **610** can be electrically coupled to the firing motor **602**, the closure motor **603**, and the articulations motor **606***a*, **606***b* at the same time. In certain instances, the switch **614** may be a mechanical switch, an electromechanical switch, a solid-state switch, or any suitable switching mechanism.

Each of the motors **602**, **603**, **606***a*, **606***b* may comprise a torque sensor to measure the output torque on the shaft of the motor. The force on an end effector may be sensed in any conventional manner, such as by force sensors on the outer sides of the jaws or by a torque sensor for the motor actuating the jaws.

In various instances, as illustrated in FIG. **16**, the common control module **610** may comprise a motor driver **626** which may comprise one or more H-Bridge FETs. The motor driver **626** may modulate the power transmitted from a power source **628** to a motor coupled to the common control module **610** based on input from a microcontroller **620** (the "controller"), for example. In certain instances, the microcontroller **620** can be employed to determine the current drawn by the motor, for example, while the motor is coupled to the common control module **610**, as described above.

In certain instances, the microcontroller **620** may include a microprocessor **622** (the "processor") and one or more non-transitory computer-readable mediums or memory units **624** (the "memory"). In certain instances, the memory **624** may store various program instructions, which when executed may cause the processor **622** to perform a plurality of functions and/or calculations described herein. In certain instances, one or more of the memory units **624** may be coupled to the processor **622**, for example.

In certain instances, the power source **628** can be employed to supply power to the microcontroller **620**, for example. In certain instances, the power source **628** may comprise a battery (or "battery pack" or "power pack"), such as a lithium-ion battery, for example. In certain instances, the battery pack may be configured to be releasably mounted to a handle for supplying power to the surgical instrument **600**. A number of battery cells connected in series may be used as the power source **628**. In certain instances, the power source **628** may be replaceable and/or rechargeable, for example.

In various instances, the processor **622** may control the motor driver **626** to control the position, direction of rotation, and/or velocity of a motor that is coupled to the common control module **610**. In certain instances, the processor **622** can signal the motor driver **626** to stop and/or disable a motor that is coupled to the common control module **610**. It should be understood that the term "processor" as used herein includes any suitable microprocessor, microcontroller, or other basic computing device that incorporates the functions of a computer's central processing unit (CPU) on an integrated circuit or, at most, a few integrated circuits. The processor is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. Processors operate on numbers and symbols represented in the binary numeral system.

In one instance, the processor **622** may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In certain instances, the microcontroller **620** may be an LM 4F230H5QR, available from Texas Instruments, for example. In at least one example, the Texas Instruments LM4F230H5QR is an ARM Cortex-M4F Processor Core comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, an internal ROM loaded with StellarisWare® software, a 2 KB EEPROM, one or more PWM modules, one or more QEI analogs, one or more 12-bit ADCs with 12 analog input channels, among other features that are readily available for the product datasheet. Other microcontrollers may be readily substituted for use with the module **4410**. Accordingly, the present disclosure should not be limited in this context.

In certain instances, the memory **624** may include program instructions for controlling each of the motors of the surgical instrument **600** that are couplable to the common control module **610**. For example, the memory **624** may include program instructions for controlling the firing motor **602**, the closure motor **603**, and the articulation motors **606***a*, **606***b*. Such program instructions may cause the processor **622** to control the firing, closure, and articulation functions in accordance with inputs from algorithms or control programs of the surgical instrument or tool.

In certain instances, one or more mechanisms and/or sensors such as, for example, sensors **630** can be employed to alert the processor **622** to the program instructions that should be used in a particular setting. For example, the sensors **630** may alert the processor **622** to use the program instructions associated with firing, closing, and articulating the end effector. In certain instances, the sensors **630** may comprise position sensors which can be employed to sense the position of the switch **614**, for example. Accordingly, the processor **622** may use the program instructions associated with firing the I-beam of the end effector upon detecting, through the sensors **630** for example, that the switch **614** is in the first position **616**; the processor **622** may use the program instructions associated with closing the anvil upon detecting, through the sensors **630** for example, that the switch **614** is in the second position **617**; and the processor **622** may use the program instructions associated with articulating the end effector upon detecting, through the sensors **630** for example, that the switch **614** is in the third or fourth position **618***a*, **618***b*.

FIG. **17** is a schematic diagram of a robotic surgical instrument **700** configured to operate a surgical tool described herein according to one aspect of this disclosure. The robotic surgical instrument **700** may be programmed or configured to control distal/proximal translation of a displacement member, distal/proximal displacement of a closure tube, shaft rotation, and articulation, either with single or multiple articulation drive links. In one aspect, the surgical instrument **700** may be programmed or configured to individually control a firing member, a closure member, a shaft member, and/or one or more articulation members. The surgical instrument **700** comprises a control circuit **710** configured to control motor-driven firing members, closure members, shaft members, and/or one or more articulation members.

In one aspect, the robotic surgical instrument **700** comprises a control circuit **710** configured to control an anvil **716** and an I-beam **714** (including a sharp cutting edge) portion of an end effector **702**, a removable staple cartridge **718**, a shaft **740**, and one or more articulation members **742***a*, **742***b* via a plurality of motors **704***a*-**704***e*. A position sensor **734** may be configured to provide position feedback of the I-beam **714** to the control circuit **710**. Other sensors **738** may be configured to provide feedback to the control circuit **710**. A timer/counter **731** provides timing and counting information to the control circuit **710**. An energy source **712** may be provided to operate the motors **704***a*-**704***e*, and a current sensor **736** provides motor current feedback to the control circuit **710**. The motors **704***a*-**704***e* can be operated individually by the control circuit **710** in an open-loop or closed-loop feedback control.

In one aspect, the control circuit **710** may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to perform one or more tasks. In one aspect, a timer/counter **731** provides an output signal, such as the elapsed time or a digital count, to the control circuit **710** to correlate the position of the I-beam **714** as determined by the position sensor **734** with the output of the timer/counter **731** such that the control circuit **710** can determine the position of the I-beam **714** at a specific time (t) relative to a starting position or the time (t) when the I-beam **714** is at a specific position relative to a starting position. The timer/counter **731** may be configured to measure elapsed time, count external events, or time external events.

In one aspect, the control circuit **710** may be programmed to control functions of the end effector **702** based on one or more tissue conditions. The control circuit **710** may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit **710** may be programmed to select a firing control program or closure control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit **710** may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit **710** may be programmed to translate the displacement member at a higher velocity and/or with higher power. A closure control program may control the closure force applied to the tissue by the anvil **716**. Other control programs control the rotation of the shaft **740** and the articulation members **742***a*, **742***b*.

In one aspect, the control circuit **710** may generate motor set point signals. The motor set point signals may be provided to various motor controllers **708***a*-**708***e*. The motor controllers **708***a*-**708***e* may comprise one or more circuits configured to provide motor drive signals to the motors **704***a*-**704***e* to drive the motors **704***a*-**704***e* as described herein. In some examples, the motors **704***a*-**704***e* may be brushed DC electric motors. For example, the velocity of the motors **704***a*-**704***e* may be proportional to the respective motor drive signals. In some examples, the motors **704***a*-**704***e* may be brushless DC electric motors, and the respective motor drive signals may comprise a PWM signal provided to one or more stator windings of the motors **704***a*-**704***e*. Also, in some examples, the motor controllers **708***a*-**708***e* may be omitted and the control circuit **710** may generate the motor drive signals directly.

In one aspect, the control circuit **710** may initially operate each of the motors **704***a*-**704***e* in an open-loop configuration for a first open-loop portion of a stroke of the displacement member. Based on the response of the robotic surgical instrument **700** during the open-loop portion of the stroke, the control circuit **710** may select a firing control program in a closed-loop configuration. The response of the instrument may include a translation distance of the displacement member during the open-loop portion, a time elapsed during the open-loop portion, the energy provided to one of the motors **704***a*-**704***e* during the open-loop portion, a sum of pulse widths of a motor drive signal, etc. After the open-loop portion, the control circuit **710** may implement the selected firing control program for a second portion of the displacement member stroke. For example, during a closed-loop portion of the stroke, the control circuit **710** may modulate one of the motors **704***a*-**704***e* based on translation data describing a position of the displacement member in a closed-loop manner to translate the displacement member at a constant velocity.

In one aspect, the motors **704***a*-**704***e* may receive power from an energy source **712**. The energy source **712** may be a DC power supply driven by a main alternating current power source, a battery, a super capacitor, or any other suitable energy source. The motors **704***a*-**704***e* may be mechanically coupled to individual movable mechanical elements such as the I-beam **714**, anvil **716**, shaft **740**, articulation **742***a*, and articulation **742***b* via respective transmissions **706***a*-**706***e*. The transmissions **706***a*-**706***e* may include one or more gears or other linkage components to couple the motors **704***a*-**704***e* to movable mechanical elements. A position sensor **734** may sense a position of the I-beam **714**. The position sensor **734** may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam **714**. In some examples, the position sensor **734** may include an encoder configured to provide a series of pulses to the control circuit **710** as the I-beam **714** translates distally and proximally. The control circuit **710** may track the pulses to determine the position of the I-beam **714**. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam **714**. Also, in some examples, the position sensor **734** may be omitted. Where any of the motors **704***a*-**704***e* is a stepper motor, the control circuit **710** may track the position of the I-beam **714** by aggregating the number and direction of steps that the motor **704** has been instructed to execute. The position sensor **734** may be located in the end effector **702** or at any other portion of the instrument. The outputs of each of the motors **704***a*-**704***e* include a torque sensor **744***a*-**744***e* to sense force and have an encoder to sense rotation of the drive shaft.

In one aspect, the control circuit **710** is configured to drive a firing member such as the I-beam **714** portion of the end effector **702**. The control circuit **710** provides a motor set point to a motor control **708***a*, which provides a drive signal to the motor **704***a*. The output shaft of the motor **704***a* is coupled to a torque sensor **744***a*. The torque sensor **744***a* is coupled to a transmission **706***a* which is coupled to the I-beam **714**. The transmission **706***a* comprises movable mechanical elements such as rotating elements and a firing member to control the movement of the I-beam **714** distally and proximally along a longitudinal axis of the end effector **702**. In one aspect, the motor **704***a* may be coupled to the knife gear assembly, which includes a knife gear reduction set that includes a first knife drive gear and a second knife drive gear. A torque sensor **744***a* provides a firing force feedback signal to the control circuit **710**. The firing force signal represents the force required to fire or displace the I-beam **714**. A position sensor **734** may be configured to provide the position of the I-beam **714** along the firing stroke or the position of the firing member as a feedback signal to the control circuit **710**. The end effector **702** may include additional sensors **738** configured to provide feedback signals to the control circuit **710**. When ready to use, the control circuit **710** may provide a firing signal to the motor control **708***a*. In response to the firing signal, the motor **704***a* may drive the firing member distally along the longitudinal axis of the end effector **702** from a proximal stroke start position to a stroke end position distal to the stroke start position. As the firing member translates distally, an I-beam **714**, with a cutting element positioned at a distal end, advances distally to cut tissue located between the staple cartridge **718** and the anvil **716**.

In one aspect, the control circuit **710** is configured to drive a closure member such as the anvil **716** portion of the end effector **702**. The control circuit **710** provides a motor set point to a motor control **708***b*, which provides a drive signal to the motor **704***b*. The output shaft of the motor **704***b* is coupled to a torque sensor **744***b*. The torque sensor **744***b* is coupled to a transmission **706***b* which is coupled to the anvil **716**. The transmission **706***b* comprises movable mechanical elements such as rotating elements and a closure member to control the movement of the anvil **716** from the open and closed positions. In one aspect, the motor **704***b* is coupled to a closure gear assembly, which includes a closure reduction gear set that is supported in meshing engagement with the closure spur gear. The torque sensor **744***b* provides a closure force feedback signal to the control circuit **710**. The closure force feedback signal represents the closure force applied to the anvil **716**. The position sensor **734** may be configured to provide the position of the closure member as a feedback signal to the control circuit **710**. Additional sensors **738** in the end effector **702** may provide the closure force feedback signal to the control circuit **710**. The pivotable anvil **716** is positioned opposite the staple cartridge **718**. When ready to use, the control circuit **710** may provide a closure signal to the motor control **708***b*. In response to the closure signal, the motor **704***b* advances a closure member to grasp tissue between the anvil **716** and the staple cartridge **718**.

In one aspect, the control circuit **710** is configured to rotate a shaft member such as the shaft **740** to rotate the end effector **702**. The control circuit **710** provides a motor set point to a motor control **708***c*, which provides a drive signal to the motor **704***c*. The output shaft of the motor **704***c* is coupled to a torque sensor **744***c*. The torque sensor **744***c* is coupled to a transmission **706***c* which is coupled to the shaft **740**. The transmission **706***c* comprises movable mechanical elements such as rotating elements to control the rotation of the shaft **740** clockwise or counterclockwise up to and over 360°. In one aspect, the motor **704***c* is coupled to the rotational transmission assembly, which includes a tube gear segment that is formed on (or attached to) the proximal end of the proximal closure tube for operable engagement by a rotational gear assembly that is operably supported on the tool mounting plate. The torque sensor **744***c* provides a rotation force feedback signal to the control circuit **710**. The rotation force feedback signal represents the rotation force applied to the shaft **740**. The position sensor **734** may be configured to provide the position of the closure member as a feedback signal to the control circuit **710**. Additional sensors **738** such as a shaft encoder may provide the rotational position of the shaft **740** to the control circuit **710**.

In one aspect, the control circuit **710** is configured to articulate the end effector **702**. The control circuit **710** provides a motor set point to a motor control **708***d*, which provides a drive signal to the motor **704***d*. The output shaft of the motor **704***d* is coupled to a torque sensor **744***d*. The torque sensor **744***d* is coupled to a transmission **706***d* which is coupled to an articulation member **742***a*. The transmission **706***d* comprises movable mechanical elements such as articulation elements to control the articulation of the end effector **702** ±65°. In one aspect, the motor **704***d* is coupled to an articulation nut, which is rotatably journaled on the proximal end portion of the distal spine portion and is rotatably driven thereon by an articulation gear assembly. The torque sensor **744***d* provides an articulation force feedback signal to the control circuit **710**. The articulation force feedback signal represents the articulation force applied to the end effector **702**. Sensors **738**, such as an articulation encoder, may provide the articulation position of the end effector **702** to the control circuit **710**.

In another aspect, the articulation function of the robotic surgical system **700** may comprise two articulation members, or links, **742***a*, **742***b*. These articulation members **742***a*, **742***b* are driven by separate disks on the robot interface (the rack) which are driven by the two motors **708***d*, **708***e*. When the separate firing motor **704***a* is provided, each of articulation links **742***a*, **742***b* can be antagonistically driven with respect to the other link in order to provide a resistive holding motion and a load to the head when it is not moving and to provide an articulation motion as the head is articulated. The articulation members **742***a*, **742***b* attach to the head at a fixed radius as the head is rotated. Accordingly, the mechanical advantage of the push-and-pull link changes as the head is rotated. This change in the mechanical advantage may be more pronounced with other articulation link drive systems.

In one aspect, the one or more motors **704***a*-**704***e* may comprise a brushed DC motor with a gearbox and mechanical links to a firing member, closure member, or articulation member. Another example includes electric motors **704***a*-**704***e* that operate the movable mechanical elements such as the displacement member, articulation links, closure tube, and shaft. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies, and friction on the physical system. Such outside influence can be referred to as drag, which acts in opposition to one of electric motors **704***a*-**704***e*. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

In one aspect, the position sensor **734** may be implemented as an absolute positioning system. In one aspect, the position sensor **734** may comprise a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **734** may interface with the control circuit **710** to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor, also known as the digit-by-digit method and Volder's algorithm, that is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

In one aspect, the control circuit **710** may be in communication with one or more sensors **738**. The sensors **738** may be positioned on the end effector **702** and adapted to operate with the robotic surgical instrument **700** to measure the various derived parameters such as the gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors **738** may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a load cell, a pressure sensor, a force sensor, a torque sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **702**. The sensors **738** may include one or more sensors. The sensors **738** may be located on the staple cartridge **718** deck to determine tissue location using segmented electrodes. The torque sensors **744***a*-**744***e* may be configured to sense force such as firing force, closure force, and/or articulation force, among others. Accordingly, the control circuit **710** can sense (1) the closure load experienced by the distal closure tube and its position, (2) the firing member at the rack and its position, (3) what portion of the staple cartridge **718** has tissue on it, and (4) the load and position on both articulation rods.

In one aspect, the one or more sensors **738** may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil **716** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors **738** may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil **716** and the staple cartridge **718**. The sensors **738** may be configured to detect impedance of a tissue section located between the anvil **716** and the staple cartridge **718** that is indicative of the thickness and/or fullness of tissue located therebetween.

In one aspect, the sensors **738** may be implemented as one or more limit switches, electromechanical devices, solid-state switches, Hall-effect devices, magneto-resistive (MR) devices, giant magneto-resistive (GMR) devices, magnetometers, among others. In other implementations, the sensors **738** may be implemented as solid-state switches that operate under the influence of light, such as optical sensors, IR sensors, ultraviolet sensors, among others. Still, the switches may be solid-state devices such as transistors (e.g., FET, junction FET, MOSFET, bipolar, and the like). In other implementations, the sensors **738** may include electrical conductorless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

In one aspect, the sensors **738** may be configured to measure forces exerted on the anvil **716** by the closure drive system. For example, one or more sensors **738** can be at an interaction point between the closure tube and the anvil **716** to detect the closure forces applied by the closure tube to the anvil **716**. The forces exerted on the anvil **716** can be representative of the tissue compression experienced by the tissue section captured between the anvil **716** and the staple cartridge **718**. The one or more sensors **738** can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil **716** by the closure drive system. The one or more sensors **738** may be sampled in real time during a clamping operation by the processor of the control circuit **710**. The control circuit **710** receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil **716**.

In one aspect, a current sensor **736** can be employed to measure the current drawn by each of the motors **704***a*-**704***e*. The force required to advance any of the movable mechanical elements such as the I-beam **714** corresponds to the current drawn by one of the motors **704***a*-**704***e*. The force is converted to a digital signal and provided to the control circuit **710**. The control circuit **710** can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move an I-beam **714** in the end effector **702** at or near a target velocity. The robotic surgical instrument **700** can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, a linear-quadratic (LQR), and/or an adaptive controller, for example. The robotic surgical instrument **700** can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example. Additional details are disclosed in U.S. patent application Ser. No. 15/636,829, titled CLOSED LOOP VELOCITY CONTROL TECH-

NIQUES FOR ROBOTIC SURGICAL INSTRUMENT, filed Jun. 29, 2017, which is herein incorporated by reference in its entirety.

FIG. **18** illustrates a block diagram of a surgical instrument **750** programmed to control the distal translation of a displacement member according to one aspect of this disclosure. In one aspect, the surgical instrument **750** is programmed to control the distal translation of a displacement member such as the I-beam **764**. The surgical instrument **750** comprises an end effector **752** that may comprise an anvil **766**, an I-beam **764** (including a sharp cutting edge), and a removable staple cartridge **768**.

The position, movement, displacement, and/or translation of a linear displacement member, such as the I-beam **764**, can be measured by an absolute positioning system, sensor arrangement, and position sensor **784**. Because the I-beam **764** is coupled to a longitudinally movable drive member, the position of the I-beam **764** can be determined by measuring the position of the longitudinally movable drive member employing the position sensor **784**. Accordingly, in the following description, the position, displacement, and/or translation of the I-beam **764** can be achieved by the position sensor **784** as described herein. A control circuit **760** may be programmed to control the translation of the displacement member, such as the I-beam **764**. The control circuit **760**, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the I-beam **764**, in the manner described. In one aspect, a timer/counter **781** provides an output signal, such as the elapsed time or a digital count, to the control circuit **760** to correlate the position of the I-beam **764** as determined by the position sensor **784** with the output of the timer/counter **781** such that the control circuit **760** can determine the position of the I-beam **764** at a specific time (t) relative to a starting position. The timer/counter **781** may be configured to measure elapsed time, count external events, or time external events.

The control circuit **760** may generate a motor set point signal **772**. The motor set point signal **772** may be provided to a motor controller **758**. The motor controller **758** may comprise one or more circuits configured to provide a motor drive signal **774** to the motor **754** to drive the motor **754** as described herein. In some examples, the motor **754** may be a brushed DC electric motor. For example, the velocity of the motor **754** may be proportional to the motor drive signal **774**. In some examples, the motor **754** may be a brushless DC electric motor and the motor drive signal **774** may comprise a PWM signal provided to one or more stator windings of the motor **754**. Also, in some examples, the motor controller **758** may be omitted, and the control circuit **760** may generate the motor drive signal **774** directly.

The motor **754** may receive power from an energy source **762**. The energy source **762** may be or include a battery, a super capacitor, or any other suitable energy source. The motor **754** may be mechanically coupled to the I-beam **764** via a transmission **756**. The transmission **756** may include one or more gears or other linkage components to couple the motor **754** to the I-beam **764**. A position sensor **784** may sense a position of the I-beam **764**. The position sensor **784** may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam **764**. In some examples, the position sensor **784** may include an encoder configured to provide a series of pulses to the control circuit **760** as the I-beam **764** translates distally and proximally. The control circuit **760** may track the pulses to determine the position of the I-beam **764**. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam **764**. Also, in some examples, the position sensor **784** may be omitted. Where the motor **754** is a stepper motor, the control circuit **760** may track the position of the I-beam **764** by aggregating the number and direction of steps that the motor **754** has been instructed to execute. The position sensor **784** may be located in the end effector **752** or at any other portion of the instrument.

The control circuit **760** may be in communication with one or more sensors **788**. The sensors **788** may be positioned on the end effector **752** and adapted to operate with the surgical instrument **750** to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors **788** may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **752**. The sensors **788** may include one or more sensors.

The one or more sensors **788** may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil **766** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors **788** may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil **766** and the staple cartridge **768**. The sensors **788** may be configured to detect impedance of a tissue section located between the anvil **766** and the staple cartridge **768** that is indicative of the thickness and/or fullness of tissue located therebetween.

The sensors **788** may be is configured to measure forces exerted on the anvil **766** by a closure drive system. For example, one or more sensors **788** can be at an interaction point between a closure tube and the anvil **766** to detect the closure forces applied by a closure tube to the anvil **766**. The forces exerted on the anvil **766** can be representative of the tissue compression experienced by the tissue section captured between the anvil **766** and the staple cartridge **768**. The one or more sensors **788** can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil **766** by the closure drive system. The one or more sensors **788** may be sampled in real time during a clamping operation by a processor of the control circuit **760**. The control circuit **760** receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil **766**.

A current sensor **786** can be employed to measure the current drawn by the motor **754**. The force required to advance the I-beam **764** corresponds to the current drawn by the motor **754**. The force is converted to a digital signal and provided to the control circuit **760**.

The control circuit **760** can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move an I-beam **764** in the end effector **752** at or near a target velocity. The surgical instrument **750** can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, LQR, and/or an adaptive controller, for example. The surgical instrument **750** can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example.

The actual drive system of the surgical instrument **750** is configured to drive the displacement member, cutting member, or I-beam **764**, by a brushed DC motor with gearbox and mechanical links to an articulation and/or knife system. Another example is the electric motor **754** that operates the displacement member and the articulation driver, for example, of an interchangeable shaft assembly. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies and friction on the physical system. Such outside influence can be referred to as drag which acts in opposition to the electric motor **754**. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

Various example aspects are directed to a surgical instrument **750** comprising an end effector **752** with motor-driven surgical stapling and cutting implements. For example, a motor **754** may drive a displacement member distally and proximally along a longitudinal axis of the end effector **752**. The end effector **752** may comprise a pivotable anvil **766** and, when configured for use, a staple cartridge **768** positioned opposite the anvil **766**. A clinician may grasp tissue between the anvil **766** and the staple cartridge **768**, as described herein. When ready to use the instrument **750**, the clinician may provide a firing signal, for example by depressing a trigger of the instrument **750**. In response to the firing signal, the motor **754** may drive the displacement member distally along the longitudinal axis of the end effector **752** from a proximal stroke begin position to a stroke end position distal of the stroke begin position. As the displacement member translates distally, an I-beam **764** with a cutting element positioned at a distal end, may cut the tissue between the staple cartridge **768** and the anvil **766**.

In various examples, the surgical instrument **750** may comprise a control circuit **760** programmed to control the distal translation of the displacement member, such as the I-beam **764**, for example, based on one or more tissue conditions. The control circuit **760** may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit **760** may be programmed to select a firing control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit **760** may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit **760** may be programmed to translate the displacement member at a higher velocity and/or with higher power.

In some examples, the control circuit **760** may initially operate the motor **754** in an open loop configuration for a first open loop portion of a stroke of the displacement member. Based on a response of the instrument **750** during the open loop portion of the stroke, the control circuit **760** may select a firing control program. The response of the instrument may include, a translation distance of the displacement member during the open loop portion, a time elapsed during the open loop portion, energy provided to the motor **754** during the open loop portion, a sum of pulse widths of a motor drive signal, etc. After the open loop portion, the control circuit **760** may implement the selected firing control program for a second portion of the displacement member stroke. For example, during the closed loop portion of the stroke, the control circuit **760** may modulate the motor **754** based on translation data describing a position of the displacement member in a closed loop manner to translate the displacement member at a constant velocity. Additional details are disclosed in U.S. patent application Ser. No. 15/720,852, titled SYSTEM AND METHODS FOR CONTROLLING A DISPLAY OF A SURGICAL INSTRUMENT, filed Sep. 29, 2017, which is herein incorporated by reference in its entirety.

FIG. **19** is a schematic diagram of a surgical instrument **790** configured to control various functions according to one aspect of this disclosure. In one aspect, the surgical instrument **790** is programmed to control distal translation of a displacement member such as the I-beam **764**. The surgical instrument **790** comprises an end effector **792** that may comprise an anvil **766**, an I-beam **764**, and a removable staple cartridge **768** which may be interchanged with an RF cartridge **796** (shown in dashed line).

In one aspect, sensors **788** may be implemented as a limit switch, electromechanical device, solid-state switches, Hall-effect devices, MR devices, GMR devices, magnetometers, among others. In other implementations, the sensors **638** may be solid-state switches that operate under the influence of light, such as optical sensors, IR sensors, ultraviolet sensors, among others. Still, the switches may be solid-state devices such as transistors (e.g., FET, junction FET, MOSFET, bipolar, and the like). In other implementations, the sensors **788** may include electrical conductorless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

In one aspect, the position sensor **784** may be implemented as an absolute positioning system comprising a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **784** may interface with the control circuit **760** to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor, also known as the digit-by-digit method and Volder's algorithm, that is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

In one aspect, the I-beam **764** may be implemented as a knife member comprising a knife body that operably supports a tissue cutting blade thereon and may further include anvil engagement tabs or features and channel engagement features or a foot. In one aspect, the staple cartridge **768** may be implemented as a standard (mechanical) surgical fastener cartridge. In one aspect, the RF cartridge **796** may be implemented as an RF cartridge. These and other sensors arrangements are described in commonly owned U.S. patent application Ser. No. 15/628,175, titled TECHNIQUES FOR ADAPTIVE CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, filed Jun. 20, 2017, which is herein incorporated by reference in its entirety.

The position, movement, displacement, and/or translation of a linear displacement member, such as the I-beam **764**, can be measured by an absolute positioning system, sensor arrangement, and position sensor represented as position sensor **784**. Because the I-beam **764** is coupled to the longitudinally movable drive member, the position of the I-beam **764** can be determined by measuring the position of the longitudinally movable drive member employing the position sensor **784**. Accordingly, in the following description, the position, displacement, and/or translation of the I-beam **764** can be achieved by the position sensor **784** as described herein. A control circuit **760** may be programmed to control the translation of the displacement member, such as the I-beam **764**, as described herein. The control circuit **760**, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the I-beam **764**, in the manner described. In one aspect, a timer/counter **781** provides an output signal, such as the elapsed time or a digital count, to the control circuit **760** to correlate the position of the I-beam **764** as determined by the position sensor **784** with the output of the timer/counter **781** such that the control circuit **760** can determine the position of the I-beam **764** at a specific time (t) relative to a starting position. The timer/counter **781** may be configured to measure elapsed time, count external events, or time external events.

The control circuit **760** may generate a motor set point signal **772**. The motor set point signal **772** may be provided to a motor controller **758**. The motor controller **758** may comprise one or more circuits configured to provide a motor drive signal **774** to the motor **754** to drive the motor **754** as described herein. In some examples, the motor **754** may be a brushed DC electric motor. For example, the velocity of the motor **754** may be proportional to the motor drive signal **774**. In some examples, the motor **754** may be a brushless DC electric motor and the motor drive signal **774** may comprise a PWM signal provided to one or more stator windings of the motor **754**. Also, in some examples, the motor controller **758** may be omitted, and the control circuit **760** may generate the motor drive signal **774** directly.

The motor **754** may receive power from an energy source **762**. The energy source **762** may be or include a battery, a super capacitor, or any other suitable energy source. The motor **754** may be mechanically coupled to the I-beam **764** via a transmission **756**. The transmission **756** may include one or more gears or other linkage components to couple the motor **754** to the I-beam **764**. A position sensor **784** may sense a position of the I-beam **764**. The position sensor **784** may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam **764**. In some examples, the position sensor **784** may include an encoder configured to provide a series of pulses to the control circuit **760** as the I-beam **764** translates distally and proximally. The control circuit **760** may track the pulses to determine the position of the I-beam **764**. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam **764**. Also, in some examples, the position sensor **784** may be omitted. Where the motor **754** is a stepper motor, the control circuit **760** may track the position of the I-beam **764** by aggregating the number and direction of steps that the motor has been instructed to execute. The position sensor **784** may be located in the end effector **792** or at any other portion of the instrument.

The control circuit **760** may be in communication with one or more sensors **788**. The sensors **788** may be positioned on the end effector **792** and adapted to operate with the surgical instrument **790** to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors **788** may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **792**. The sensors **788** may include one or more sensors.

The one or more sensors **788** may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil **766** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors **788** may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil **766** and the staple cartridge **768**. The sensors **788** may be configured to detect impedance of a tissue section located between the anvil **766** and the staple cartridge **768** that is indicative of the thickness and/or fullness of tissue located therebetween.

The sensors **788** may be is configured to measure forces exerted on the anvil **766** by the closure drive system. For example, one or more sensors **788** can be at an interaction point between a closure tube and the anvil **766** to detect the closure forces applied by a closure tube to the anvil **766**. The forces exerted on the anvil **766** can be representative of the tissue compression experienced by the tissue section captured between the anvil **766** and the staple cartridge **768**. The one or more sensors **788** can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil **766** by the closure drive system. The one or more sensors **788** may be sampled in real time during a clamping operation by a processor portion of the control circuit **760**. The control circuit **760** receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil **766**.

A current sensor **786** can be employed to measure the current drawn by the motor **754**. The force required to advance the I-beam **764** corresponds to the current drawn by the motor **754**. The force is converted to a digital signal and provided to the control circuit **760**.

An RF energy source **794** is coupled to the end effector **792** and is applied to the RF cartridge **796** when the RF cartridge **796** is loaded in the end effector **792** in place of the staple cartridge **768**. The control circuit **760** controls the delivery of the RF energy to the RF cartridge **796**.

Additional details are disclosed in U.S. patent application Ser. No. 15/636,096, titled SURGICAL SYSTEM COUPLABLE WITH STAPLE CARTRIDGE AND RADIO FREQUENCY CARTRIDGE, AND METHOD OF USING SAME, filed Jun. 28, 2017, which is herein incorporated by reference in its entirety.

Generator Hardware

FIG. **20** is a simplified block diagram of a generator **800** configured to provide inductorless tuning, among other benefits. Additional details of the generator **800** are described in U.S. Pat. No. 9,060,775, titled SURGICAL GENERATOR FOR ULTRASONIC AND ELECTROSURGICAL DEVICES, which issued on Jun. 23, 2015, which is herein incorporated by reference in its entirety. The generator **800** may comprise a patient isolated stage **802** in communication with a non-isolated stage **804** via a power transformer **806**. A secondary winding **808** of the power transformer **806** is contained in the isolated stage **802** and may comprise a tapped configuration (e.g., a center-tapped or a non-center-tapped configuration) to define drive signal outputs **810***a*, **810***b*, **810***c* for delivering drive signals to different surgical instruments, such as, for example, an ultrasonic surgical instrument, an RF electrosurgical instrument, and a multifunction surgical instrument which includes ultrasonic and RF energy modes that can be delivered alone or simultaneously. In particular, drive signal outputs **810***a*, **810***c* may output an ultrasonic drive signal (e.g., a 420V root-mean-square (RMS) drive signal) to an ultrasonic surgical instrument, and drive signal outputs **810***b*, **810***c* may output an RF electrosurgical drive signal (e.g., a 100V RMS drive signal) to an RF electrosurgical instrument, with the drive signal output **810***b* corresponding to the center tap of the power transformer **806**.

In certain forms, the ultrasonic and electrosurgical drive signals may be provided simultaneously to distinct surgical instruments and/or to a single surgical instrument, such as the multifunction surgical instrument, having the capability to deliver both ultrasonic and electrosurgical energy to tissue. It will be appreciated that the electrosurgical signal, provided either to a dedicated electrosurgical instrument and/or to a combined multifunction ultrasonic/electrosurgical instrument may be either a therapeutic or sub-therapeutic level signal where the sub-therapeutic signal can be used, for example, to monitor tissue or instrument conditions and provide feedback to the generator. For example, the ultrasonic and RF signals can be delivered separately or simultaneously from a generator with a single output port in order to provide the desired output signal to the surgical instrument, as will be discussed in more detail below. Accordingly, the generator can combine the ultrasonic and electrosurgical RF energies and deliver the combined energies to the multifunction ultrasonic/electrosurgical instrument. Bipolar electrodes can be placed on one or both jaws of the end effector. One jaw may be driven by ultrasonic energy in addition to electrosurgical RF energy, working simultaneously. The ultrasonic energy may be employed to dissect tissue, while the electrosurgical RF energy may be employed for vessel sealing.

The non-isolated stage **804** may comprise a power amplifier **812** having an output connected to a primary winding **814** of the power transformer **806**. In certain forms, the power amplifier **812** may comprise a push-pull amplifier. For example, the non-isolated stage **804** may further comprise a logic device **816** for supplying a digital output to a digital-to-analog converter (DAC) circuit **818**, which in turn supplies a corresponding analog signal to an input of the power amplifier **812**. In certain forms, the logic device **816** may comprise a programmable gate array (PGA), a FPGA, programmable logic device (PLD), among other logic circuits, for example. The logic device **816**, by virtue of controlling the input of the power amplifier **812** via the DAC circuit **818**, may therefore control any of a number of parameters (e.g., frequency, waveform shape, waveform amplitude) of drive signals appearing at the drive signal outputs **810***a*, **810***b*, **810***c*. In certain forms and as discussed below, the logic device **816**, in conjunction with a processor (e.g., a DSP discussed below), may implement a number of DSP-based and/or other control algorithms to control parameters of the drive signals output by the generator **800**.

Power may be supplied to a power rail of the power amplifier **812** by a switch-mode regulator **820**, e.g., a power converter. In certain forms, the switch-mode regulator **820** may comprise an adjustable buck regulator, for example. The non-isolated stage **804** may further comprise a first processor **822**, which in one form may comprise a DSP processor such as an Analog Devices ADSP-21469 SHARC DSP, available from Analog Devices, Norwood, Mass., for example, although in various forms any suitable processor may be employed. In certain forms the DSP processor **822** may control the operation of the switch-mode regulator **820** responsive to voltage feedback data received from the power amplifier **812** by the DSP processor **822** via an ADC circuit **824**. In one form, for example, the DSP processor **822** may receive as input, via the ADC circuit **824**, the waveform envelope of a signal (e.g., an RF signal) being amplified by the power amplifier **812**. The DSP processor **822** may then control the switch-mode regulator **820** (e.g., via a PWM output) such that the rail voltage supplied to the power amplifier **812** tracks the waveform envelope of the amplified signal. By dynamically modulating the rail voltage of the power amplifier **812** based on the waveform envelope, the efficiency of the power amplifier **812** may be significantly improved relative to a fixed rail voltage amplifier schemes.

In certain forms, the logic device **816**, in conjunction with the DSP processor **822**, may implement a digital synthesis circuit such as a direct digital synthesizer control scheme to control the waveform shape, frequency, and/or amplitude of drive signals output by the generator **800**. In one form, for example, the logic device **816** may implement a DDS control algorithm by recalling waveform samples stored in a dynamically updated lookup table (LUT), such as a RAM LUT, which may be embedded in an FPGA. This control algorithm is particularly useful for ultrasonic applications in which an ultrasonic transducer, such as an ultrasonic transducer, may be driven by a clean sinusoidal current at its resonant frequency. Because other frequencies may excite parasitic resonances, minimizing or reducing the total distortion of the motional branch current may correspondingly minimize or reduce undesirable resonance effects. Because the waveform shape of a drive signal output by the generator **800** is impacted by various sources of distortion present in the output drive circuit (e.g., the power transformer **806**, the power amplifier **812**), voltage and current feedback data based on the drive signal may be input into an algorithm, such as an error control algorithm implemented by the DSP processor **822**, which compensates for distortion by suitably pre-distorting or modifying the waveform samples stored in the LUT on a dynamic, ongoing basis (e.g., in real time). In one form, the amount or degree of pre-distortion applied to the LUT samples may be based on the error between a computed motional branch current and a desired current waveform shape, with the error being determined on a sample-by-sample basis. In this way, the pre-distorted LUT samples, when processed through the drive circuit, may result in a motional branch drive signal having the desired waveform shape (e.g., sinusoidal) for optimally driving the ultrasonic transducer. In such forms, the LUT waveform samples will therefore not represent the desired waveform shape of the drive signal, but rather the waveform shape that is required to ultimately produce the desired waveform shape of the motional branch drive signal when distortion effects are taken into account.

The non-isolated stage **804** may further comprise a first ADC circuit **826** and a second ADC circuit **828** coupled to the output of the power transformer **806** via respective isolation transformers **830**, **832** for respectively sampling the voltage and current of drive signals output by the generator **800**. In certain forms, the ADC circuits **826**, **828** may be configured to sample at high speeds (e.g., 80 mega samples per second (MSPS)) to enable oversampling of the drive signals. In one form, for example, the sampling speed of the ADC circuits **826**, **828** may enable approximately 200× (depending on frequency) oversampling of the drive signals. In certain forms, the sampling operations of the ADC circuit **826**, **828** may be performed by a single ADC circuit receiving input voltage and current signals via a two-way multiplexer. The use of high-speed sampling in forms of the generator **800** may enable, among other things, calculation of the complex current flowing through the motional branch (which may be used in certain forms to implement DDS-based waveform shape control described above), accurate digital filtering of the sampled signals, and calculation of real power consumption with a high degree of precision. Voltage and current feedback data output by the ADC circuits **826**, **828** may be received and processed (e.g., first-in-first-out (FIFO) buffer, multiplexer) by the logic device **816** and stored in data memory for subsequent retrieval by, for example, the DSP processor **822**. As noted above, voltage and current feedback data may be used as input to an algorithm for pre-distorting or modifying LUT waveform samples on a dynamic and ongoing basis. In certain forms, this may require each stored voltage and current feedback data pair to be indexed based on, or otherwise associated with, a corresponding LUT sample that was output by the logic device **816** when the voltage and current feedback data pair was acquired. Synchronization of the LUT samples and the voltage and current feedback data in this manner contributes to the correct timing and stability of the pre-distortion algorithm.

In certain forms, the voltage and current feedback data may be used to control the frequency and/or amplitude (e.g., current amplitude) of the drive signals. In one form, for example, voltage and current feedback data may be used to determine impedance phase. The frequency of the drive signal may then be controlled to minimize or reduce the difference between the determined impedance phase and an impedance phase setpoint (e.g., 0°), thereby minimizing or reducing the effects of harmonic distortion and correspondingly enhancing impedance phase measurement accuracy. The determination of phase impedance and a frequency control signal may be implemented in the DSP processor **822**, for example, with the frequency control signal being supplied as input to a DDS control algorithm implemented by the logic device **816**.

In another form, for example, the current feedback data may be monitored in order to maintain the current amplitude of the drive signal at a current amplitude setpoint. The current amplitude setpoint may be specified directly or determined indirectly based on specified voltage amplitude and power setpoints. In certain forms, control of the current amplitude may be implemented by control algorithm, such as, for example, a proportional—integral—derivative (PID) control algorithm, in the DSP processor **822**. Variables controlled by the control algorithm to suitably control the current amplitude of the drive signal may include, for example, the scaling of the LUT waveform samples stored in the logic device **816** and/or the full-scale output voltage of the DAC circuit **818** (which supplies the input to the power amplifier **812**) via a DAC circuit **834**.

The non-isolated stage **804** may further comprise a second processor **836** for providing, among other things user interface (UI) functionality. In one form, the UI processor **836** may comprise an Atmel AT91SAM9263 processor having an ARM 926EJ-S core, available from Atmel Corporation, San Jose, Calif., for example. Examples of UI functionality supported by the UI processor **836** may include audible and visual user feedback, communication with peripheral devices (e.g., via a USB interface), communication with a foot switch, communication with an input device (e.g., a touch screen display) and communication with an output device (e.g., a speaker). The UI processor **836** may communicate with the DSP processor **822** and the logic device **816** (e.g., via SPI buses). Although the UI processor **836** may primarily support UI functionality, it may also coordinate with the DSP processor **822** to implement hazard mitigation in certain forms. For example, the UI processor **836** may be programmed to monitor various aspects of user input and/or other inputs (e.g., touch screen inputs, foot switch inputs, temperature sensor inputs) and may disable the drive output of the generator **800** when an erroneous condition is detected.

In certain forms, both the DSP processor **822** and the UI processor **836**, for example, may determine and monitor the operating state of the generator **800**. For the DSP processor **822**, the operating state of the generator **800** may dictate, for example, which control and/or diagnostic processes are implemented by the DSP processor **822**. For the UI processor **836**, the operating state of the generator **800** may dictate, for example, which elements of a UI (e.g., display screens, sounds) are presented to a user. The respective DSP and UI processors **822**, **836** may independently maintain the current operating state of the generator **800** and recognize and evaluate possible transitions out of the current operating state. The DSP processor **822** may function as the master in this relationship and determine when transitions between operating states are to occur. The UI processor **836** may be aware of valid transitions between operating states and may confirm if a particular transition is appropriate. For example, when the DSP processor **822** instructs the UI processor **836** to transition to a specific state, the UI processor **836** may verify that requested transition is valid. In the event that a requested transition between states is determined to be invalid by the UI processor **836**, the UI processor **836** may cause the generator **800** to enter a failure mode.

The non-isolated stage **804** may further comprise a controller **838** for monitoring input devices (e.g., a capacitive touch sensor used for turning the generator **800** on and off, a capacitive touch screen). In certain forms, the controller **838** may comprise at least one processor and/or other controller device in communication with the UI processor **836**. In one form, for example, the controller **838** may comprise a processor (e.g., a Meg168 8-bit controller available from Atmel) configured to monitor user input provided via one or more capacitive touch sensors. In one form, the controller **838** may comprise a touch screen controller (e.g., a QT5480 touch screen controller available from Atmel) to control and manage the acquisition of touch data from a capacitive touch screen.

In certain forms, when the generator **800** is in a "power off" state, the controller **838** may continue to receive operating power (e.g., via a line from a power supply of the generator **800**, such as the power supply **854** discussed below). In this way, the controller **838** may continue to monitor an input device (e.g., a capacitive touch sensor located on a front panel of the generator **800**) for turning the generator **800** on and off. When the generator **800** is in the power off state, the controller **838** may wake the power supply (e.g., enable operation of one or more DC/DC voltage converters **856** of the power supply **854**) if activation of the "on/off" input device by a user is detected. The controller **838** may therefore initiate a sequence for transitioning the generator **800** to a "power on" state. Conversely, the controller **838** may initiate a sequence for transitioning the generator **800** to the power off state if activation of the "on/off" input device is detected when the generator **800** is in the power on state. In certain forms, for example, the controller **838** may report activation of the "on/off" input device to the UI processor **836**, which in turn implements the necessary process sequence for transitioning the generator

800 to the power off state. In such forms, the controller **838** may have no independent ability for causing the removal of power from the generator **800** after its power on state has been established.

In certain forms, the controller **838** may cause the generator **800** to provide audible or other sensory feedback for alerting the user that a power on or power off sequence has been initiated. Such an alert may be provided at the beginning of a power on or power off sequence and prior to the commencement of other processes associated with the sequence.

In certain forms, the isolated stage **802** may comprise an instrument interface circuit **840** to, for example, provide a communication interface between a control circuit of a surgical instrument (e.g., a control circuit comprising handpiece switches) and components of the non-isolated stage **804**, such as, for example, the logic device **816**, the DSP processor **822**, and/or the UI processor **836**. The instrument interface circuit **840** may exchange information with components of the non-isolated stage **804** via a communication link that maintains a suitable degree of electrical isolation between the isolated and non-isolated stages **802**, **804**, such as, for example, an IR-based communication link. Power may be supplied to the instrument interface circuit **840** using, for example, a low-dropout voltage regulator powered by an isolation transformer driven from the non-isolated stage **804**.

In one form, the instrument interface circuit **840** may comprise a logic circuit **842** (e.g., logic circuit, programmable logic circuit, PGA, FPGA, PLD) in communication with a signal conditioning circuit **844**. The signal conditioning circuit **844** may be configured to receive a periodic signal from the logic circuit **842** (e.g., a 2 kHz square wave) to generate a bipolar interrogation signal having an identical frequency. The interrogation signal may be generated, for example, using a bipolar current source fed by a differential amplifier. The interrogation signal may be communicated to a surgical instrument control circuit (e.g., by using a conductive pair in a cable that connects the generator **800** to the surgical instrument) and monitored to determine a state or configuration of the control circuit. The control circuit may comprise a number of switches, resistors, and/or diodes to modify one or more characteristics (e.g., amplitude, rectification) of the interrogation signal such that a state or configuration of the control circuit is uniquely discernable based on the one or more characteristics. In one form, for example, the signal conditioning circuit **844** may comprise an ADC circuit for generating samples of a voltage signal appearing across inputs of the control circuit resulting from passage of interrogation signal therethrough. The logic circuit **842** (or a component of the non-isolated stage **804**) may then determine the state or configuration of the control circuit based on the ADC circuit samples.

In one form, the instrument interface circuit **840** may comprise a first data circuit interface **846** to enable information exchange between the logic circuit **842** (or other element of the instrument interface circuit **840**) and a first data circuit disposed in or otherwise associated with a surgical instrument. In certain forms, for example, a first data circuit may be disposed in a cable integrally attached to a surgical instrument handpiece or in an adaptor for interfacing a specific surgical instrument type or model with the generator **800**. The first data circuit may be implemented in any suitable manner and may communicate with the generator according to any suitable protocol, including, for example, as described herein with respect to the first data circuit. In certain forms, the first data circuit may comprise a non-volatile storage device, such as an EEPROM device. In certain forms, the first data circuit interface **846** may be implemented separately from the logic circuit **842** and comprise suitable circuitry (e.g., discrete logic devices, a processor) to enable communication between the logic circuit **842** and the first data circuit. In other forms, the first data circuit interface **846** may be integral with the logic circuit **842**.

In certain forms, the first data circuit may store information pertaining to the particular surgical instrument with which it is associated. Such information may include, for example, a model number, a serial number, a number of operations in which the surgical instrument has been used, and/or any other type of information. This information may be read by the instrument interface circuit **840** (e.g., by the logic circuit **842**), transferred to a component of the non-isolated stage **804** (e.g., to logic device **816**, DSP processor **822**, and/or UI processor **836**) for presentation to a user via an output device and/or for controlling a function or operation of the generator **800**. Additionally, any type of information may be communicated to the first data circuit for storage therein via the first data circuit interface **846** (e.g., using the logic circuit **842**). Such information may comprise, for example, an updated number of operations in which the surgical instrument has been used and/or dates and/or times of its usage.

As discussed previously, a surgical instrument may be detachable from a handpiece (e.g., the multifunction surgical instrument may be detachable from the handpiece) to promote instrument interchangeability and/or disposability. In such cases, conventional generators may be limited in their ability to recognize particular instrument configurations being used and to optimize control and diagnostic processes accordingly. The addition of readable data circuits to surgical instruments to address this issue is problematic from a compatibility standpoint, however. For example, designing a surgical instrument to remain backwardly compatible with generators that lack the requisite data reading functionality may be impractical due to, for example, differing signal schemes, design complexity, and cost. Forms of instruments discussed herein address these concerns by using data circuits that may be implemented in existing surgical instruments economically and with minimal design changes to preserve compatibility of the surgical instruments with current generator platforms.

Additionally, forms of the generator **800** may enable communication with instrument-based data circuits. For example, the generator **800** may be configured to communicate with a second data circuit contained in an instrument (e.g., the multifunction surgical instrument). In some forms, the second data circuit may be implemented in a many similar to that of the first data circuit described herein. The instrument interface circuit **840** may comprise a second data circuit interface **848** to enable this communication. In one form, the second data circuit interface **848** may comprise a tri-state digital interface, although other interfaces may also be used. In certain forms, the second data circuit may generally be any circuit for transmitting and/or receiving data. In one form, for example, the second data circuit may store information pertaining to the particular surgical instrument with which it is associated. Such information may include, for example, a model number, a serial number, a number of operations in which the surgical instrument has been used, and/or any other type of information.

In some forms, the second data circuit may store information about the electrical and/or ultrasonic properties of an associated ultrasonic transducer, end effector, or ultrasonic drive system. For example, the first data circuit may indicate a burn-in frequency slope, as described herein. Additionally or alternatively, any type of information may be communicated to second data circuit for storage therein via the second data circuit interface **848** (e.g., using the logic circuit **842**). Such information may comprise, for example, an updated number of operations in which the instrument has been used and/or dates and/or times of its usage. In certain forms, the second data circuit may transmit data acquired by one or more sensors (e.g., an instrument-based temperature sensor). In certain forms, the second data circuit may receive data from the generator **800** and provide an indication to a user (e.g., a light emitting diode indication or other visible indication) based on the received data.

In certain forms, the second data circuit and the second data circuit interface **848** may be configured such that communication between the logic circuit **842** and the second data circuit can be effected without the need to provide additional conductors for this purpose (e.g., dedicated conductors of a cable connecting a handpiece to the generator **800**). In one form, for example, information may be communicated to and from the second data circuit using a one-wire bus communication scheme implemented on existing cabling, such as one of the conductors used transmit interrogation signals from the signal conditioning circuit **844** to a control circuit in a handpiece. In this way, design changes or modifications to the surgical instrument that might otherwise be necessary are minimized or reduced. Moreover, because different types of communications implemented over a common physical channel can be frequency-band separated, the presence of a second data circuit may be "invisible" to generators that do not have the requisite data reading functionality, thus enabling backward compatibility of the surgical instrument.

In certain forms, the isolated stage **802** may comprise at least one blocking capacitor **850-1** connected to the drive signal output **810***b* to prevent passage of DC current to a patient. A single blocking capacitor may be required to comply with medical regulations or standards, for example. While failure in single-capacitor designs is relatively uncommon, such failure may nonetheless have negative consequences. In one form, a second blocking capacitor **850-2** may be provided in series with the blocking capacitor **850-1**, with current leakage from a point between the blocking capacitors **850-1**, **850-2** being monitored by, for example, an ADC circuit **852** for sampling a voltage induced by leakage current. The samples may be received by the logic circuit **842**, for example. Based changes in the leakage current (as indicated by the voltage samples), the generator **800** may determine when at least one of the blocking capacitors **850-1**, **850-2** has failed, thus providing a benefit over single-capacitor designs having a single point of failure.

In certain forms, the non-isolated stage **804** may comprise a power supply **854** for delivering DC power at a suitable voltage and current. The power supply may comprise, for example, a 400 W power supply for delivering a 48 VDC system voltage. The power supply **854** may further comprise one or more DC/DC voltage converters **856** for receiving the output of the power supply to generate DC outputs at the voltages and currents required by the various components of the generator **800**. As discussed above in connection with the controller **838**, one or more of the DC/DC voltage converters **856** may receive an input from the controller **838** when activation of the "on/off" input device by a user is detected by the controller **838** to enable operation of, or wake, the DC/DC voltage converters **856**.

FIG. **21** illustrates an example of a generator **900**, which is one form of the generator **800** (FIG. **20**). The generator **900** is configured to deliver multiple energy modalities to a surgical instrument. The generator **900** provides RF and ultrasonic signals for delivering energy to a surgical instrument either independently or simultaneously. The RF and ultrasonic signals may be provided alone or in combination and may be provided simultaneously. As noted above, at least one generator output can deliver multiple energy modalities (e.g., ultrasonic, bipolar or monopolar RF, irreversible and/or reversible electroporation, and/or microwave energy, among others) through a single port, and these signals can be delivered separately or simultaneously to the end effector to treat tissue. The generator **900** comprises a processor **902** coupled to a waveform generator **904**. The processor **902** and waveform generator **904** are configured to generate a variety of signal waveforms based on information stored in a memory coupled to the processor **902**, not shown for clarity of disclosure. The digital information associated with a waveform is provided to the waveform generator **904** which includes one or more DAC circuits to convert the digital input into an analog output. The analog output is fed to an amplifier **1106** for signal conditioning and amplification. The conditioned and amplified output of the amplifier **906** is coupled to a power transformer **908**. The signals are coupled across the power transformer **908** to the secondary side, which is in the patient isolation side. A first signal of a first energy modality is provided to the surgical instrument between the terminals labeled ENERGY**1** and RETURN. A second signal of a second energy modality is coupled across a capacitor **910** and is provided to the surgical instrument between the terminals labeled ENERGY**2** and RETURN. It will be appreciated that more than two energy modalities may be output and thus the subscript "n" may be used to designate that up to n ENERGYn terminals may be provided, where n is a positive integer greater than 1. It also will be appreciated that up to "n" return paths RETURNn may be provided without departing from the scope of the present disclosure.

A first voltage sensing circuit **912** is coupled across the terminals labeled ENERGY**1** and the RETURN path to measure the output voltage therebetween. A second voltage sensing circuit **924** is coupled across the terminals labeled ENERGY**2** and the RETURN path to measure the output voltage therebetween. A current sensing circuit **914** is disposed in series with the RETURN leg of the secondary side of the power transformer **908** as shown to measure the output current for either energy modality. If different return paths are provided for each energy modality, then a separate current sensing circuit should be provided in each return leg. The outputs of the first and second voltage sensing circuits **912**, **924** are provided to respective isolation transformers **916**, **922** and the output of the current sensing circuit **914** is provided to another isolation transformer **918**. The outputs of the isolation transformers **916**, **928**, **922** in the on the primary side of the power transformer **908** (non-patient isolated side) are provided to a one or more ADC circuit **926**. The digitized output of the ADC circuit **926** is provided to the processor **902** for further processing and computation. The output voltages and output current feedback information can be employed to adjust the output voltage and current provided to the surgical instrument and to compute output impedance, among other parameters. Input/output communications between the processor **902** and patient isolated circuits is provided through an interface circuit **920**. Sensors also may be in electrical communication with the processor **902** by way of the interface circuit **920**.

In one aspect, the impedance may be determined by the processor **902** by dividing the output of either the first voltage sensing circuit **912** coupled across the terminals labeled ENERGY**1**/RETURN or the second voltage sensing circuit **924** coupled across the terminals labeled ENERGY**2**/RETURN by the output of the current sensing circuit **914** disposed in series with the RETURN leg of the secondary side of the power transformer **908**. The outputs of the first and second voltage sensing circuits **912**, **924** are provided to separate isolations transformers **916**, **922** and the output of the current sensing circuit **914** is provided to another isolation transformer **916**. The digitized voltage and current sensing measurements from the ADC circuit **926** are provided the processor **902** for computing impedance. As an example, the first energy modality ENERGY**1** may be ultrasonic energy and the second energy modality ENERGY**2** may be RF energy. Nevertheless, in addition to ultrasonic and bipolar or monopolar RF energy modalities, other energy modalities include irreversible and/or reversible electroporation and/or microwave energy, among others. Also, although the example illustrated in FIG. **21** shows a single return path RETURN may be provided for two or more energy modalities, in other aspects, multiple return paths RETURNn may be provided for each energy modality ENERGYn. Thus, as described herein, the ultrasonic transducer impedance may be measured by dividing the output of the first voltage sensing circuit **912** by the current sensing circuit **914** and the tissue impedance may be measured by dividing the output of the second voltage sensing circuit **924** by the current sensing circuit **914**.

As shown in FIG. **21**, the generator **900** comprising at least one output port can include a power transformer **908** with a single output and with multiple taps to provide power in the form of one or more energy modalities, such as ultrasonic, bipolar or monopolar RF, irreversible and/or reversible electroporation, and/or microwave energy, among others, for example, to the end effector depending on the type of treatment of tissue being performed. For example, the generator **900** can deliver energy with higher voltage and lower current to drive an ultrasonic transducer, with lower voltage and higher current to drive RF electrodes for sealing tissue, or with a coagulation waveform for spot coagulation using either monopolar or bipolar RF electrosurgical electrodes. The output waveform from the generator **900** can be steered, switched, or filtered to provide the frequency to the end effector of the surgical instrument. The connection of an ultrasonic transducer to the generator **900** output would be preferably located between the output labeled ENERGY**1** and RETURN as shown in FIG. **21**. In one example, a connection of RF bipolar electrodes to the generator **900** output would be preferably located between the output labeled ENERGY**2** and RETURN. In the case of monopolar output, the preferred connections would be active electrode (e.g., pencil or other probe) to the ENERGY**2** output and a suitable return pad connected to the RETURN output.

Additional details are disclosed in U.S. Patent Application Publication No. 2017/0086914, titled TECHNIQUES FOR OPERATING GENERATOR FOR DIGITALLY GENERATING ELECTRICAL SIGNAL WAVEFORMS AND SURGICAL INSTRUMENTS, which published on Mar. 30, 2017, which is herein incorporated by reference in its entirety.

As used throughout this description, the term "wireless" and its derivatives may be used to describe circuits, devices, systems, methods, techniques, communications channels, etc., that may communicate data through the use of modulated electromagnetic radiation through a non-solid medium. The term does not imply that the associated devices do not contain any wires, although in some aspects they might not. The communication module may implement any of a number of wireless or wired communication standards or protocols, including but not limited to W-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long term evolution (LTE), Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, Bluetooth, Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter range wireless communications such as Wi-Fi and Bluetooth and a second communication module may be dedicated to longer range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

As used herein a processor or processing unit is an electronic circuit which performs operations on some external data source, usually memory or some other data stream. The term is used herein to refer to the central processor (central processing unit) in a system or computer systems (especially systems on a chip (SoCs)) that combine a number of specialized "processors."

As used herein, a system on a chip or system on chip (SoC or SOC) is an integrated circuit (also known as an "IC" or "chip") that integrates all components of a computer or other electronic systems. It may contain digital, analog, mixed-signal, and often radio-frequency functions—all on a single substrate. A SoC integrates a microcontroller (or microprocessor) with advanced peripherals like graphics processing unit (GPU), Wi-Fi module, or coprocessor. A SoC may or may not contain built-in memory.

As used herein, a microcontroller or controller is a system that integrates a microprocessor with peripheral circuits and memory. A microcontroller (or MCU for microcontroller unit) may be implemented as a small computer on a single integrated circuit. It may be similar to a SoC; an SoC may include a microcontroller as one of its components. A microcontroller may contain one or more core processing units (CPUs) along with memory and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM. Microcontrollers may be employed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips.

As used herein, the term controller or microcontroller may be a stand-alone IC or chip device that interfaces with a peripheral device. This may be a link between two parts of a computer or a controller on an external device that manages the operation of (and connection with) that device.

Any of the processors or microcontrollers described herein, may be implemented by any single core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), internal read-only memory (ROM) loaded with StellarisWare® software, 2 KB electrically erasable programmable read-only memory (EEPROM), one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analog, one or more 12-bit Analog-to-Digital Converters (ADC) with 12 analog input channels, details of which are available for the product datasheet.

In one aspect, the processor may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

Modular devices include the modules (as described in connection with FIGS. **3** and **9**, for example) that are receivable within a surgical hub and the surgical devices or instruments that can be connected to the various modules in order to connect or pair with the corresponding surgical hub. The modular devices include, for example, intelligent surgical instruments, medical imaging devices, suction/irrigation devices, smoke evacuators, energy generators, ventilators, insufflators, and displays. The modular devices described herein can be controlled by control algorithms. The control algorithms can be executed on the modular device itself, on the surgical hub to which the particular modular device is paired, or on both the modular device and the surgical hub (e.g., via a distributed computing architecture). In some exemplifications, the modular devices' control algorithms control the devices based on data sensed by the modular device itself (i.e., by sensors in, on, or connected to the modular device). This data can be related to the patient being operated on (e.g., tissue properties or insufflation pressure) or the modular device itself (e.g., the rate at which a knife is being advanced, motor current, or energy levels). For example, a control algorithm for a surgical stapling and cutting instrument can control the rate at which the instrument's motor drives its knife through tissue according to resistance encountered by the knife as it advances.

Long Distance Communication and Condition Handling of Devices and Data

Surgical procedures are performed by different surgeons at different locations, some with much less experience than others. For a given surgical procedure, there are many parameters that can be varied to attempt to realize a desired outcome. For example, for a given surgical procedure which utilizes energy supplied by a generator, the surgeon often relies on experience alone for determining which mode of energy to utilize, which level of output power to utilize, the duration of the application of the energy, etc., in order to attempt to realize the desired outcome. To increase the likelihood of realizing desired outcomes for a plurality of different surgical procedures, each surgeon should be provided with best practice recommendations which are based on important relationships identified within large, accurate data sets of information associated with multiple surgical procedures performed in multiple locations over time. However, there are many ways that such data sets can be rendered compromised, inaccurate, and/or unsecure, thereby calling into question the applicability of the best practice recommendations derived therefrom. For example, for data sent from a source to a cloud-based system, the data can be lost while in transit to the cloud-based system, the data can be corrupted while in transit to the cloud-based system, the confidentiality of the data can be comprised while in transit to the cloud-based system, and/or the content of the data can be altered while in transit to the cloud-based system.

A plurality of operating rooms located in multiple locations can each be equipped with a surgical hub. When a given surgical procedure is performed in a given operating room, the surgical hub can receive data associated with the surgical procedure and communicate the data to a cloud-based system. Over time, the cloud-based system will receive large data sets of information associated with the surgeries. The data can be communicated from the surgical hubs to the cloud-based system in a manner which allows for the cloud-based system to (1) verify the authenticity of the communicated data, (2) authenticate each of the respective surgical hubs which communicated the data, and (3) trace the paths the data followed from the respective surgical hubs to the cloud-based system.

Accordingly, in one aspect, the present disclosure provides a surgical hub for transmitting generator data associated with a surgical procedure to a cloud-based system communicatively coupled to a plurality of surgical hubs. The surgical hub comprises a processor and a memory coupled to the processor. The memory stores instructions executable by the processor to receive data from a generator, encrypt the data, generate a message authentication code (MAC) based on the data, generate a datagram comprising the encrypted data, the generated MAC, a source identifier, and a destination identifier, and transmit the datagram to a cloud-based system. The data is structured into a data packet comprising at least two of the following fields: a field that indicates the source of the data, a unique time stamp, a field indicating an energy mode of the generator, a field indicating the power output of the generator, and a field indicating a duration of the power output of the generator. The datagram allows for the cloud-based system to decrypt the encrypted data of the transmitted datagram, verify integrity of the data based on the MAC, authenticate the surgical hub as the source of the datagram, and validate a transmission path followed by the datagram between the surgical hub and the cloud-based system.

In various aspects, the present disclosure provides a control circuit to transmit generator data associated with a surgical procedure to a cloud-based system communicatively coupled to a plurality of surgical hubs, as described above. In various aspects, the present disclosure provides a non-transitory computer-readable medium storing computer-readable instructions which, when executed, causes a machine to transmit generator data associated with a surgical procedure to a cloud-based system communicatively coupled to a plurality of surgical hubs, as described above.

In another aspect, the present disclosure provides a cloud-based system communicatively coupled to a plurality of surgical hubs. Each surgical hub is configured to transmit generator data associated with a surgical procedure to the cloud-based system. The cloud-based system comprises a processor and a memory coupled to the processor. The memory stores instructions executable by the processor to receive a datagram generated by a surgical hub, decrypt the encrypted generator data of the received datagram, verify integrity of the generator data based on the MAC, authenticate the surgical hub as the source of the datagram, and validate a transmission path followed by the datagram between the surgical hub and the cloud-based system. The datagram comprises generator data captured from a generator associated with the surgical hub, a MAC generated by the surgical hub based on the generator data, a source identifier, and a destination identifier. The generator data has been encrypted by the surgical hub. The encrypted generator data has been structured into a data packet comprising at least two of the following fields: a field that indicates the source of the data, a unique time stamp, a field indicating an energy mode, a field indicating power output, and a field indicating a duration of applied power.

In various aspects, the present disclosure provides a control circuit to transmit generator data associated with a surgical procedure to the cloud-based system. In various aspects, the present disclosure provides a non-transitory computer-readable medium storing computer-readable instructions which, when executed, causes a machine to transmit generator data associated with a surgical procedure to the cloud-based system.

In another aspect, the present disclosure provides a method, comprising capturing data from a combination generator of a surgical hub during a surgical procedure, wherein the combination generator is configured to supply two or more different modes of energy. Encrypting the captured generator data, generating a MAC based on the captured generator data, generating a datagram comprising the encrypted generator data, the MAC, a source identifier, and a destination identifier, and communicating the datagram from the surgical hub to a cloud-based system. The datagram allows for the cloud-based system to authenticate integrity of the communicated generator data, authenticate the surgical hub as a source of the datagram, and determine a communication path followed by the datagram between the surgical hub and the cloud-based system.

By sending captured generator data from a plurality of different surgical hubs to a cloud-based system, the cloud-based system is able to quickly build large data sets of information associated with multiple surgical procedures performed in multiple locations over time. Furthermore, due to the composition of the respective datagrams, for a given datagram, the cloud-based system is able to determine whether the datagram was originally sent by one of the surgical hubs (source validation), thereby providing an indication that the generator data received at the cloud-based system is legitimate data. For the given datagram, the cloud-based system is also able to determine whether the generator data received at the cloud-based system is identical to the generator data sent by the given surgical hub (data integrity), thereby allowing for the authenticity of the received generator data to be verified. Additionally, for the given datagram, the cloud-based system is also able to re-trace the communication path followed by the datagram, thereby allowing for enhanced troubleshooting if a datagram received by the cloud-based system was originally sent from a device other than the surgical hubs and/or if the content of the datagram was altered while in transit to the cloud-based system. Notably, the present disclosure references generator data in particular. Here, the present disclosure should not be limited as being able to process only generator data. For example, the surgical hub **206** and/or the cloud-based system **205** may process data received from any component (e.g., imaging module **238**, generator module **240**, smoke evacuator module **226**, suction/irrigation module **228**, communication module **230**, processor module **232**, storage array **234**, smart device/instrument **235**, non-contact sensor module **242**, robot hub **222**, a non-robotic surgical hub **206**, wireless smart device/instrument **235**, visualization system **208**) of the surgical system **202** that is coupled to the surgical hub **206** and/or data from any devices (e.g., endoscope **239**, energy device **241**) coupled to/through such components (e.g., see FIGS. **9-10**), in a similar manner as discussed herein.

Unfortunately, the outcome of a surgical procedure is not always optimal. For example, a failure event such as a surgical device failure, an unwanted tissue perforation, an unwanted post-operative bleeding, or the like can occur. The occurrence of a failure event can be attributed to any of a variety of different people and devices, including one or more surgeons, one or more devices associated with the surgery, a condition of the patient, and combinations thereof. When a given failure event occurs, it is not always clear regarding who or what caused the failure event or how the occurrence of the failure event can be mitigated in connection with a future surgery.

During a given surgical procedure, a large amount of data associated with the surgical procedure can be generated and captured. All of the captured data can be communicated to a surgical hub, and the captured data can be time-stamped either before or after being received at the surgical hub. When a failure event associated with the surgical procedure is detected and/or identified, it can be determined which of the captured data is associated with the failure event and/or which of the captured data is not associated with the failure event. In making this determination, the failure event can be defined to include a period of time prior to the detection/identification of the failure event. Once the determination is made regarding the captured data associated with the failure event, the surgical hub can separate the captured data associated with the failure event from all other captured data, and the captured data can be separated based on tagging, flagging, or the like. The captured data associated with the failure event can then be chronologized based on the time-stamping and the defined time period applicable to the failure event. The chronologized captured data can then be communicated to a cloud-based system on a prioritized basis for analysis, where the prioritized basis is relative to the captured data which is not associated with the failure event. Whether or not the analysis identifies a device associated with the surgical procedure as the causation of the failure event, the surgical hub can tag the device for removal of the device from future use, further analysis of the device, and/or to return the device to the manufacturer.

When a given surgical procedure is performed, a large amount of data associated with the surgical procedure can be generated and captured. All of the captured data can be communicated to a surgical hub, where the information can be stripped of all "personal" associations. The captured data can be time-stamped before being received at the surgical hub, after being received at the surgical hub, before being stripped of the "personal" associations, or after being stripped of the "personal" associations. The surgical hub can communicate the stripped data to the cloud-based system for subsequent analysis. Over time, the cloud-based system will receive large data sets of information associated with the surgeries. Accordingly, in one aspect, the present disclosure provides a surgical hub for prioritizing surgical data associated with a surgical procedure to a cloud-based system communicatively coupled to a plurality of surgical hubs. The surgical hub comprises a processor and a memory coupled to the processor. The memory stores instructions executable by the processor to capture surgical data, wherein the surgical data comprises data associated with a surgical device, time-stamp the captured surgical data, identify a failure event, identify a time period associated with the failure event, isolate failure event surgical data from surgical data not associated with the failure event based on the identified time period, chronologize the failure event surgical data by time-stamp, encrypt the chronologized failure event surgical data, generate a datagram comprising the encrypted failure event surgical data, and transmit the datagram to a cloud-based system. The datagram is structured to include a field which includes a flag that prioritizes the encrypted failure event surgical data over other encrypted data of the datagram. The datagram allows for the cloud-based system to decrypt the encrypted failure event surgical data, focus analysis on the failure event surgical data rather than surgical data not associated with the failure event, and flag the surgical device associated with the failure event for at least one of the following: removal from an operating room, return to a manufacturer, or future inoperability in the cloud-based system.

In various aspects, the present disclosure provides a control circuit to prioritize surgical data associated with a surgical procedure to a cloud-based system communicatively coupled to a plurality of surgical hubs. In various aspects, the present disclosure provides a non-transitory computer-readable medium storing computer-readable instructions which, when executed, causes a machine to prioritize surgical data associated with a surgical procedure to a cloud-based system communicatively coupled to a plurality of surgical hubs.

In another aspect, the present disclosure provides a method, comprising capturing data during a surgical procedure, communicating the captured data to a surgical hub, time-stamping the captured data, identifying a failure event associated with the surgical procedure, determining which of the captured data is associated with the failure event, separating the captured data associated with the failure event from all other captured data, chronologizing the captured data associated with the failure event, and communicating the chronologized captured data to a cloud-based system on a prioritized basis.

By capturing the large amount of data associated with the surgical procedure, and with having the captured data time-stamped, the portion of the captured data which is relevant to the detected/identified failure event can be more easily isolated from all of the other captured data, thereby allowing for a more focused subsequent analysis on just the relevant captured data. The data associated with the failure event can then be chronologized (this requires less processing power than chronologizing all of the captured data), thereby allowing for the events leading up to the detection/identification of the failure event to be more easily considered during the subsequent analysis of the failure event. The chronologized data can then be communicated to the cloud-based system (this requires less communication resources than communicating all of the captured data at the same time) on a prioritized basis, thereby allowing for the focused subsequent analysis of the fault event to be performed by the cloud-based system in a more time-sensitive manner.

To help ensure that the best practice recommendations are developed based on accurate data, it would be desirable to ensure that the generator data received at the cloud-based system is the same as the generator data communicated to the cloud-based system. Also, to help to be able to determine the cause of a failure event as quickly as possible, it would be desirable to ensure that surgical data associated with the failure event is communicated to the cloud-based system in a prioritized manner (relative to surgical data not associated with the failure event) so that analysis of the surgical data can be performed in an expedited manner.

Aspects of a system and method for communicating data associated with a surgical procedure are described herein. As shown in FIG. **9**, various aspects of the computer implemented interactive surgical system **200** includes a device/instrument **235**, a generator module **240**, a modular control tower **236**, and a cloud-based system **205**. As shown in FIG. **10**, the device/instrument **235**, the generator module **240**, and the modular control tower **236** are components/portions of a surgical hub **206**.

In various aspects, the generator module **240** of the surgical hub **206** can supply radio-frequency energy such as monopolar radio-frequency energy, bipolar radio-frequency energy, and advanced bipolar energy and/or ultrasonic energy to a device/instrument **235** for use in a surgical procedure. Thus, the generator module **240** may be referred to as a combination generator. An example of such a combination generator is shown in FIG. **22**, where the combination generator **3700** is shown as including a monopolar module **3702**, a bipolar module **3704**, an advanced bipolar module **3706**, and an ultrasound module **3708**. When utilized during a surgical procedure, the respective energy modules (e.g., **3702**, **3704**, **3706**, and/or **3708**) of the combination generator **3700** can provide generator data such as type of energy supplied to the device instrument (e.g., radio-frequency energy, ultrasound energy, radio-frequency energy and ultrasound energy), type of radio-frequency energy (e.g., monoplar, bipolar, advanced bipolar), frequency, power output, duration, etc., to the data communication module **3710** of the combination generator **3700**.

FIG. **23** illustrates various aspects of a method of capturing data from a combination generator **3700** and communicating the captured generator data to a cloud-based system **205**. Notably, as discussed herein, the present disclosure should not be limited to processing generator data. As such, the method of FIG. **23** similarly extends to other types of data received from other components coupled to the surgical hub **206** (e.g., imaging module data, smoke evacuator data, suction/irrigation data, device/instrument data). The method comprises (1) capturing **3712** data from a combination generator **3700** of a surgical hub **206** during a surgical procedure, wherein the combination generator **3700** is configured to supply two or more different modes of energy; (2) encrypting **3714** the captured generator data; (3) generating **3716** a MAC based on the captured generator data; (4) generating **3718** a datagram comprising the encrypted generator data, the MAC, a source identifier, and a destination identifier; and (5) communicating **3720** the datagram from the surgical hub **206** to a cloud-based system **205**, wherein the datagram allows for the cloud-based system **205** to (i) authenticate integrity of the communicated generator data, (ii) authenticate the surgical hub as a source of the datagram, and (iii) determine a communication path followed by the datagram between the surgical hub **206** and the cloud-based system **205**.

More specifically, once the generator data is received at the data communication module **3710** of the combination generator **3700**, the generator data can be communicated to the modular communication hub **203** of the surgical hub **206** for subsequent communication to the cloud-based system **205**. The data communication module **3710** can communicate the generator data to the modular communication hub **203** serially over a single communication line or in parallel over a plurality of communication lines, and such communication can be performed in real time or near real time. Alternatively, such communication can be performed in batches.

According to various aspects, prior to communicating the generator data to the modular communication hub **203**, a component of the combination generator **3700** (e.g., the data communication module **3710**) can organize the generator data into data packets. An example of such a data packet is shown in FIG. **24**, where the data packet **3722** includes a preamble **3724** or self-describing data header which defines what the data is (e.g., combination generator data—CGD) and fields which indicate where the generator data came from [e.g., combination generator ID number **3726**—(e.g., 017), a unique time stamp **3728** (e.g., 08:27:16), the energy mode utilized 3730 (e.g., RF, U, RF+U), the type of radiofrequency energy or radio frequency mode **3732** (e.g., MP, BP, ABP), the frequency **3734** (e.g., 500Khz), the power output **3736** (e.g., 30 watts), the duration of applied power **3738** (e.g., 45 milliseconds), and an authentication/identification certificate of the data point **3740** (e.g., 01101011001011)]. The example data packet **3722** may be considered a self-describing data packet, and the combination generator **3700** and other intelligent devices (e.g., the surgical hub **206**) can use the self-describing data packets to minimize data size and data-handling resources. Again, as discussed herein, the present disclosure should not be limited to processing generator data received from a combination generator **3700**. As such, the data packet **3722** of FIG. **24** similarly extends to other types of data received from other components coupled to the surgical hub **206**. In one aspect, the data packet **3722** may comprise data associated with endoscope **239** (e.g., image data) received from a component of the imaging module **238**. In another aspect, the data packet **3722** may comprises data associated with an evacuation system (e.g., pressures, particle counts, flow rates, motor speeds) received from a component of the smoke evacuator module **226**. In yet another aspect, the data packet **3722** may comprise data associated with a device/instrument (e.g., temperature sensor data, firing data, sealing data) received from a component of the device/instrument **235**. In various other aspects, the data packet **3722** may similarly comprise data received from other components coupled to the surgical hub **206** (e.g., suction/irrigation module **228**, non-contact sensor module **242**)

Additionally, the data communication module **3710** can compress the generator data and/or encrypt the generator data prior to communicating the generator data to the modular communication hub **203**. The specific method of compressing and/or encrypting can be the same as or different from the compressing and/or encrypting which may be performed by the surgical hub **206** as described in more detail below.

The modular communication hub **203** can receive the generator data communicated from the combination generator **3700** (e.g., via the data communication module **3710**), and the generator data can be subsequently communicated to the cloud-based system **205** (e.g., through the Internet). According to various aspects, the modular communication hub **203** can receive the generator data through a hub/switch **207**/**209** of the modular communication hub **203** (See FIG. **10**), and the generator data can be communicated to the cloud-based system **205** by a router **211** of the modular communication hub **203** (See FIG. **10**). The generator data may be communicated in real time, near real time, or in batches to the cloud-based system **205** or may be stored at the surgical hub **206** prior to being communicated to the cloud-based system **205**. The generator data can be stored, for example, at the storage array **234** or at the memory **249** of the computer system **210** of the surgical hub **206**.

In various aspects, for instances where the generator data received at the modular communication hub **203** is not encrypted, prior to the received generator data being communicated to the cloud-based system **205**, the generator data is encrypted to help ensure the confidentiality of the generator data, either while it is being stored at the surgical hub **206** or while it is being transmitted to the cloud **204** using the Internet or other computer networks. According to various aspects, a component of the surgical hub **206** utilizes an encryption algorithm to convert the generator data from a readable version to an encoded version, thereby forming the encrypted generator data. The component of the surgical hub **206** which utilizes/executes the encryption algorithm can be, for example, the processor module **232**, the processor **244** of the computer system **210**, and/or combinations thereof. The utilized/executed encryption algorithm can be a symmetric encryption algorithm and/or an asymmetric encryption algorithm.

Using a symmetric encryption algorithm, the surgical hub **206** would encrypt the generator data using a shared secret (e.g., private key, passphrase, password). In such an aspect, a recipient of the encrypted generator data (e.g., cloud-based system **205**) would then decrypt the encrypted generator data using the same shared secret. In such an aspect, the surgical hub **206** and the recipient would need access to and/or knowledge of the same shared secret. In one aspect, a shared secret can be generated/chosen by the surgical hub **206** and securely delivered (e.g., physically) to the recipient before encrypted communications to the recipient.

Alternatively, using an asymmetric encryption algorithm, the surgical hub **206** would encrypt the generator data using a public key associated with a recipient (e.g., cloud-based system **205**). This public key could be received by the surgical hub **206** from a certificate authority that issues a digital certificate certifying the public key as owned by the recipient. The certificate authority can be any entity trusted by the surgical hub **206** and the recipient. In such an aspect, the recipient of the encrypted generator data would then decrypt the encrypted generator data using a private key (i.e., known only by the recipient) paired to the public key used by the surgical hub **206** to encrypt the generator data. Notably, in such an aspect, the encrypted generator data can only be decrypted using the recipient's private key.

According to aspects of the present disclosure, components (e.g., surgical device/instrument **235**, energy device **241**, endoscope **239**) of the surgical system **202** are associated with unique identifiers, which can be in the form of serial numbers. As such, according to various aspects of the present disclosure, when a component is coupled to a surgical hub **206**, the component may establish a shared secret with the surgical hub **206** using the unique identifier of the coupled component as the shared secret. Further, in such an aspect, the component may derive a checksum value by applying a checksum function/algorithm to the unique identifier and/or other data being communicated to the surgical hub **206**. Here, the checksum function/algorithm is configured to output a significantly different checksum value if there is a modification to the underlying data.

In one aspect, the component may initially encrypt the unique identifier of a coupled component using a public key associated with the surgical hub (e.g., received by the component from the surgical hub **206** upon/after connection) and communicate the encrypted unique identifier to the surgical hub **206**. In other aspects, the component may encrypt the unique identifier and the derived checksum value of a coupled component using a public key associated with the surgical hub **206** and communicate the encrypted unique identifier and linked/associated checksum value to the surgical hub **206**.

In yet other aspects, the component may encrypt the unique identifier and a checksum function/algorithm using a public key associated with the surgical hub **206** and communicate the encrypted unique identifier and the checksum function/algorithm to the surgical hub **206**. In such aspects, the surgical hub **206** would then decrypt the encrypted unique identifier or the encrypted unique identifier and the linked/associated checksum value or the encrypted unique identifier and the checksum function/algorithm using a private key (i.e., known only by the surgical hub **206**) paired to the public key used by the component to encrypt the unique identifier.

Since the encrypted unique identifier can only be decrypted using the surgical hub's **206** private key and the private key is only known by the surgical hub, this is a secure way to communicate a shared secret (e.g., the unique identifier of the coupled component) to the surgical hub **206**. Further, in aspects where a checksum value is linked to/associated with the unique identifier, the surgical hub **206** may apply the same checksum function/algorithm to the decrypted unique identifier to generate a validating checksum value. If the validating checksum value matches the decrypted checksum value, the integrity of the decrypted unique identifier is further verified. Further, in such aspects, with a shared secret established, the component can encrypt future communications to the surgical hub **206**, and the surgical hub **206** can decrypt the future communications from the component using the shared secret (e.g., the unique identifier of the coupled component). Here, according to various aspects, a checksum value may be derived for and communicated with each communication between the component and the surgical hub **206** (e.g., the checksum value based on the communicated data or at least a designated portion thereof). Here, a checksum function/algorithm (e.g., known by the surgical hub **206** and/or component or communicated when establishing the shared secret between the surgical hub **206** and the component as described above) may be used to generate validating checksum values for comparison with communicated checksum values to further verify the integrity of communicated data in each communication.

Notably, asymmetric encryption algorithms may be complex and may require significant computational resources to execute each communication. As such, establishing the unique identifier of the coupled component as the shared secret is not only quicker (e.g., no need to generate a shared secret using a pseudorandom key generator) but also increases computational efficiency (e.g., enables the execution of faster, less complex symmetric encryption algorithms) for all subsequent communications. In various aspects, this established shared secret may be utilized by the component and surgical hub **206** until the component is decoupled from the surgical hub (e.g., surgical procedure ended).

According to other aspects of the present disclosure, components (e.g., surgical device/instrument **235**, energy device **241**, endoscope **239**) of the surgical system **202** may comprise sub-components (e.g., handle, shaft, end effector, cartridge) each associated with its own unique identifier. As such, according to various aspects of the present disclosure, when a component is coupled to the surgical hub **206**, the component may establish a shared secret with the surgical hub **206** using a unique compilation/string (e.g., ordered or random) of the unique identifiers associated with the sub-components that combine to form the coupled component. In one aspect, the component may initially encrypt the unique compilation/string of the coupled component using a public key associated with the surgical hub **206** and communicate the encrypted unique compilation/string to the surgical hub **206**. In such an aspect, the surgical hub **206** would then decrypt the encrypted unique compilation/string using a private key (i.e., known only by the surgical hub **206**) paired to the public key used by the component to encrypt the unique compilation/string. Since the encrypted unique compilation/string can only be decrypted using the surgical hub's **206** private key and the private key is only known by the surgical hub **206**, this is a secure way to communicate a shared secret (e.g., the unique compilation/string of the coupled component) to the surgical hub **206**. Further, in such an aspect, with a shared secret established, the component can encrypt future communications to the surgical hub **206**, and the surgical hub **206** can decrypt the future communications from the component using the shared secret (e.g., the unique compilation/string of the coupled component).

Again, asymmetric encryption algorithms may be complex and may require significant computational resources to execute each communication. As such, establishing the unique compilation/string of the coupled component (i.e., readily combinable by the component) as the shared secret is not only quicker (e.g., no need to generate a shared secret using a pseudorandom key generator) but also increases computational efficiency (e.g., enables the execution of faster, less complex symmetric encryption algorithms) for all subsequent communications. In various aspects, this established shared secret may be utilized by the component and surgical hub **206** until the component is decoupled from the surgical hub **206** (e.g., surgical procedure ended). Furthermore, in such an aspect, since various sub-components may be reusable (e.g., handle, shaft, end effector) while other sub-components may not be reusable (e.g., end effector, cartridge) each new combination of sub-components that combine to form the coupled component provide a unique compilation/string usable as a shared secret for component communications to the surgical hub **206**.

According to further aspects of the present disclosure, components (e.g., surgical device/instrument **235**, energy device **241**, endoscope **239**) of the surgical system **202** are associated with unique identifiers. As such, according to various aspects of the present disclosure, when a component is coupled to the surgical hub **206**, the surgical hub **206** may establish a shared secret with a recipient (e.g., cloud-based system **205**) using the unique identifier of the coupled component. In one aspect, the surgical hub **206** may initially encrypt the unique identifier of a coupled component using a public key associated with the recipient and communicate the encrypted unique identifier to the recipient. In such an aspect, the recipient would then decrypt the encrypted unique identifier using a private key (i.e., known only by the recipient) paired to the public key used by the surgical hub **206** to encrypt the unique identifier. Since the encrypted unique identifier can only be decrypted using the recipient's private key and the private key is only known by the recipient, this is a secure way to communicate a shared secret (e.g., the unique identifier of the coupled component) to the recipient (e.g., cloud-based system). Further in such an aspect, with a shared secret established, the surgical hub **206** can encrypt future communications to the recipient (e.g., cloud-based system **205**), and the recipient can decrypt the future communications from the surgical hub **206** using the shared secret (e.g., the unique identifier of the coupled component).

Notably, asymmetric encryption algorithms may be complex and may require significant computational resources to execute each communication. As such, establishing the unique identifier of the coupled component (i.e., already available to the surgical hub **206**) as the shared secret is not only quicker (e.g., no need to generate a shared secret using a pseudorandom key generator) but also increases computational efficiency by, for example, enabling the execution of faster, less complex symmetric encryption algorithms for all subsequent communications. In various aspects, this established shared secret may be utilized by the surgical hub **206** until the component is decoupled from the surgical hub (e.g., surgical procedure ended).

According to yet further aspects of the present disclosure, components (e.g., surgical device/instrument **235**, energy device **241**, endoscope **239**) of the surgical system **202** may comprise sub-components (e.g., handle, shaft, end effector, cartridge) each associated with its own unique identifier. As such, according to various aspects of the present disclosure, when a component is coupled to the surgical hub **206**, the surgical hub **206** may establish a shared secret with a recipient (e.g., cloud-based system **205**) using a unique compilation/string (e.g., ordered or random) of the unique identifiers associated with the sub-components that combine to form the coupled component.

In one aspect, the surgical hub **206** may initially encrypt the unique compilation/string of the coupled component using a public key associated with the recipient and communicate the encrypted unique compilation/string to the recipient. In such an aspect, the recipient would then decrypt the encrypted unique compilation/string using a private key (i.e., known only by the recipient) paired to the public key used by the surgical hub **206** to encrypt the unique compilation/string. Since the encrypted unique compilation/string can only be decrypted using the recipient's private key and the private key is only known by the recipient, this is a secure way to communicate a shared secret (e.g., the unique compilation/string of the coupled component) to the recipient. With a shared secret established, the surgical hub **206** can encrypt future communications to the recipient (e.g., cloud-based system **205**), and the recipient can decrypt the future communications from the surgical hub **206** using the shared secret (e.g., the unique compilation/string of the coupled component). Again, asymmetric encryption algorithms may be complex and may require significant computational resources to execute each communication. As such, establishing the unique compilation/string of the coupled component (i.e., readily combinable by the surgical hub **206**) as the shared secret is not only quicker (e.g., no need to generate a shared secret using a pseudorandom key generator) but also increases computational efficiency (e.g., enables the execution of faster, less complex symmetric encryption algorithms) for all subsequent communications.

In various aspects, this established shared secret may be utilized by the surgical hub **206** until the component is decoupled from the surgical hub (e.g., surgical procedure ended). Furthermore, in such an aspect, since various sub-components may be reusable (e.g., handle, shaft, end effector) while other sub-components may not be reusable (e.g., end effector, cartridge) each new combination of sub-components that combine to form the coupled component provide a unique compilation/string usable as a shared secret for surgical hub **206** communications to the recipient.

In some aspects, an encrypt-then-MAC (EtM) approach may be utilized to produce the encrypted generator data. An example of this approach is shown in FIG. **25**, where the non-encrypted generator data (i.e., the plaintext **3742**, e.g., data packet **3722**) is first encrypted **3743** (e.g., via key **3746**) to produce a ciphertext **3744** (i.e., the encrypted generator data), then a MAC **3745** is produced based on the resulting ciphertext **3744**, the key **3746**, and a MAC algorithm (e.g., a hash function **3747**). More specifically, the ciphertext **3744** is processed through the MAC algorithm using the key **3746**. In one aspect similar to symmetric encryption discussed herein, the key **3746** is a secret key accessible/known by the surgical hub **206** and the recipient (e.g., cloud-based system **205**). In such an aspect, the secret key is a shared secret associated with/chosen by the surgical hub **206**, a shared secret associated with/chosen by the recipient, or a key selected via a pseudorandom key generator. For this approach, as shown generally at **3748**, the encrypted generator data (i.e., the ciphertext **3744**) and the MAC **3745** would be communicated together to the cloud-based system **205**.

In other aspects, an encrypt-and-MAC (E&M) approach may be utilized to produce the encrypted generator data. An example of this approach is shown in FIG. **26**, where the MAC **3755** is produced based on the non-encrypted generator data (i.e., the plaintext **3752**, e.g., data packet **3722**), a key **3756**, and a MAC algorithm (e.g., a hash function **3757**). More specifically, the plaintext **3752** is processed through the MAC algorithm using the key **3756**. In one aspect similar to symmetric encryption discussed herein, the key **3756** is a secret key accessible/known by the surgical hub **206** and the recipient (e.g., cloud-based system **205**). In such an aspect, the secret key is a shared secret associated with/chosen by the surgical hub **206**, a shared secret associated with/chosen by the recipient, or a key selected via a pseudorandom key generator. Further, in such an aspect, the non-encrypted generator data (i.e., the plaintext **3752**, e.g., data packet **3722**) is encrypted **3753** (e.g., via key **3756**) to produce a ciphertext **3754**. For this approach, as shown generally at **3758**, the MAC **3755** (i.e., produced based on the non-encrypted generator data) and the encrypted generator data (i.e., the ciphertext **3754**) would be communicated together to the cloud-based system **205**.

In yet other aspects, a MAC-then-encrypt (MtE) approach may be utilized to produce the encrypted generator data. An example of this approach is shown in FIG. **27**, where the MAC **3765** is produced based on the non-encrypted generator data (i.e., the plaintext **3762**), a key **3766**, and a MAC algorithm (e.g., a hash function **3767**). More specifically, the plaintext **3762** is processed through the MAC algorithm using the key **3766**. In one aspect similar to symmetric encryption discussed herein, the key **3766** is a secret key accessible/known by the surgical hub **206** and the recipient (e.g., cloud-based system **205**). In such an aspect, the secret key is a shared secret associated with/chosen by the surgical hub **206**, a shared secret associated with/chosen by the recipient, or a key selected via a pseudorandom key generator. Next, the non-encrypted generator data (i.e., the plaintext **3762**) and the MAC **3765** are together encrypted **3763** (e.g., via key **3766**) to produce a ciphertext **3764** based on both. For this approach, as shown generally at **3768**, the ciphertext **3764** (i.e., which includes the encrypted generator data and the encrypted MAC **3765**) would be communicated to the cloud-based system **205**.

In alternative aspects, the key used to encrypt the non-encrypted generator data (e.g., FIG. **25** and FIG. **26**) or the non-encrypted generator data and the MAC (e.g., FIG. **27**) may be different from the key (e.g., keys **3746**, **3756**, **3766**) used to produce the MAC. For example, the key used to encrypt the non-encrypted generator data (e.g., FIG. **25** and FIG. **26**) or the non-encrypted generator data and the MAC (e.g., FIG. **27**) may be a different shared secret or a public key associated with the recipient.

In lieu of utilizing the MAC to provide for a subsequent assurance of data integrity to the cloud-based system **205**, according to other aspects, the surgical hub **206** can utilize a digital signature to allow the cloud-based system **205** to subsequently authenticate integrity of the communicated generator data. For example, the processor module **232** and/or the processor **244** of the computer system **210** can utilize one or more algorithms to generate a digital signature associated with the generator data, and the cloud-based system **205** can utilize an algorithm to determine the authenticity of the received generator data. The algorithms utilized by the processor module **232** and/or the processor **244** of the computer system **210** can include: (1) a key generation algorithm that selects a private key uniformly at random from a set of possible private keys, where the key generation algorithm outputs the private key and a corresponding public key; and (2) a signing algorithm that, given the generator data and a private key, produces a digital signature associated with the generator data. The cloud-based system **205** can utilize a signature verifying algorithm that, given the received generator data, public key, and digital signature, can accept the received generator data as authentic if the digital signature is determined to be authentic or consider the generator data to be compromised or altered if the digital signature is not determined to be authentic.

According to other aspects of the present disclosure, the surgical hub **206** can utilize a commercial authentication program (e.g., Secure Hash Algorithm, SHA-2 comprising SHA-256) to provide for a subsequent assurance of data integrity of the communicated generator data to the cloud-based system **205**.

After the generator data has been encrypted (e.g., via EtM, E&M, MtE), a component of the surgical hub **206** can communicate the encrypted generator data to the cloud-based system **205**. The component of the surgical hub **206** which communicates the encrypted generator data to the cloud-based system **205** can be, for example, the processor module **232**, a hub/switch **207**/**209** of the modular communication hub **203**, the router **211** of the modular communication hub **203**, the communication module **247** of the computer system **210**, etc.

According to various aspects, the communication of the encrypted generator data through the Internet can follow an IP which: (1) defines datagrams that encapsulate the encrypted generator data to be delivered and/or (2) defines addressing methods that are used to label the datagram with source and destination information. A high-level representation of an example datagram **3770** is shown in FIG. **28**, where the datagram **3770** includes a header **3772** and a payload **3774**, and in other aspects also may include a trailer (not shown). A more detailed representation of an example datagram **3780** is shown in FIG. **29**, where the header **3782** can include fields for information such as, for example, the IP address of the source **3786** which is sending the datagram (e.g., the router **211** of the modular communication hub **203**), the IP address of the destination **3788** which is to receive the datagram (e.g., the cloud **204** and/or the remote server **213** associated with the cloud-based system **205**), a type of service designation (not shown), a header length **3790**, a payload length **3792**, and a checksum value **3794**. In such an aspect, the surgical hub **206** may further apply a checksum function/algorithm to the non-encrypted generator data (i.e., the plaintext **3742**, e.g., data packet **3722**) or at least a portion of the non-encrypted generator data (e.g., combination generator ID **3726**) to derive the checksum value **3794**. Here, the checksum function/algorithm is configured to output a significantly different checksum value if there is any modification (e.g., even a slight change) to the underlying data (e.g., generator data). After decryption of the encrypted generator data by its recipient (e.g., cloud-based system **205**), the recipient may apply the same checksum function/algorithm to the decrypted generator data to generate a validating checksum value. If the validating checksum value matches the checksum value **3794** (i.e., stored in the header **3782** of the received datagram **3780**), the integrity of the received generator data is further verified. The payload **3784** may include the encrypted generator data **3796** and can also include padding **3798** if the encrypted generator data **3796** is less than a specified payload length. Notably, the communicated encrypted generator data **3796** may comprise a MAC as discussed in FIGS. **25**, **26**, and **27** above (e.g., references **3748**, **3758**, and **3768**, respectively). In some aspects, the header **3782** can further include a specific path the datagram is to follow when the datagram is communicated from the surgical hub **206** to the cloud-based system **205** (e.g., from IP address of the source, to IP address of at least one intermediate network component (e.g., specified routers, specified servers), to IP address of the destination).

According to various aspects, prior to the generator data being encrypted, the generator data can be time-stamped (if not already time-stamped by the combination generator **3700**) and/or the generator data can be compressed (if not already compressed by the combination generator **3700**). Time-stamping allows for the cloud-based system **205** to correlate the generator data with other data (e.g., stripped patient data) which may be communicated to the cloud-based system **205**. The compression allows for a smaller representation of the generator data to be subsequently encrypted and communicated to the cloud-based system **205**. For the compression, a component of the surgical hub **206** can utilize a compression algorithm to convert a representation of the generator data to a smaller representation of the generator data, thereby allowing for a more efficient and economical encryption of the generator data (e.g., less data to encrypt utilizes less processing resources) and a more efficient and economical communication of the encrypted generator data (e.g., smaller representations of the generator data within the payload of the datagrams (e.g., FIGS. **28** and **29**) allow for more generator data to be included in a given datagram, for more generator data to be communicated within a given time period, and/or for generator data to be communicated with fewer communication resources). The component of the surgical hub **206** which utilizes/executes the compression algorithm can be, for example, the processor module **232**, the processor **244** of the computer system, and/or combinations thereof. The utilized/executed compression algorithm can be a lossless compression algorithm or a lossy compression algorithm.

Once the generator data and the MAC for a given datagram has been received at the cloud-based system **205** (e.g., FIG. **25**, reference **3748**; FIG. **26**, reference **3758**; and FIG. **27**, reference **3768**), the cloud-based system **205** can decrypt the encrypted generator data from the payload of the communicated datagram to realize the communicated generator data.

In one aspect, referring back to FIG. **25**, the recipient (e.g., cloud-based system **205**) may, similar to the surgical hub **206**, process the ciphertext **3744** through the same MAC algorithm using the same known/accessible secret key to produce an authenticating MAC. If the received MAC **3745** matches this authenticating MAC, the recipient (e.g., cloud-based system **205**) may safely assume that the ciphertext **3744** has not been altered and is from the surgical hub **206**. The recipient (e.g., cloud-based system **205**) may then decrypt the ciphertext **3744** (e.g., via key **3746**) to realize the plaintext **3742** (e.g., data packet comprising generator data).

In another aspect, referring back to FIG. **26**, the recipient (e.g., cloud-based system **205**) may decrypt the ciphertext **3754** (e.g., via key **3756**) to realize the plaintext **3752** (e.g., data packet comprising generator data). Next, similar to the surgical hub **206**, the recipient (e.g., cloud-based system **205**) may process the plaintext **3752** through the same MAC algorithm using the same known/accessible secret key to produce an authenticating MAC. If the received MAC **3755** matches this authenticating MAC, the recipient (e.g., cloud-based system **205**) may safely assume that the plaintext **3752** has not been altered and is from the surgical hub **206**.

In yet another aspect, referring back to FIG. **27**, the recipient (e.g., cloud-based system **205**) may decrypt the ciphertext **3764** (e.g., via key **3766**) to realize the plaintext **3762** (e.g., data packet comprising generator data) and the MAC **3765**. Next, similar to the surgical hub **206**, the recipient (e.g., cloud-based system **205**) may process the plaintext **3762** through the same MAC algorithm using the same known/accessible secret key to produce an authenticating MAC. If the received MAC **3765** matches this authenticating MAC, the recipient (e.g., cloud-based system **205**) may safely assume that the plaintext **3762** has not been altered and is from the surgical hub **206**.

In alternative aspects, the key used to encrypt the non-encrypted generator data (e.g., FIG. **25** and FIG. **26**) or the non-encrypted generator data and the MAC (e.g., FIG. **27**) may be different from the key (e.g., keys **3746**, **3756**, **3766**) used to produce the MAC. For example, the key used to encrypt the non-encrypted generator data (e.g., FIG. **25** and FIG. **26**) or the non-encrypted generator data and the MAC (e.g., FIG. **27**) may be a different shared secret or a public key associated with the recipient. In such aspects, referring to FIG. **25**, the recipient (e.g., cloud-based system **205**) may, after verifying the authenticating MAC via key **3746** (described above), then decrypt the ciphertext **3744** (e.g., via the different shared secret or private key associated with the recipient) to realize the plaintext **3742** (e.g., data packet comprising generator data). In such aspects, referring to FIG. **26**, the recipient may decrypt the ciphertext **3754** (e.g., via the different shared secret or private key associated with the recipient) to realize the plaintext **3752** (e.g., data packet comprising generator data), then verify the authenticating MAC via key **3756** (described above). In such aspects, referring to FIG. **27**, the recipient may decrypt the ciphertext **3764** (e.g., via the different shared secret or private key associated with the recipient) to realize the plaintext **3762** (e.g., data packet comprising generator data) and the MAC **3765**, then verify the authenticating MAC via key **3766** (described above).

In sum, referring to FIGS. **25-27**, if an authenticating MAC, as determined/calculated by the cloud-based system **205**, is the same as the MAC which was received with the datagram, the cloud-based system **205** can have confidence that the received generator data is authentic (i.e., it is the same as the generator data which was communicated by the surgical hub **206**) and that the data integrity of the communicated generator data has not been compromised or altered. As described above, the recipient may further apply the plaintext **3742**, **3752**, **3762**, or at least a portion thereof to the same checksum function/algorithm (i.e., used by the surgical hub **206**) to generate a validating checksum value to further verify the integrity of the generator data based on the checksum value stored in the header of the communicated datagram.

Additionally, based on the decrypted datagram, the IP address of the source (e.g., FIG. **29**, reference **3786**) which originally communicated the datagram to the cloud-based system **205** can be determined from the header of the communicated datagram. If the determined source is a recognized source, the cloud-based system **205** can have confidence that the generator data originated from a trusted source, thereby providing source authentication and even more assurance of the data integrity of the generator data. Furthermore, since each router the datagram passed through in route to the cloud-based system **205** includes its IP address with its forwarded communication, the cloud-based system **205** is able to trace back the path followed by the datagram and identify each router which handled the datagram. The ability to identify the respective routers can be helpful in instances where the content of the datagram received at the cloud-based system **205** is not the same as the content of the datagram as originally communicated by the surgical hub **206**. For aspects where the communication path was pre-specified and included in the header of the communicated datagram, the ability to identify the respective routers can allow for path validation and provide additional confidence of the authenticity of the received generator data.

Furthermore, according to various aspects, after authenticating the received generator data, the cloud-based system **205** can communicate a message (e.g., a handshake or similar message) to the surgical hub **206** via the Internet or another communication network, confirming/guaranteeing that the datagram communicated from the surgical hub **206** was received intact by the cloud-based system **205**, thereby effectively closing the loop for that particular datagram.

Aspects of the above-described communication method, and/or variations thereof, can also be employed to communicate data other than generator data to the cloud-based system **205** and/or to communicate generator data and/or other data from the surgical hub **206** to systems and/or devices other than the cloud-based system **205**. For example, according to various aspects, the generator data and/or other data can be communicated from the surgical hub **206** to a hand-held surgical device/instrument (e.g., wireless device/instrument **235**), to a robotic interface of a surgical device/instrument (e.g., robot hub **222**) and/or to other servers, including servers (e.g., similar to server **213**) associated with other cloud-based systems (e.g., similar to cloud-based system **205**) in accordance with the above-described communication method. For example, in certain instances, an EEPROM chip of a given surgical instrument can initially be provided with merely an electronic chip device ID. Upon connection of the given surgical instrument to the combination generator **3700**, data can be downloaded from the cloud-based system **205** to the surgical hub **206** and subsequently to the EEPROM of the surgical instrument in accordance with the above-described communication method.

In addition to communicating generator data to the cloud-based system **205**, the surgical hub **206** can also utilize the above-described method of communication, and/or variations thereof, to communicate data other than generator data to the cloud-based system **205**. For example, the surgical hub **206** can also communicate other information associated with the surgical procedure to the cloud-based system **205**. Such other information can include, for example, the type of surgical procedure being performed, the name of the facility where the surgical procedure is being performed, the location of the facility where the surgical procedure is being performed, an identification of the operating room within the facility where the surgical procedure is being performed, the name of the surgeon performing the surgical procedure, the age of the patient, and data associated with the condition of the patient (e.g., blood pressure, heart rate, current medications). According to various aspects, such other information may be stripped of all information which could identify the specific surgery, the patient, or the surgeon, so that the information is essentially anonymized for further processing and analysis by the cloud-based system **205**. In other words, the stripped data is not correlated to a specific surgery, patient, or surgeon. The stripped information can be communicated to the cloud-based system **205** either together with or distinct from the communicated generator data.

For instances where the stripped/other data is to be communicated apart from the generator data, the stripped/other data can be time-stamped, compressed, and/or encrypted in a manner identical to or different from that described above regarding the generator data, and the surgical hub **206** may be programmed/configured to generate a datagram which includes the encrypted stripped/other information in lieu of the encrypted generator data. The datagram can then be communicated from the surgical hub **206** through the Internet to the cloud-based system **205** following an IP which: (1) defines datagrams that encapsulate the encrypted stripped/other data to be delivered, and (2) defines addressing methods that are used to label the datagram with source and destination information.

For instances where the stripped/other information is to be communicated with the generator data, the stripped/other data can be time-stamped, compressed, and/or encrypted in a manner identical to or different from that described above regarding the generator data, and the surgical hub **206** may be programmed/configured to generate a datagram which includes both the encrypted generator data and the encrypted stripped/other information. An example of such a datagram in shown in FIG. **30**, where the payload **3804** of the datagram **3800** is divided into two or more distinct payload data portions (e.g., one for the encrypted generator data **3834**, one for the encrypted stripped/other information **3836**), with each portion having an identifying bit (e.g., generator data (GD) **3806**, other data (OD) **3812**), the associated encrypted data **3808**, **3814**, and the associated padding **3810**, **3816**, if needed, respectively. Further, as shown in FIG. **30**, the header **3802** may be the same as (e.g., IP address source **3818**, IP address destination **3820**, header length **3822**) or different from the header **3782** described with reference to the datagram **3780** shown in FIG. **29**. For example, the header **3802** may be different in that the header **3802** further includes a field designating the number of payload data portions **3824** (e.g., 2) included in the payload **3804** of the datagram **3800**. The header **3802** can also be different in that it can include fields designating the payload length **3826**, **3830** and the checksum value **3828**, **2832** for each payload data portion **3834**, **3836**, respectively. Although only two payload data portions are shown in FIG. **30**, it will be appreciated that the payload **3804** of the datagram **3800** may include any quantity/number of payload data portions (e.g., 1, 2, 3, 4, 5), where each payload data portion includes data associated with a different aspect of the surgical procedure. The datagram **3800** can then be communicated from the surgical hub **206** through the Internet to the cloud-based system **205** following an IP which: (1) defines datagrams that encapsulate the encrypted generator data and the encrypted stripped/other data to be delivered, and (2) defines addressing methods that are used to label the datagram with source and destination information.

As set forth above, it is an unfortunate reality that the outcomes of all surgical procedures are not always optimal and/or successful. For instances where a failure event is detected and/or identified, a variation of the above-described communication methods can be utilized to isolate surgical data which is associated with the failure event (e.g., failure event surgical data) from surgical data which is not associated with the failure event (e.g., non-failure event surgical data) and communicate the surgical data which is associated with the failure event (e.g., failure event data) from the surgical hub **206** to the cloud-based system **205** on a prioritized basis for analysis. According to one aspect of the present disclosure, failure event surgical data is communicated from the surgical hub **206** to the cloud-based system **205** on a prioritized basis relative to non-failure event surgical data.

FIG. **31** illustrates various aspects of a system-implemented method of identifying surgical data associated with a failure event (e.g., failure event surgical data) and communicating the identified surgical data to a cloud-based system **205** on a prioritized basis. The method comprises (1) receiving **3838** surgical data at a surgical hub **206**, wherein the surgical data is associated with a surgical procedure; (2) time-stamping **3840** the surgical data; (3) identifying **3842** a failure event associated with the surgical procedure; (4) determining **3844** which of the surgical data is associated with the failure event (e.g., failure event surgical data); (5) separating **3846** the surgical data associated with the failure event from all other surgical data (e.g., non-failure event surgical data) received at the surgical hub **206**; (6) chronologizing **3848** the surgical data associated with the failure event; (7) encrypting **3850** the surgical data associated with the failure event; and (8) communicating **3852** the encrypted surgical data to a cloud-based system **205** on a prioritized basis.

More specifically, various surgical data can be captured during a surgical procedure and the captured surgical data, as well as other surgical data associated with the surgical procedure, can be communicated to the surgical hub **206**. The surgical data can include, for example, data associated with a surgical device/instrument (e.g., FIG. **9**, surgical device/instrument **235**) utilized during the surgery, data associated with the patient, data associated with the facility where the surgical procedure was performed, and data associated with the surgeon. Either prior to or subsequent to the surgical data being communicated to and received by the surgical hub **206**, the surgical data can be time-stamped and/or stripped of all information which could identify the specific surgery, the patient, or the surgeon, so that the information is essentially anonymized for further processing and analysis by the cloud-based system **205**.

Once a failure event has been detected and/or identified (e.g., which can be either during or after the surgical procedure), the surgical hub **206** can determine which of the surgical data is associated with the failure event (e.g., failure event surgical data) and which of the surgical data is not associated with the surgical event (e.g., non-failure event surgical data). According to one aspect of the present disclosure, a failure event can include, for example, a detection of one or more misfired staples during a stapling portion of a surgical procedure. For example, in one aspect, referring to FIG. **9**, an endoscope **239** may take snapshots while a surgical device/instrument **235** comprising an end effector including a staple cartridge performs a stapling portion of a surgical procedure. In such an aspect, an imaging module **238** may compare the snapshots to stored images and/or images downloaded from the cloud-based system **205** that convey correctly fired staples to detect a misfired staple and/or evidence of a misfired staple (e.g., a leak). In another aspect, the imaging module **238** may analyze the snapshots themselves to detect a misfired staple and/or evidence of a misfired staple. In one alternative aspect, the surgical hub **206** may communicate the snapshots to the cloud-based system **205**, and a component of the cloud-based system **205** may perform the various imaging module functions described above to detect a misfired staple and/or evidence of a misfired staple and to report the detection to the surgical hub **206**. According to another aspect of the present disclosure, a failure event can include a detection of a tissue temperature which is below the expected temperature during a tissue-sealing portion of a surgical procedure and/or a visual indication of excessive bleeding or oozing following a surgical procedure (e.g., FIG. **9**, via endoscope **239**). For example, in one aspect, referring to FIG. **9**, the surgical device/instrument **235** may comprise an end effector, including a temperature sensor and the surgical hub **206**, and/or the cloud-based system may compare at least one temperature detected by the temperature sensor (e.g., during a tissue-sealing portion of a surgical procedure) to a stored temperature and/or a range of temperatures expected and/or associated with that surgical procedure to detect an inadequate/low sealing temperature. In another aspect, an endoscope **239** may take snapshots during a surgical procedure. In such an aspect, an imaging module **238** may compare the snapshots to stored images and/or images downloaded from the cloud-based system **205** that convey tissue correctly sealed at expected temperatures to detect evidence of an improper/insufficient sealing temperature (e.g., charring, oozing/bleeding). Further, in such an aspect, the imaging module **238** may analyze the snapshots themselves to detect evidence of an improper/insufficient sealing temperature (e.g., charring, oozing/bleeding). In one alternative aspect, the surgical hub **206** may communicate the snapshots to the cloud-based system **205**, and a component of the cloud-based system **205** may perform the various imaging module functions described above to detect evidence of an improper/insufficient sealing temperature and to report the detection to the surgical hub **206**. According to the various aspects described above, in response to the detected and/or identified failure event, the surgical hub **206** may download a program from the cloud-based system **205** for execution by the surgical device/instrument **235** that corrects the detected issue (i.e., program that alters surgical device/instrument parameters to prevent misfired staples, program that alters surgical device/instrument parameters to ensure correct sealing temperature).

In some aspects, a failure event is deemed to cover a certain time period, and all surgical data associated with that certain time period can be deemed to be associated with the failure event.

After the surgical data associated with the failure event has been identified, the identified surgical data (e.g., failure event surgical data) can be separated or isolated from all of the other surgical data associated with the surgical procedure (e.g., non-failure event surgical data). The separation can be realized, for example, by tagging or flagging the identified surgical data, by storing the identified surgical data apart from all of the other surgical data associated with the surgical procedure, or by storing only the other surgical data while continuing to process the identified surgical data for subsequent prioritized communication to the cloud-based system **205**. According to various aspects, the tagging or flagging of the identified surgical data can occur during the communication process when the datagram is generated as described in more detail below.

The time-stamping of all of the surgical data (e.g., either before or after the surgical data is received at the surgical hub) can be utilized by a component of the surgical hub **206** to chronologize the identified surgical data associated with the failure event. The component of the surgical hub **206** which utilizes the time-stamping to chronologize the identified surgical data can be, for example, the processor module **232**, the processor **244** of the computer system **210**, and/or combinations thereof. By chronologizing the identified surgical data, the cloud-based system **205** and/or other interested parties can subsequently better understand the conditions which were present leading up to the occurrence of the failure event and possibly pinpoint the exact cause of the failure event, thereby providing the knowledge to potentially mitigate a similar failure event from occurring during a similar surgical procedure performed at a future date.

Once the identified surgical data has been chronologized, the chronologized surgical data may be encrypted in a manner similar to that described above with respect to the encryption of the generator data. Thus, the identified surgical data can be encrypted to help ensure the confidentiality of the identified surgical data, either while it is being stored at the surgical hub **206** or while it is being transmitted to the cloud-based system **205** using the Internet or other computer networks. According to various aspects, a component of the surgical hub **206** utilizes an encryption algorithm to convert the identified surgical data from a readable version to an encoded version, thereby forming the encrypted surgical data associated with the failure event (e.g., FIGS. **25-27**). The component of the surgical hub which utilizes the encryption algorithm can be, for example, the processor module **232**, the processor **244** of the computer system **210**, and/or combinations thereof. The utilized encryption algorithm can be a symmetric encryption algorithm or an asymmetric encryption algorithm.

After the identified surgical data has been encrypted, a component of the surgical hub can communicate the encrypted surgical data associated with the failure event (e.g., encrypted failure event surgical data) to the cloud-based system **205**. The component of the surgical hub which communicates the encrypted surgical data to the cloud-based system **205** can be, for example, the processor module **232**, a hub/switch **207**/**209** of the modular communication hub **203**, the router **211** of the modular communication hub **203**, or the communication module **247** of the computer system **210**. According to various aspects, the communication of the encrypted surgical data (e.g., encrypted failure event surgical data) through the Internet can follow an IP which: (1) defines datagrams that encapsulate the encrypted surgical data to be delivered, and (2) defines addressing methods that are used to label the datagram with source and destination information. The datagram can be similar to the datagram shown in FIG. **29** or the datagram shown in FIG. **30**, but can be different in that either the header or the payload of the datagram can include a field which includes a flag or a tag which identifies the encrypted surgical data (e.g., encrypted failure event surgical data) as being prioritized relative to other non-prioritized surgical data (e.g., encrypted non-failure event surgical data). An example of such a datagram is shown in FIG. **32**, where the payload **3864** of the datagram **3860** includes a field which indicates (e.g., a prioritized designation **3834**) that the payload **3864** includes prioritized surgical data (e.g., combination generator data **3868**). According to various aspects, the payload **3864** of the datagram **3860** can also include non-flagged/non-tagged/non-prioritized surgical data **3836** (e.g., other surgical data **3874**) as shown in FIG. **32**.

According to various aspects, prior to the identified surgical data (e.g., failure event surgical data) being encrypted, the identified surgical data can be compressed (if not already compressed by the source(s) of the relevant surgical data). The compression allows for a smaller representation of the surgical data associated with the failure event to be subsequently encrypted and communicated to the cloud-based system **205**. For the compression, a component of the surgical hub **206** can utilize a compression algorithm to convert a representation of the identified surgical data to a smaller representation of the identified surgical data, thereby allowing for a more efficient and economical encryption of the identified surgical data (less data to encrypt utilizes less processing resources) and a more efficient and economical communication of the encrypted surgical data (smaller representations of the surgical data within the payload of the datagrams allow for more identified surgical data to be included in a given datagram, for more identified surgical data to be communicated within a given time period, and/or for identified surgical data to be communicated with fewer communication resources). The component of the surgical hub **206** which utilizes the compression algorithm can be, for example, the processor module **232**, the processor **244** of the computer system **210**, and/or combinations thereof. The utilized compression algorithm can be a lossless compression algorithm or a lossy compression algorithm.

In instances where other non-prioritized surgical data (e.g., non-failure event surgical data) is to be communicated with prioritized surgical data (e.g., failure event surgical data), the other non-prioritized surgical data can be time-stamped, compressed, and/or encrypted in a manner identical to or different from that described above regarding the surgical data identified as associated with a failure event (e.g., failure event surgical data), and the surgical hub **206** may be programmed/configured to generate a datagram which includes both the encrypted prioritized surgical data (e.g., encrypted failure event surgical data) and the encrypted other non-prioritized surgical data (e.g., encrypted non-failure event surgical data). For example, in light of FIG. **32**, the payload **3864** of the datagram **3860** may be divided into two or more distinct payload data portions (e.g., one for the prioritized surgical data **3834**, one for the non-prioritized surgical data **3836**), with each portion having an identifying bit (e.g., generator data (GD) **3866**, other data (OD) **3872**), the associated encrypted data (e.g., encrypted prioritized surgical data **3868**, encrypted non-prioritized surgical data **3874**), and the associated padding **3870**, **3876**, if needed, respectively. Further, similar to FIG. **30**, the header **3862** may be the same as (e.g., IP address source **3878**, IP address destination **3880**, header length **3882**) or different from the header **3782** described with reference to the datagram **3780** shown in FIG. **29**. For example, the header **3862** may be different in that the header **3862** further includes a field designating the number of payload data portions **3884** (e.g., 2) included in the payload **3864** of the datagram **3860**. The header **3862** can also be different in that it can include fields designating the payload length **3886**, **3890** and the checksum value **3888**, **2892** for each payload data portion **3834**, **3836**, respectively. Although only two payload data portions are shown in FIG. **32**, it will be appreciated that the payload **3864** of the datagram **3860** may include any quantity/number of payload data portions (e.g., 1, 2, 3, 4, 5), where each payload data portion includes data associated with a different aspect of the surgical procedure. The datagram **3860** can then be communicated from the surgical hub **206** through the Internet to the cloud-based system **205** following an IP which: (1) defines datagrams that encapsulate the encrypted generator data and the encrypted stripped/other data to be delivered, and (2) defines addressing methods that are used to label the datagram with source and destination information.

In some aspects, once a failure event associated with a surgical procedure has been identified, the surgical hub **206** and/or the cloud-based system **205** can subsequently flag or tag a surgical device/instrument **235** which was utilized during the surgical procedure for inoperability and/or removal. For example, in one aspect, information (e.g., serial number, ID) associated with the surgical device/instrument **235** and stored at the surgical hub **206** and/or the cloud-based system **205** can be utilized to effectively block the surgical device/instrument **235** from being used again (e.g., blacklisted). In another aspect, information (e.g., serial number, ID) associated with the surgical device/instrument can initiate the printing of a shipping slip and shipping instructions for returning the surgical device/instrument **235** back to a manufacturer or other designated party so that a thorough analysis/inspection of the surgical device/instrument **235** can be performed (e.g., to determine the cause of the failure). According to various aspects described herein, once the cause of a failure is determined (e.g., via the surgical hub **206** and/or the cloud-based system **205**), the surgical hub **206** may download a program from the cloud-based system **205** for execution by the surgical device/instrument **235** that corrects the determined cause of the failure (i.e., program that alters surgical device/instrument parameters to prevent the failure from occurring again).

According to some aspects, the surgical hub **206** and/or the cloud-based system **205** can also provide/display a reminder (e.g., via hub display **215** and/or surgical device/instrument display **237**) to administrators, staff, and/or other personnel to physically remove the surgical device/instrument **235** from the operating room (e.g., if detected as still present in the operating room) and/or to send the surgical device/instrument **235** to the manufacturer or the other designated party. In one aspect, the reminder may be set up to be provided/displayed periodically until an administrator can remove the flag or tag of the surgical device/instrument **235** from the surgical hub **206** and/or the cloud-based system **205**. According to various aspects, an administrator may remove the flag or tag once the administrator can confirm (e.g., system tracking of the surgical device/instrument **235** via its serial number/ID) that the surgical device/instrument **235** has been received by the manufacturer or the other designated party. By using the above-described method to flag and/or track surgical data associated with a failure event, a closed loop control of the surgical data associated with the failure event and/or with a surgical device/instrument **235** can be realized. Additionally, in view of the above, it will be appreciated that the surgical hub **206** can be utilized to effectively manage the utilization (or non-utilization) of surgical devices/instruments **235** which have or potentially could be utilized during a surgical procedure.

In various aspects of the present disclosure, the surgical hub **206** and/or cloud-based system **205** may want to control which components (e.g., surgical device/instrument **235**, energy device **241**) are being utilized in its interactive surgical system **100**/**200** to perform surgical procedures (e.g., to minimize future failure events, to avoid the use of unauthorized or knock-off components).

As such, in various aspects of the present disclosure, since an interactive surgical system **100** may comprise a plurality of surgical hubs **106**, a cloud-based system **105** and/or each surgical hub **106** of the interactive surgical system **100** may want to track component-surgical hub combinations utilized over time. In one aspect, upon/after a component (See FIG. **9**, e.g., surgical device/instrument **235**, energy device **241**) is connected to/used with a particular surgical hub **106** (e.g., surgical device/instrument **235** wired/wirelessly connected to the particular surgical hub **106**, energy device **241** connected to the particular surgical hub **106** via generator module **240**), the particular surgical hub **106** may communicate a record/block of that connection/use (e.g., linking respective unique identifiers of the connected devices) to the cloud-based system **105** and/or to the other surgical hubs **106** in the interactive surgical system **100**. For example, upon/after the connection/use of an energy device **241**, a particular surgical hub **106** may communicate a record/block (e.g., linking a unique identifier of the energy device **241** to a unique identifier of a generator module **240** to a unique identifier of the particular surgical hub **106**) to the cloud-based system **105** and/or other surgical hubs **106** in the interactive surgical system **100**. In such an aspect, if this is the first time the component (e.g., energy device) is connected to/used with a surgical hub **106** in the interactive surgical system **100**, the cloud-based system **105** and/or each surgical hub **106** of the interactive surgical system **100** may store the record/block as a genesis record/block. In such an aspect, the genesis record/block stored at the cloud-based system **105** and/or each surgical hub **106** may comprise a time stamp. However, in such an aspect, if this is not the first time the component (e.g., energy device **241**) has been connected to/used with a surgical hub **106** in the interactive surgical system **100**, the cloud-based system **105** and/or each surgical hub **106** of the interactive surgical system may store the record/block as a new record/block in a chain of record/blocks associated with the component. In such an aspect, the new record/block may comprise a cryptographic hash of the most recently communicated record/block stored at the cloud-based system **105** and/or each surgical hub **106**, the communicated linkage data, and a time stamp. In such an aspect, each cryptographic hash links each new record/block (e.g., each use of the component) to its prior record/block to form a chain confirming the integrity of each prior record/block(s) back to an original genesis record/block (e.g., first use of the component). According to such an aspect, this blockchain of records/blocks may be developed at the cloud-based system **105** and/or each surgical hub **106** of the interactive surgical system **100** to permanently and verifiably tie usage of a particular component to one or more than one surgical hub **106** in the interactive surgical system **100** over time. Here, according to another aspect, this approach may be similarly applied to sub-components (e.g., handle, shaft, end effector, cartridge) of a component when/after the component is connected to/used with a particular surgical hub **106** of an interactive surgical system **100**.

According to various aspects of the present disclosure, the cloud-based system **105** and/or each surgical hub **106** may utilize such records/blocks to trace usage of a particular component and/or a sub-component back to its initial usage in the interactive surgical system **100**. For example, if a particular component (e.g., surgical device/instrument **235**) is flagged/tagged as related to a failure event, the cloud-based system **105** and/or a surgical hub **106** may analyze such records/blocks to determine whether past usage of that component and/or a sub-component of that component contributed to or caused the failure event (e.g., overused). In one example, the cloud-based system **105** may determine that a sub-component (e.g., end effector) of that component may actually be contributing/causing the failure event and then tag/flag that component for inoperability and/or removal based on the determination.

According to another aspect, the cloud-based system **205** and/or surgical hub **206** may control which components (e.g., surgical device/instrument **235**, energy device **241**) are being utilized in an interactive surgical system **200** to perform surgical procedures by authenticating the component and/or its supplier/manufacturer. In one aspect, the supplier/manufacturer of a component may associate a serial number and a source ID with the component. In such an aspect, the supplier/manufacturer may create/generate a private key for the serial number, encrypt the serial number with the private key, and store the encrypted serial number and the source ID on an electronic chip (e.g., memory) in the component prior to shipment to a surgical site. Here, upon/after connection of the component to a surgical hub **206**, the surgical hub **206** may read the encrypted serial number and the source ID from the electronic chip. In response, the surgical hub **206** may send a message (i.e., comprising the encrypted serial number) to a server of the supplier/manufacturer associated with the source ID (e.g., directly or via the cloud-based system **205**). In such an aspect, the surgical hub **206** may encrypt the message using a public key associated with that supplier/manufacturer. In response, the surgical hub **206** may receive a message (i.e., comprising the private key the supplier/manufacturer generated for/associated with that encrypted serial number) from the supplier/manufacturer server (e.g., directly or via the cloud-based system **205**). In such an aspect, the supplier/manufacturer server may encrypt the message using a public key associated with the surgical hub **206**. Further, in such an aspect, the surgical hub **206** may then decrypt the message (e.g., using a private key paired to the public key used to encrypt the message) to reveal the private key associated with the encrypted serial number. The surgical hub **206** may then decrypt the encrypted serial number, using that private key, to reveal the serial number. Further, in such an aspect, the surgical hub **206** may then compare the decrypted serial number to a comprehensive list of authorized serial numbers (e.g., stored at the surgical hub **206** and/or the cloud-based system and/or downloaded from the cloud-based system, e.g., received separately from the supplier/manufacturer) and permit use of the connected component if the decrypted serial number matches an authorized serial number. Initially, such a process permits the surgical hub **206** to authenticate the supplier/manufacturer. In particular, the surgical hub **206** encrypted the message comprising the encrypted serial number using a public key associated with the supplier/manufacturer. As such, receiving a response message (i.e., comprising the private key) authenticates the supplier/manufacturer to the surgical hub **206** (i.e., otherwise the supplier/manufacturer would not have access to the private key paired to the public key used by the surgical hub **206** to encrypt the message, and the supplier/manufacturer would not have been able to associate the encrypted serial number received in the message to its already generated private key). Furthermore, such a process permits the surgical hub **206** to authenticate the connected component/device itself. In particular, the supplier/manufacturer (e.g., just authenticated) encrypted the serial number of the component using the delivered private key. Upon secure receipt of the private key, the surgical hub **206** is able to decrypt the encrypted serial number (i.e., read from the connected component), which authenticates the component and/or its association with the supplier/manufacturer (i.e., only that private key as received from that supplier/manufacturer would decrypt the encrypted serial number). Nonetheless, the surgical hub **206** further verifies the component as authentic (e.g., compares the decrypted serial number to a comprehensive list of authorized serial numbers received separately from the supplier/manufacturer). Notably, such aspects as described above can alternatively be performed by the cloud-based system **205** and/or a combination of the cloud-based system **205** and the surgical hub **206** to control which components (e.g., surgical device/instrument **235**, energy device **241**) are being utilized in an interactive surgical system **200** (e.g., to perform surgical procedures) by authenticating the component and/or its supplier/manufacturer. In one aspect, such described approaches may prevent the use of knock-off component(s) within the interactive surgical system **200** and ensure the safety and well-being of surgical patients.

According to another aspect, the electronic chip of a component (e.g., surgical device/instrument **235**, energy device **241**) may store (e.g., in memory) data associated with usage of that component (i.e., usage data, e.g., number of uses with a limited use device, number of uses remaining, firing algorithms executed, designation as a single-use component). In such an aspect, the surgical hub **206** and/or the cloud-based system **205**, upon/after connection of the component to the interactive surgical system, may read such usage data from the memory of a component and write back at least a portion of that usage data for storage (e.g., in memory **249**) at the surgical hub **206** and/or for storage at the cloud-based system **205** (e.g., individually and/or under a blockchain approach discussed herein). According to such an aspect, the surgical hub **206** and/or the cloud-based system **205**, upon/after a subsequent connection of that component to the interactive surgical system, may again read such usage data and compare that usage to previously stored usage data. Here, if a discrepancy exists or if a predetermined/authorized usage has been met, the surgical hub **206** and/or the cloud-based system **205** may prevent use of that component (e.g., blacklisted, rendered inoperable, flagged for removal) on the interactive surgical system **200**. In various aspects, such an approach prevents bypass of the encryption chip systems. If the component's electronic chip/memory has been tampered with (e.g., memory reset, number of uses altered, firing algorithms altered, single-use device designated as a multi-use device), a discrepancy will exist, and the component's use will be controlled/prevented.

Additional details are disclosed in U.S. Patent Application Publication No. 2017/0086914, entitled TECHNIQUES FOR OPERATING GENERATOR FOR DIGITALLY GENERATING ELECTRICAL SIGNAL WAVEFORMS AND SURGICAL INSTRUMENTS, which published on Mar. 30, 2017, which is incorporated herein by reference in its entirety.

Surgical Hub Coordination of Device Pairing in an Operating Room

One of the functions of the surgical hub **106** is to pair (also referred to herein as "connect" or "couple") with other components of the surgical system **102** to control, gather information from, or coordinate interactions between the components of the surgical system **102**. Since the operating rooms of a hospital are likely in close physical proximity to one another, a surgical hub **106** of a surgical system **102** may unknowingly pair with components of a surgical system **102** in a neighboring operating room, which would significantly interfere with the functions of the surgical hub **106**. For example, the surgical hub **106** may unintentionally activate a surgical instrument in a different operating room or record information from a different ongoing surgical procedure in a neighboring operating room.

Aspects of the present disclosure present a solution, wherein a surgical hub **106** only pairs with detected devices of the surgical system **102** that are located within the bounds of its operating room.

Furthermore, the surgical hub **106** relies on its knowledge of the location of other components of the surgical system **102** within its operating room in making decisions about, for example, which surgical instruments should be paired with one another or activated. A change in the position of the surgical hub **106** or another component of the surgical system **102** can be problematic.

Aspects of the present disclosure further present a solution wherein the surgical hub **106** is configured to reevaluate or redetermined the bounds of its operating room upon detecting that the surgical hub **106** has been moved. Aspects of the present disclosure further present a solution wherein the surgical hub **106** is configured to redetermined the bounds of its operating room upon detection of a potential device of the surgical system **102**, which can be an indication that the surgical hub **106** has been moved.

In various aspects, a surgical hub **106** is used with a surgical system **102** in a surgical procedure performed in an operating room. The surgical hub **106** comprises a control circuit configured to determine the bounds of the operating room, determine devices of the surgical system **102** located within the bounds of the operating room, and pair the surgical hub **106** with the devices of the surgical system **102** located within the bounds of the operating room.

In one aspect, the control circuit is configured to determine the bounds of the operating room after activation of the surgical hub **106**. In one aspect, the surgical hub **106** includes a communication circuit configured to detect and pair with the devices of the surgical system located within the bounds of the operating room. In one aspect, the control circuit is configured to redetermine the bounds of the operating room after a potential device of the surgical system **102** is detected. In one aspect, the control circuit is configured to periodically determine the bounds of the operating room.

In one aspect, the surgical hub **106** comprises an operating room mapping circuit that includes a plurality of non-contact sensors configured to measure the bounds of the operating room.

In various aspects, the surgical hub **106** includes a processor and a memory coupled to the processor. The memory stores instructions executable by the processor to pair the surgical hub with devices of the surgical system **102** located within the bounds of the operating room, as described above. In various aspects, the present disclosure provides a non-transitory computer-readable medium storing computer-readable instructions which, when executed, cause a machine to pair the surgical hub **106** with devices of the surgical system **102** located within the bounds of the operating room, as described above.

FIGS. **35** and **36** are logic flow diagrams of processes depicting control programs or logic configurations for pairing the surgical hub **106** with devices of the surgical system **102** located within the bounds of the operating room, as described above.

The surgical hub **106** performs a wide range of functions that requires short- and long-range communication, such as assisting in a surgical procedure, coordinating between devices of the surgical system **102**, and gathering and transmitting data to the cloud **104**. To properly perform its functions, the surgical hub **106** is equipped with a communication module **130** capable of short-range communication with other devices of the surgical system **102**. The communication module **130** is also capable of long-range communication with the cloud **104**.

The surgical hub **106** is also equipped with an operating-room mapping module **133** which is capable of identifying the bounds of an operating room, and identifying devices of the surgical system **102** within the operating room. The surgical hub **106** is configured to identify the bounds of an operating room, and only pair with or connect to potential devices of the surgical system **102** that are detected within the operating room.

In one aspect, the pairing comprises establishing a communication link or pathway. In another aspect, the pairing comprises establishing a control link or pathway.

An initial mapping or evaluation of the bounds of the operating room takes place during an initial activation of the surgical hub **106**. Furthermore, the surgical hub **106** is configured to maintain spatial awareness during operation by periodically mapping its operating room, which can be helpful in determining if the surgical hub **106** has been moved. The reevaluation **3017** can be performed periodically or it can be triggered by an event such as observing a change in the devices of the surgical system **102** that are deemed within the operating room. In one aspect, the change is detection **3010** of a new device that was not previously deemed as within the bounds of the operating room, as illustrated in FIG. **37**. In another aspect, the change is a disappearance, disconnection, or un-pairing of a paired device that was previously deemed as residing within the operating room, as illustrated in FIG. **38**. The surgical hub **106** may continuously monitor **3035** the connection with paired devices to detect **3034** the disappearance, disconnection, or un-pairing of a paired device.

In other aspects, reevaluation triggering events can be, for example, changes in surgeons' positions, instrument exchanges, or sensing of a new set of tasks being performed by the surgical hub **106**.

In one aspect, the evaluation of the bounds of the room by the surgical hub **106** is accomplished by activation of a sensor array of the operating-room mapping module **133** within the surgical hub **106** which enables it to detect the walls of the operating room.

Other components of the surgical system **102** can be made to be spatially aware in the same, or a similar, manner as the surgical hub **106**. For example, a robotic hub **122** may also be equipped with an operating-room mapping module **133**.

The spatial awareness of the surgical hub **106** and its ability to map an operating room for potential components of the surgical system **102** allows the surgical hub **106** to make autonomous decisions about whether to include or exclude such potential components as part of the surgical system **102**, which relieves the surgical staff from dealing with such tasks. Furthermore, the surgical hub **106** is configured to make inferences about, for example, the type of surgical procedure to be performed in the operating room based on information gathered prior to, during, and/or after the performance of the surgical procedure. Examples of gathered information include the types of devices that are brought into the operating room, time of introduction of such devices into the operating room, and/or the devices sequence of activation.

In one aspect, the surgical hub **106** employs the operating-room mapping module **133** to determine the bounds of the surgical theater (e.g., a fixed, mobile, or temporary operating room or space) using either ultrasonic or laser non-contact measurement devices.

Referring to FIG. **34**, ultrasound based non-contact sensors **3002** can be employed to scan the operating theater by transmitting a burst of ultrasound and receiving the echo when it bounces off a perimeter wall **3006** of an operating theater to determine the size of the operating theater and to adjust Bluetooth pairing distance limits. In one example, the non-contact sensors **3002** can be Ping ultrasonic distance sensors, as illustrated in FIG. **34**.

FIG. **34** shows how an ultrasonic sensor **3002** sends a brief chirp with its ultrasonic speaker **3003** and makes it possible for a micro-controller **3004** of the operating-room mapping module **133** to measure how long the echo takes to return to the ultrasonic sensor's ultrasonic microphone **3005**. The micro-controller **3004** has to send the ultrasonic sensor **3002** a pulse to begin the measurement. The ultrasonic sensor **3002** then waits long enough for the micro-controller program to start a pulse input command. Then, at about the same time the ultrasonic sensor **3002** chirps a 40 kHz tone, it sends a high signal to the micro-controller **3004**. When the ultrasonic sensor **3002** detects the echo with its ultrasonic microphone **3005**, it changes that high signal back to low. The micro-controller's pulse input command measures the time between the high and low changes and stores its measurement in a variable. This value can be used along with the speed of sound in air to calculate the distance between the surgical hub **106** and the operating-room wall **3006**.

In one example, as illustrated in FIG. **33**, a surgical hub **106** can be equipped with four ultrasonic sensors **3002**, wherein each of the four ultrasonic sensors is configured to assess the distance between the surgical hub **106** and a wall of the operating room **3000**. A surgical hub **106** can be equipped with more or less than four ultrasonic sensors **3002** to determine the bounds of an operating room.

Other distance sensors can be employed by the operating-room mapping module **133** to determine the bounds of an operating room. In one example, the operating-room mapping module **133** can be equipped with one or more photoelectric sensors that can be employed to assess the bounds of an operating room. In one example, suitable laser distance sensors can also be employed to assess the bounds of an operating room. Laser-based non-contact sensors may scan the operating theater by transmitting laser light pulses, receiving laser light pulses that bounce off the perimeter walls of the operating theater, and comparing the phase of the transmitted pulse to the received pulse to determine the size of the operating theater and to adjust Bluetooth pairing distance limits.

Referring to the top left corner of FIG. **33**, a surgical hub **106** is brought into an operating room **3000**. The surgical hub **106** is activated at the beginning of the set-up that occurs prior to the surgical procedure. In the example of FIG. **33**, the set-up starts at an actual time of 11:31:14 (EST) based on a real-time clock. However, at the stated procedure set-up start time, the surgical hub **106** starts **3001** an artificial randomized real-time clock timing scheme at artificial real time 07:36:00 to protect private patient information.

At artificial real time 07:36:01, the operating-room mapping module **133** employs the ultrasonic distance sensors to ultrasonically ping the room (e.g., sends out a burst of ultrasound and listens for the echo when it bounces off the perimeter walls of the operating room as described above) to verify the size of the operating room and to adjust pairing distance limits.

At artificial real time 07:36:03, the data is stripped and time-stamped. At artificial real time 07:36:05, the surgical hub **106** begins pairing devices located only within the operating room **3000** as verified using ultrasonic distance sensors **3002** of the operating-room mapping module **133**. The top right corner of FIG. **33** illustrates several example devices that are within the bounds of the operating room **3000** and are paired with the surgical hub **106**, including a secondary display device **3020**, a secondary hub **3021**, a common interface device **3022**, a powered stapler **3023**, a video tower module **3024**, and a powered handheld dissector

3025. On the other hand, secondary hub **3021'**, secondary display device **3020'**, and powered stapler **3026** are all outside the bounds of the operating room **3000** and, accordingly, are not paired with the surgical hub **106**.

In addition to establishing a communication link with the devices of the surgical system **102** that are within the operating room, the surgical hub **106** also assigns a unique identification and communication sequence or number to each of the devices. The unique sequence may include the device's name and a time stamp of when the communication was first established. Other suitable device information may also be incorporated into the unique sequence of the device.

As illustrated in the top left corner of FIG. **33**, the surgical hub **106** has determined that the operating room **3000** bounds are at distances a, −a, b, and −b from the surgical hub **106**. Since Device "D" is outside the determined bounds of its operating room **3000**, the surgical hub **106** will not pair with the Device "D." FIG. **35** is an example algorithm illustrating how the surgical hub **106** only pairs with devices within the bounds of its operating room. After activation, the surgical hub **106** determines **3007** bounds of the operating room using the operating-room mapping module **133**, as described above. After the initial determination, the surgical hub **106** continuously searches for or detects **3008** devices within a pairing range. If a device is detected **3010**, the surgical hub **106** then determines **3011** whether the detected device is within the bounds of the operating room. The surgical hub **106** pairs **3012** with the device if it is determined that the device is within the bounds of the operating room. In certain instances, the surgical hub **106** will also assign **3013** an identifier to the device. If, however, the surgical hub **106** determines that the detected device is outside the bounds of the operating room, the surgical hub **106** will ignore **3014** the device.

Referring to FIG. **36**, after an initial determination of the bounds of the room, and after an initial pairing of devices located within such bounds, the surgical hub **106** continues to detect **3015** new devices that become available for pairing. If a new device is detected **3016**, the surgical hub **106** is configured to reevaluate **3017** the bounds of the operating room prior to pairing with the new device. If the new device is determined **3018** to be within the newly determined bounds of the operating room, then the surgical hub **106** pairs with the device **3019** and assigns **3030** a unique identifier to the new device. If, however, the surgical hub **106** determines that the new device is outside the newly determined bounds of the operating room, the surgical hub **106** will ignore **3031** the device.

For pairing, the operating-room mapping module **133** contains a compass and integrated Bluetooth transceiver. Other communication mechanisms, which are not significantly affected by the hospital environment or geographical location, can be employed. Bluetooth Low Energy (BLE) beacon technology can currently achieve indoor distance measurements with accuracy of about 1-2 meters, with improved accuracy in closer proximities (within 0-6 meters). To improve the accuracy of the distance measurements, a compass is used with the BLE. The operating-room mapping module **133** utilizes the BLE and the compass to determine where modules are located in relation to the patient. For example, two modules facing each other (detected by compass) with greater than one meter distance between them may clearly indicate that the modules are on opposite sides of the patient. The more "Hub"-enabled modules that reside in the operating room, the greater the achievable accuracy becomes due to triangulation techniques.

In the situations where multiple surgical hubs **106**, modules, and/or other peripherals are present in the same operating room, as illustrated in the top right corner of FIG. **33**, the operating-room mapping module **133** is configured to map the physical location of each module that resides within the operating room. This information could be used by the user interface to display a virtual map of the room, enabling the user to more easily identify which modules are present and enabled, as well as their current status. In one aspect, the mapping data collected by surgical hubs **106** are uploaded to the cloud **104**, where the data are analyzed for identifying how an operating room is physically setup, for example.

The surgical hub **106** is configured to determine a device's location by assessing transmission radio signal strength and direction. For Bluetooth protocols, the Received Signal Strength Indication (RSSI) is a measurement of the received radio signal strength. In one aspect, the devices of the surgical system **102** can be equipped with USB Bluetooth dongles. The surgical hub **106** may scan the USB Bluetooth beacons to get distance information. In another aspect, multiple high-gain antennas on a Bluetooth access point with variable attenuators can produce more accurate results than RSSI measurements. In one aspect, the hub is configured to determine the location of a device by measuring the signal strength from multiple antennas. Alternatively, in some examples, the surgical hub **106** can be equipped with one or more motion sensor devices configured to detect a change in the position of the surgical hub **106**.

Referring to the bottom left corner of FIG. **33**, the surgical hub **106** has been moved from its original position, which is depicted in dashed lines, to a new position closer to the device "D," which is still outside the bounds of the operating room **3000**. The surgical hub **106** in its new position, and based on the previously determined bounds of the operating room, would naturally conclude that the device "D" is a potential component of the surgical system **102**. However, the introduction of a new device is a triggering event for reevaluation **3017** of the bounds of the operating room, as illustrated in the example algorithm of FIGS. **35**, **37**. After performing the reevaluation, the surgical hub **106** determines that the operating room bounds have changed. Based on the new bounds, at distances a_{new}, $-a_{new}$, b_{new}, and $-b_{new}$, the surgical hub **106** concludes that it has been moved and that the Device "D" is outside the newly determined bounds of its operating room. Accordingly, the surgical hub **106** will still not pair with the Device "D."

In one aspect, one or more of the processes depicted in FIGS. **35-39** can be executed by a control circuit of a surgical hub **106**, as depicted in FIG. **10** (processor **244**). In another aspect, one or more of the processes depicted in FIGS. **35-39** can be executed by a cloud computing system **104**, as depicted in FIG. **1**. In yet another aspect, one or more of the processes depicted in FIGS. **35-39** can be executed by at least one of the aforementioned cloud computing systems **104** and/or a control circuit of a surgical hub **106** in combination with a control circuit of a modular device, such as the microcontroller **461** of the surgical instrument depicted in FIG. **12**, the microcontroller **620** of the surgical instrument depicted in FIG. **16**, the control circuit **710** of the robotic surgical instrument **700** depicted in FIG. **17**, the control circuit **760** of the surgical instruments **750**, **790** depicted in FIGS. **18-19**, or the controller **838** of the generator **800** depicted in FIG. **20**.

Spatial Awareness of Surgical Hubs in Operating Rooms

During a surgical procedure, a surgical instrument such as an ultrasonic or an RF surgical instrument can be coupled to a generator module **140** of the surgical hub **106**. In addition, a separate surgical instrument controller such as a foot, or hand, switch or activation device can be used by an operator of the surgical instrument to activate the energy flow from the generator to the surgical instrument. Multiple surgical instrument controllers and multiple surgical instruments can be used concurrently in an operating room. Pressing or activating the wrong surgical instrument controller can lead to undesirable consequences. Aspects of the present disclosure present a solution in which the surgical hub **106** coordinates the pairing of surgical instrument controllers and surgical instruments to ensure patient and operator safety.

Aspects of the present disclosure are presented for a surgical hub **106** configured to establish and sever pairings between components of the surgical system **102** within the bounds of the operating room to coordinate flow of information and control actions between such components. The surgical hub **106** can be configured to establish a pairing between a surgical instrument controller and a surgical instrument that reside within the bounds of an operating room of surgical hub **106**.

In various aspects, the surgical hub **106** can be configured to establish and sever pairings between components of the surgical system **102** based on operator request or situational and/or spatial awareness. The hub situational awareness is described in greater detail below in connection with FIG. **62**.

Aspects of the present disclosure are presented for a surgical hub for use with a surgical system in a surgical procedure performed in an operating room. The surgical hub includes a control circuit that selectively forms and severs pairings between devices of the surgical system. In one aspect, the hub includes a control circuit is configured to pair the hub with a first device of the surgical system, assign a first identifier to the first device, pair the hub with a second device of the surgical system, assign a second identifier to the second device, and selectively pair the first device with the second device. In one aspect, the surgical hub includes a storage medium, wherein the control circuit is configured to store a record indicative of the pairing between the first device and the second device in the storage medium. In one aspect, the pairing between the first device and the second device defines a communication pathway therebetween. In one aspect, the pairing between the first device and the second device defines a control pathway for transmitting control actions from the second device to the first device.

Further to the above, in one aspect, the control circuit is further configured to pair the hub with a third device of the surgical system, assign a third identifier to the third device, sever the pairing between the first device and the second device, and selectively pair the first device with the third device. In one aspect, the control circuit is further configured to store a record indicative of the pairing between the first device and the third device in the storage medium. In one aspect, the pairing between the first device and the third device defines a communication pathway therebetween. In one aspect, the pairing between the first device and the third device defines a control pathway for transmitting control actions from the third device to the first device.

In various aspects, the surgical hub includes a processor and a memory coupled to the processor. The memory stores instructions executable by the processor to selectively form and sever pairings between the devices of the surgical system, as described above. In various aspects, the present disclosure provides a non-transitory computer-readable medium storing computer-readable instructions which, when executed, cause a machine to selectively form and sever pairings between the devices of the surgical system, as described above. FIGS. **40** and **41** are logic flow diagrams of processes depicting control programs or logic configurations for selectively forming and severing pairings between the devices of the surgical system, as described above.

In one aspect, the surgical hub **106** establishes a first pairing with a surgical instrument and a second pairing with the surgical instrument controller. The surgical hub **106** then links the pairings together allowing the surgical instrument and the surgical instrument controller to operate with one another. In another aspect, the surgical hub **106** may sever an existing communication link between a surgical instrument and a surgical instrument controller, then link the surgical instrument to another surgical instrument controller that is linked to the surgical hub **106**.

In one aspect, the surgical instrument controller is paired to two sources. First, the surgical instrument controller is paired to the surgical hub **106**, which includes the generator module **140**, for control of its activation. Second, the surgical instrument controller is also paired to a specific surgical instrument to prevent inadvertent activation of the wrong surgical instrument.

Referring to FIGS. **40** and **42**, the surgical hub **106** may cause the communication module **130** to pair **3100** or establish a first communication link **3101** with a first device **3102** of the surgical system **102**, which can be a first surgical instrument. Then, the hub may assign **3104** a first identification number to the first device **3102**. This is a unique identification and communication sequence or number that may include the device's name and a time stamp of when the communication was first established.

In addition, the surgical hub **106** may then cause the communication module **130** to pair **3106** or establish a second communication link **3107** with a second device **3108** of the surgical system **102**, which can be a surgical instrument controller. The surgical hub **106** then assigns **3110** a second identification number to the second device **3108**.

In various aspects, the steps of pairing a surgical hub **106** with a device may include detecting the presence of a new device, determining that the new device is within bounds of the operating room, as described above in greater detail, and only pairing with the new device if the new device is located within the bounds of the operating room.

The surgical hub **106** may then pair **3112** or authorize a communication link **3114** to be established between the first device **3102** and the second device **3108**, as illustrated in FIG. **42**. A record indicative of the communication link **3114** is stored by the surgical hub **106** in the storage array **134**. In one aspect, the communication link **3114** is established through the surgical hub **106**. In another aspect, as illustrated in FIG. **42**, the communication link **3114** is a direct link between the first device **3102** and the second device **3108**.

Referring to FIGS. **41** and **43**, the surgical hub **106** may then detect and pair **3120** or establish a third communication link **3124** with a third device **3116** of the surgical system **102**, which can be another surgical instrument controller, for example. The surgical hub **106** may then assign **3126** a third identification number to the third device **3116**.

In certain aspects, as illustrated in FIG. **43**, the surgical hub **106** may then pair **3130** or authorize a communication link **3118** to be established between the first device **3102** and the third device **3116**, while causing the communication link **3114** to be severed **3128**, as illustrated in FIG. **43**. A record indicative of the formation of the communication link **3118** and severing of the communication link **3114** is stored by the surgical hub **106** in the storage array **134**. In one aspect, the communication link **3118** is established through the surgical hub **106**. In another aspect, as illustrated in FIG. **43**, the communication link **3118** is a direct link between the first device **3102** and the third device **3116**.

As described above, the surgical hub **106** can manage an indirect communication between devices of the surgical system **102**. For example, in situations where the first device **3102** is a surgical instrument and the second device **3108** is a surgical instrument controller, an output of the surgical instrument controller can be transmitted through the communication link **3107** to the surgical hub **106**, which may then transmit the output to the surgical instrument through the communication link **3101**.

In making a decision to connect or sever a connection between devices of the surgical system **102**, the surgical hub **106** may rely on perioperative data received or generated by the surgical hub **106**. Perioperative data includes operator input, hub-situational awareness, hub-spatial awareness, and/or cloud data. For example, a request can be transmitted to the surgical hub **106** from an operator user-interface to assign a surgical instrument controller to a surgical instrument. If the surgical hub **106** determines that the surgical instrument controller is already connected to another surgical instrument, the surgical hub **106** may sever the connection and establish a new connection per the operator's request.

In certain examples, the surgical hub **106** may establish a first communication link between the visualization system **108** and the primary display **119** to transmit an image, or other information, from the visualization system **108**, which resides outside the sterile field, to the primary display **119**, which is located within the sterile field. The surgical hub **106** may then sever the first communication link and establish a second communication link between a robotic hub **122** and the primary display **119** to transmit another image, or other information, from the robotic hub **122** to the primary display **119**, for example. The ability of the surgical hub **106** to assign and reassign the primary display **119** to different components of the surgical system **102** allows the surgical hub **106** to manage the information flow within the operating room, particularly between components inside the sterile field and outside the sterile field, without physically moving these components.

In another example that involves the hub-situational awareness, the surgical hub **106** may selectively connect or disconnect devices of the surgical system **102** within an operating room based on the type of surgical procedure being performed or based on a determination of an upcoming step of the surgical procedure that requires the devices to be connected or disconnected. The hub situational awareness is described in greater detail below in connection with FIG. **62**.

Referring to FIG. **44**, the surgical hub **106** may track **3140** the progression of surgical steps in a surgical procedure and may coordinate pairing and unpairing of the devices of the surgical system **102** based upon such progression. For example, the surgical hub **106** may determine that a first surgical step requires use of a first surgical instrument, while a second surgical step, occurring after completion of the first surgical step, requires use of a second surgical instrument. Accordingly, the surgical hub **106** may assign a surgical instrument controller to the first surgical instrument for the duration of the first surgical step. After detecting completion **3142** of the first surgical step, the surgical hub **106** may cause the communication link between the first surgical instrument and the surgical instrument controller to be severed **3144**. The surgical hub **106** may then assign the surgical instrument controller to the second surgical instrument by pairing **3146** or authorizing the establishment of a communication link between the surgical instrument controller and the second surgical instrument.

Various other examples of the hub-situational awareness, which can influence the decision to connect or disconnect devices of the surgical system **102**, are described in greater detail below in connection with FIG. **62**.

In certain aspects, the surgical hub **106** may utilize its spatial awareness capabilities, as described in greater detail elsewhere herein, to track progression of the surgical steps of a surgical procedure and autonomously reassign a surgical instrument controller from one surgical instrument to another surgical instrument within the operating room of the surgical hub **106**. In one aspect, the surgical hub **106** uses Bluetooth pairing and compass information to determine the physical position of the components of the surgical system **102**.

In the example illustrated in FIG. **2**, the surgical hub **106** is paired with a first surgical instrument held by a surgical operator at the operating table and a second surgical instrument positioned on a side tray. A surgical instrument controller can be selectively paired with either the first surgical instrument or the second surgical instrument. Utilizing the Bluetooth pairing and compass information, the surgical hub **106** autonomously assigns the surgical instrument controller to the first surgical instrument because of its proximity to the patient.

After completion of the surgical step that involved using the first surgical instrument, the first surgical instrument may be returned to the side tray or otherwise moved away from the patient. Detecting a change in the position of the first surgical instrument, the surgical hub **106** may sever the communication link between the first surgical instrument and the surgical instrument controller to protect against unintended activation of the first surgical instrument by the surgical instrument controller. The surgical hub **106** may also reassign the surgical instrument controller to another surgical instrument if the surgical hub **106** detects that it has been moved to a new position at the operating table.

In various aspects, devices of the surgical system **102** are equipped with an easy hand-off operation mode that would allow one user to give activation control of a device they currently control to another surgical instrument controller within reach of another operator. In one aspect, the devices are equipped to accomplish the hand-off through a predetermined activation sequence of the devices that causes the devices that are activated in the predetermined activation sequence to pair with one another.

In one aspect, the activation sequence is accomplished by powering on the devices to be paired with one another in a particular order. In another aspect, the activation sequence is accomplished by powering on the devices to be paired with one another within a predetermined time period. In one aspect, the activation sequence is accomplished by activating communication components, such as Bluetooth, of the devices to be paired with one another in a particular order. In another aspect, the activation sequence is accomplished by activating communication components, such as Bluetooth, of the devices to be paired within one another within a predetermined time period.

Alternatively, the hand-off can also be accomplished by a selection of a device through one of the surgical-operator input devices. After the selection is completed, the next activation by another controller would allow the new controller to take control.

In various aspects, the surgical hub **106** can be configured to directly identify components of the surgical system **102** as they are brought into an operating room. In one aspect, the devices of the surgical system **102** can be equipped with an identifier recognizable by the surgical hub **106**, such as, for example, a bar code or an RFID tag. NFC can also be employed. The surgical hub **106** can be equipped with a suitable reader or scanner for detecting the devices brought into the operating room.

The surgical hub **106** can also be configured to check and/or update various control programs of the devices of the surgical system **102**. Upon detecting and establishing a communication link of a device of the surgical system **102**, the surgical hub **106** may check if its control program is up to date. If the surgical hub **106** determines that a later version of the control program is available, the surgical hub **106** may download the latest version from the cloud **104** and may update the device to the latest version. The surgical hub **106** may issue a sequential identification and communication number to each paired or connected device.

Cooperative Utilization of Data Derived from Secondary Sources by Intelligent Surgical Hubs

In a surgical procedure, the attention of a surgical operator must be focused on the tasks at hand. Receiving information from multiple sources, such as, for example, multiple displays, although helpful, can also be distracting. The imaging module **138** of the surgical hub **106** is configured to intelligently gather, analyze, organize/package, and disseminate relevant information to the surgical operator in a manner that minimizes distractions.

Aspects of the present disclosure are presented for cooperative utilization of data derived from multiple sources, such as, for example, an imaging module **138** of the surgical hub **106**. In one aspect, the imaging module **138** is configured to overlay data derived from one or more sources onto a livestream destined for the primary display **119**, for example. In one aspect, the overlaid data can be derived from one or more frames acquired by the imaging module **138**. The imaging module **138** may commandeer image frames on their way for display on a local display such as, for example, the primary display **119**. The imaging module **138** also comprises an image processor that may preform an array of local image processing on the commandeered images.

Furthermore, a surgical procedure generally includes a number of surgical tasks which can be performed by one or more surgical instruments guided by a surgical operator or a surgical robot, for example. Success or failure of a surgical procedure depends on the success or failure of each of the surgical tasks. Without relevant data on the individual surgical tasks, determining the reason for a failed surgical procedure is a question of probability.

Aspects of the present disclosure are presented for capturing one or more frames of a livestream of a surgical procedure for further processing and/or pairing with other data. The frames may be captured at the completion of a surgical task (also referred to elsewhere herein as "surgical step") to assess whether the surgical task was completed successfully. Furthermore, the frames, and the paired data, can be uploaded to the cloud for further analysis.

In one aspect, one or more captured images are used to identify at least one previously completed surgical task to evaluate the outcome of the surgical task. In one aspect, the surgical task is a tissue-stapling task. In another aspect, the surgical task is an advanced energy transection.

FIG. **45** is a logic flow diagram of a process **3210** depicting a control program or a logic configuration for overlaying information derived from one or more still frames of a livestream of a remote surgical site onto the livestream. The process **3210** includes receiving **3212** a livestream of a remote surgical site from a medical imaging device **124**, for example, capturing **3214** at least one image frame of a surgical step of the surgical procedure from the livestream, deriving **3216** information relevant to the surgical step from data extracted from the at least one image frame, and overlaying **3218** the information onto the livestream.

In one aspect, the still frames can be of a surgical step performed at the remote surgical site. The still frames can be analyzed for information regarding completion of the surgical step. In one aspect, the surgical step comprises stapling tissue at the surgical site. In another aspect, the surgical task comprises applying energy to tissue at the surgical site.

FIG. **46** is a logic flow diagram of a process **3220** depicting a control program or a logic configuration for differentiating among surgical steps of a surgical procedure. The process **3220** includes receiving **3222** a livestream of a surgical site from a medical imaging device **124**, for example, capturing **3224** at least one first image frame of a first surgical step of the surgical procedure from the livestream, deriving **3226** information relevant to the first surgical step from data extracted from the at least one image frame, capturing **3228** at least one second image frame of a second surgical step of the surgical procedure from the livestream, and differentiating **3229** among the first surgical step and the second surgical step based on the at least one first image frame and the at least one second image frame.

FIG. **47** is a logic flow diagram of a process **3230** depicting a control program or a logic configuration for differentiating among surgical steps of a surgical procedure. The process **3232** includes receiving **3232** a livestream of the surgical site from a medical imaging device **124**, for example, capturing **3234** image frames of the surgical steps of the surgical procedure from the livestream and differentiating **3236** among the surgical steps based on data extracted from the image frames.

FIG. **48** is a logic flow diagram of a process **3240** depicting a control program or a logic configuration for identifying a staple cartridge from information derived from one or more still frames of staples deployed from the staple cartridge into tissue. The process **3240** includes receiving **3242** a livestream of the surgical site from medical imaging device **124**, for example, capturing **3244** an image frame from the livestream, detecting **3246** a staple pattern in the image frame, wherein the staple pattern is defined by staples deployed from a staple cartridge into tissue at the surgical site. The process **3240** further includes identifying **3248** the staple cartridge based on the staple pattern.

In various aspects, one or more of the steps of the processes **3210**, **3220**, **3230**, **3240** can be executed by a control circuit of an imaging module of a surgical hub, as depicted in FIGS. **3**, **9**, **10**. In certain examples, the control circuit may include a processor and a memory coupled to the processor, wherein the memory stores instructions executable by the processor to perform one or more of the steps of the processes **3210**, **3220**, **3230**, **3240**. In certain examples, a non-transitory computer-readable medium stores computer-readable instructions which, when executed, cause a machine to perform one or more of the steps of the processes **3210**, **3220**, **3230**, **3240**. For economy, the following description of the processes **3210**, **3220**, **3230**, **3240** will be described as being executed by the control circuit of an imaging module of a surgical hub; however, it should be understood that the execution of the processes **3210**, **3220**, **3230**, **3240** can be accomplished by any of the aforementioned examples.

Referring to FIGS. **34** and **49**, a surgical hub **106** is in communication with a medical imaging device **124** located at a remote surgical site during a surgical procedure. The imaging module **138** receives a livestream of the remote surgical site transmitted by the imaging device **124** to a primary display **119**, for example, in accordance with steps **3212**, **3222**, **3232**, **3242**.

Further to the above, the imaging module **138** of the surgical hub **106** includes a frame grabber **3200**. The frame grabber **3200** is configured to capture (i.e., "grabs") individual, digital still frames from the livestream transmitted by the imaging device **124**, for example, to a primary display **119**, for example, during a surgical procedure, in accordance with steps **3214**, **3224**, **3234**, **3244**. The captured still frames are stored and processed by a computer platform **3203** (FIG. **49**) of the imaging module **138** to derive information about the surgical procedure. Processing of the captured frames may include performance of simple operations, such as histogram calculations, 2D filtering, and arithmetic operations on arrays of pixels to the performance of more complex tasks, such as object detection, 3D filtering, and the like.

In one aspect, the derived information can be overlaid onto the livestream. In one aspect, the still frames and/or the information resulting from processing the still frames can be communicated to a cloud **104** for data aggregation and further analysis.

In various aspects, the frame grabber **3200** may include a digital video decoder and a memory for storing the acquired still frames, such as, for example, a frame buffer. The frame grabber **3200** may also include a bus interface through which a processor can control the acquisition and access the data and a general purpose I/O for triggering image acquisition or controlling external equipment.

As described above, the imaging device **124** can be in the form of an endoscope, including a camera and a light source positioned at a remote surgical site, and configured to provide a livestream of the remote surgical site at the primary display **119**, for example.

In various aspects, image recognition algorithms can be implemented to identify features or objects in still frames of a surgical site that are captured by the frame grabber **3200**. Useful information pertaining to the surgical steps associated with the captured frames can be derived from the identified features. For example, identification of staples in the captured frames indicates that a tissue-stapling surgical step has been performed at the surgical site. The type, color, arrangement, and size of the identified staples can also be used to derive useful information regarding the staple cartridge and the surgical instrument employed to deploy the staples. As described above, such information can be overlaid on a livestream directed to a primary display **119** in the operating room.

The image recognition algorithms can be performed at least in part locally by the computer platform **3203** (FIG. **49**) of the imaging module **138**. In certain instances, the image recognition algorithms can be performed at least in part by the processor module **132** of the surgical hub **106**. An image database can be utilized in performance of the image recognition algorithms and can be stored in a memory **3202** of the computer platform **3203**. Alternatively, the imaging database can be stored in the storage array **134** (FIG. **3**) of the surgical hub **106**. The image database can be updated from the cloud **104**.

An example image recognition algorithm that can be executed by the computer platform **3203** may include a key points-based comparison and a region-based color comparison. The algorithm includes: receiving an input at a processing device, such as, for example, the computer platform **3203**; the input, including data related to a still frame of a remote surgical site; performing a retrieving step, including retrieving an image from an image database and, until the image is either accepted or rejected, designating the image as a candidate image; performing an image recognition step, including using the processing device to perform an image recognition algorithm on the still frame and candidate images in order to obtain an image recognition algorithm output; and performing a comparison step, including: if the image recognition algorithm output is within a pre-selected range, accepting the candidate image as the still frame and if the image recognition algorithm output is not within the pre-selected range, rejecting the candidate image and repeating the retrieving, image recognition, and comparison steps.

Referring to FIGS. **50-52**, in one example, a surgical step involves stapling and cutting tissue. FIG. **50** depicts a still frame **3250** of a stapled and cut tissue T. A staple deployment **3252** includes staples **3252'**, **3252"** from a first staple cartridge. A second staple deployment **3254** includes staples **3254'**, **3254"** from a second staple cartridge. A proximal portion **3253** of the staple deployment **3252** overlaps with a distal portion **3255** of the staple deployment **3254**. Six rows of staples were deployed in each deployment. Tissue T was cut between the third and fourth rows of each deployment, but only one side of the stapled tissue T is fully shown.

In various aspects, the imaging module **138** identifies one or more of the staples **3252'**, **3252"**, **3254'**, **3254"** in the still frame **3250**, which were absent in a previous still frame captured by the frame grabber **3200**. The imaging module **138** then concludes that a surgical stapling and cutting instrument has been used at the surgical site.

In the example of FIG. **50**, the staple deployment **3252** includes two different staples **3252'**, **3252"**. Likewise, the staple deployment **3254** includes two different staples **3254'**, **3254"**. For brevity, the following description focuses on the staples **3252'**, **3252"**, but is equally applicable to the staples **3254'**, **3254"**. The staples **3252'**, **3252"** are arranged in a predetermined pattern or sequence that forms a unique identifier corresponding to the staple cartridge that housed the staples **3252'**, **3252"**. The unique pattern can be in a single row or multiple rows of the staples **3250**. In one example, the unique pattern can be achieved by alternating the staples **3252'**, **3252"** at a predetermined arrangement.

In one aspect, multiple patterns can be detected in a firing of staples. Each pattern can be associated with a unique characteristic of the staples, the staple cartridge that housed the staples, and/or the surgical instrument that was employed to fire the staple. For example, a firing of staples may include patterns that represent staple form, staple size, and/or location of the firing.

In the example, of FIG. **50**, the imaging module **138** may identify a unique pattern of the staples **3252** from the still frame **3250**. A database storing staple patterns and corresponding identification numbers of staple cartridges can then be explored to determine an identification number of a staple cartridge that housed the staples **3252**.

The patterns of the example of FIG. **50** are based on only two different staples; however, other aspects may include three or more different staples. The different staples can be coated with different coatings, which can be applied to the staples by one or more of the following methods: anodizing, dying, electro-coating, photoluminescent coating, application of nitrides, methyl methacylate, painting, powder coating, coating with paraffins, oil stains or phosphor coatings, the use of hydroxyapatite, polymers, titanium oxinitrides, zinc sulfides, carbides, etc. It should be noted that, while the listed coatings are fairly specific as disclosed herein, other coatings known in the art to distinguish the staple are within the contemplated scope of the present disclosure.

In the example of FIGS. **50-52**, the staples **3252'** are anodized staples, while the staples **3252"** are non-anodized staples. In one aspect, the different staples may comprise two or more different colors. Different metal staples may comprise magnetic or radioactive staple markers that differentiate them from unmarked staples.

FIG. **51** illustrates a staple deployment **3272** deployed into tissue from a staple cartridge via a surgical instrument. Only three staple rows **3272***a*, **3272***b*, **3272***c* are depicted in FIG. **51**. The rows **3272***a*, **3272***b*, **3272***c* are arranged between a medial line, where the tissue was cut, and a lateral line at the tissue edge. For clarity, the inner row **3272***a* of staples is redrawn separately to the left and the outer two rows **3272***b*, **3272***c* are redrawn separately to the right. A proximal end **3273** and a distal end portion of the staple deployment **3272** are also redrawn in FIG. **51** for clarity.

The staple deployment **3272** includes two different staples **3272'**, **3272"** that are arranged in predetermined patterns that serve various functions. For example, the inner row **3272***a* comprises a pattern of alternating staples **3272'**, **3272"**, which defines a metric for distance measurements in the surgical field. In other words, the pattern of the inner row **3272***a* acts as a ruler for measuring distances, which can be helpful in accurately determining the position of a leak, for example. The outer rows **3272***b*, **3272***c* define a pattern that represents an identification number of the staple cartridge that housed the staples **3272'**, **3272"**.

Furthermore, unique patterns at the ends of the staple deployment **3272** identify the proximal end portion **3273** and distal end portion **3275**. In the example of FIG. **51**, a unique arrangement of three staples **3272"** identifies the distal end **3275**, while a unique arrangement of four staples **3272"** identifies the proximal end **3273**. Identification of the proximal and distal ends of a staple deployment allows the imaging module **128** to distinguish between different staple deployments within a captured frame, which can be useful in pointing the source of a leak, for example.

In various aspects, the imaging module **138** may detect a sealed tissue in a still frame of a remote surgical site captured by the frame grabber **3200**. Detection of the sealed tissue can be indicative of a surgical step that involves applying therapeutic energy to tissue.

Sealing tissue can be accomplished by the application of energy, such as electrical energy, for example, to tissue captured or clamped within an end effector of a surgical instrument in order to cause thermal effects within the tissue. Various mono-polar and bi-polar RF surgical instruments and harmonic surgical instruments have been developed for such purposes. In general, the delivery of energy to captured tissue can elevate the temperature of the tissue and, as a result, the energy can at least partially denature proteins within the tissue. Such proteins, like collagen, for example, can be denatured into a proteinaceous amalgam that intermixes and fuses, or seals, together as the proteins renature.

Accordingly, sealed tissue has a distinct color and/or shape that can be detected by the imaging module **138** using image recognition algorithms, for example. In addition, smoke detection at the surgical site can indicate that therapeutic energy application to the tissue is in progress.

Further to the above, the imaging module **138** of the surgical hub **106** is capable of differentiating between surgical steps of a surgical procedure based on the captured frames. As described above, a still frame that comprises fired staples is indicative of a surgical step involving tissue stapling, while a still frame that comprises a sealed tissue is indicative of a surgical step involving energy application to tissue.

In one aspect, the surgical hub **106** may selectively overlay information relevant to a previously completed surgical task onto the livestream. For example, the overlaid information may comprise image data from a still frame of the surgical site captured during the previously completed surgical task. Furthermore, guided by common landmark locations at the surgical site, the imaging module **138** can interlace one image frame to another to establish and detect surgical locations and relationship data of a previously completed surgical task.

In one example, the surgical hub **106** is configured to overlay information regarding a potential leak in a tissue treated by stapling or application of therapeutic energy in a previously completed surgical task. The potential leak can be spotted by the imaging module **138** during the processing of a still frame of the tissue. The surgical operator can be alerted about the leak by overlaying information about the potential leak onto the livestream.

In various aspects, still frames of an end effector of a surgical instrument at a surgical site can be used to identify the surgical instrument. For example, the end effector may include an identification number that can be recognized by the imaging module **138** during image processing of the still frame. Accordingly, the still frames captured by the imaging module **138** may be used to identify a surgical instrument utilized in a surgical step of a surgical procedure. The still frames may also include useful information regarding the performance of the surgical instrument. All such information can be uploaded to the cloud **104** for data aggregation and further analysis.

In various examples, the surgical hub **106** may also selectively overlay information relevant to a current or upcoming surgical task, such as an anatomical location or a surgical instrument suitable for the surgical task.

The imaging module **138** may employ various images and edge detection techniques to track a surgical site where a surgical instrument was used to complete a surgical task. Success or failure of the surgical task can then be assessed. For example, a surgical instrument can be employed to seal and/or cut tissue at the surgical site. A still frame of the surgical site can be stored in the memory **3202** or the storage array **134** of the surgical hub **106**, for example, upon completion of the surgical task.

In the following surgical step, the quality of the seal can be tested via different mechanisms. To ensure that the testing is accurately applied to the treated tissue, the stored still frame of the surgical site is overlaid onto the livestream in search of a match. Once a match is found, the testing can take place. One or more additional still frames can be taken during the testing, which can be later analyzed by the imaging module **138** of the surgical hub **106**. The testing mechanisms include bubble detection, bleeding detection, dye detection (where a dye is employed at the surgical site), and/or burst stretch detection (where a localized strain is applied adjacent to an anastomosis site), for example.

The imaging module **138** may capture still frames of the response of the treated tissue to these tests, which can be stored in the memory **3202** or the storage array **134** of the surgical hub **106**, for example. The still frames can be stored alone or in combination with other data, such as, for example, data from the surgical instrument that performed the tissue treatment. The paired data can also be uploaded to the cloud **104** for additional analysis and/or pairing.

In various aspects, the still frames captured by the frame grabber **3200** can be processed locally, paired with other data, and can also be transmitted to the cloud **104**. The size of the processed and/or transmitted data will depend on the number of captured frames. In various aspects, the rate at which the frame grabber **3200** captures the still frames from the livestream can be varied in an effort to reduce the size of the data without sacrificing quality.

In one aspect, the frame-capturing rate may depend on the type of surgical task being performed. Certain surgical tasks may need a higher number of still frames than others for an evaluation of success or failure. The frame-capturing rate can be scalded to accommodate such needs.

In one aspect, the frame-capturing rate is dependent upon the detected motion of the imaging device **124**. In use, an imaging device **124** may target one surgical site for a period of time. Observing no or minor changes in the still frames captured while the imaging device **124** is not being moved, the imaging module **138** may reduce the frame-capturing rate of the frame grabber **3200**. If the situation changes, however, where frequent motion is detected, the imaging module **138** may respond by increasing the frame-capturing rate of the frame grabber **3200**. In other words, the imaging module **138** may be configured to correlate the frame-capturing rate of the frame grabber **3200** with the detected degree of motion of the imaging device **124**.

For additional efficiency, only portions of the still frames, where motion is detected, need to be stored, processed, and/or transmitted to the cloud **104**. The imaging module **138** can be configured to select the portions of the still frames where motion is detected. In one example, motion detection can be achieved by comparing a still frame to a previously captured still frame. If movement is detected, the imaging module **138** may cause the frame grabber **3200** to increase the frame-capturing rate, but only the portions where motion is detected are stored, processed, and/or transmitted to the cloud **104**.

In another aspect, the data size can be managed by scaling the resolution of the captured information based on the area of the screen where the focal point is or where end effectors are located, for example. The remainder of the screen could be captured at a lower resolution.

In one aspect, the corners of the screen and the edges could generally be captured at a lower resolution. The resolution, however, can be scalded up if an event of significance is observed.

During a surgical procedure, the surgical hub **106** can be connected to various operating-room monitoring devices, such as, for example, heart rate monitors and insufflation pumps. Data collected from these devices can improve the situational awareness of the surgical hub **106**. The hub situational awareness is described in greater detail below in connection with FIG. **62**.

In one example, the surgical hub **106** can be configured to utilize patient data received from a heart rate monitor connected along with data regarding the location of the surgical site to assess proximity of the surgical site to sensory nerves. An increase in the patient's heart rate, when combined with anatomical data indicating that the surgical site is in a region high in sensory nerves, can be construed as an indication of sensory nerve proximity. Anatomical data can be available to the surgical hub **106** through accessing patient records (e.g., an EMR database containing patient records).

The surgical hub **106** may be configured to determine the type of surgical procedure being performed on a patient from data received from one or more of the operating-room monitoring devices, such as, for example, heart rate monitors and insufflation pumps. Abdominal surgical procedures generally require insufflation of the abdomen, while insufflation is not required in theoretic surgery. The surgical hub **106** can be configured to determine whether a surgical procedure is an abdominal or a thoracic surgical procedure by detecting whether the insufflation pump is active. In one aspect, the surgical hub **106** may be configured to monitor insufflation pressure on the output side of the insufflation pump in order to determine whether the surgical procedure being performed is one that requires insufflation.

The surgical hub **106** may also gather information from other secondary devices in the operating room to assess, for example, whether the surgical procedure is a vascular or avascular procedure.

The surgical hub **106** may also monitor AC current supply to one or more of its components to assess whether a component is active. In one example, the surgical hub **106** is configured to monitor AC current supply to the generator module to assess whether the generator is active, which can be an indication that the surgical procedure being performed is one that requires application of energy to seal tissue.

In various aspects, secondary devices in the operating room that are incapable of communication with the surgical hub **106** can be equipped with communication interface devices (communication modules) that can facilitate pairing of these devices with the surgical hub **106**. In one aspect, the communication interface devices may be configured to be bridging elements, which would allow them two-way communication between the surgical hub **106** and such devices.

In one aspect, the surgical hub **106** can be configured to control one or more operational parameters of a secondary device through a communication interface device. For example, the surgical hub **106** can be configured to increase or decrease the insufflation pressure through a communication interface device coupled to an insufflation device.

In one aspect, the communication interface device can be configured to engage with an interface port of the device. In another aspect, the communication interface device may comprise an overlay or other interface that directly interacts with a control panel of the secondary device. In other aspects, the secondary devices, such as, for example, the heart rate monitor and/or the insufflation devices, can be equipped with integrated communication modules that allow them to pair with the hub for two-way communication therewith.

In one aspect, the surgical hub **106** can also be connected through a communication interface device, for example, to muscle pads that are connected to the neuro-stim detection devices to improve resolution of a nerve-sensing device.

Furthermore, the surgical hub **106** can also be configured to manage operating room supplies. Different surgical procedures require different supplies. For example, two different surgical procedures may require different sets of surgical instruments. Certain surgical procedures may involve using a robotic system, while others may not. Furthermore, two different surgical procedures may require staple cartridges that are different in number, type, and/or size. Accordingly, the supplies brought into the operating room can provide clues as to the nature of the surgical procedure that will be performed.

In various aspects, the surgical hub **106** can be integrated with an operating room supplies scanner to identify items pulled into the operating room and introduced into the sterile field. The surgical hub **106** may utilize data from the operating room supplies scanner, along with data from the devices of the surgical system **102** that are paired with the surgical hub **106**, to autonomously determine the type of surgical procedure that will be performed. In one example, the surgical hub **106** may record a list of serial numbers of the smart cartridge that are going to be used in the surgical procedure. During the surgical procedure, the surgical hub **106** may gradually remove the staples that have been fired, based on information collected from the staple cartridge chips. In one aspect, the surgical hub **106** is configured to make sure that all the items are accounted for at the end of the procedure.

Surgical Hub Control Arrangements

In a surgical procedure, a second surgical hub may be brought into an operating room already under the control of a first surgical hub. The second surgical hub can be, for example, a surgical robotic hub brought into the operating room as a part of a robotic system. Without coordination between the first and second surgical hubs, the robotic surgical hub will attempt to pair with all the other components of the surgical system **102** that are within the operating room. The confusion arising from the competition between two hubs in a single operating room can lead to undesirable consequences. Also, sorting out the instrument distribution between the hubs during the surgical procedure can be time consuming.

Aspects of the present disclosure are presented for a surgical hub for use with a surgical system in a surgical procedure performed in an operating room. A control circuit of the surgical hub is configured to determine the bounds of the operating room and establish a control arrangement with a detected surgical hub located within the bounds of the operating room.

In one aspect, the control arrangement is a peer-to-peer arrangement. In another aspect, the control arrangement is a master-slave arrangement. In one aspect, the control circuit is configured to select one of a master mode of operation or a slave mode of operation in the master-slave arrangement. In one aspect, the control circuit is configured to surrender control of at least one surgical instrument to the detected surgical hub in the slave mode of operation.

In one aspect, the surgical hub includes an operating room mapping circuit that includes a plurality of non-contact sensors configured to measure the bounds of the operating room.

In various aspects, the surgical hub includes a processor and a memory coupled to the processor. The memory stores instructions executable by the processor to coordinate a control arrangement between surgical hubs, as described above. In various aspects, the present disclosure provides a non-transitory computer-readable medium storing computer-readable instructions which, when executed, cause a machine to coordinate a control arrangement between surgical hubs, as described above.

Aspects of the present disclosure are presented for a surgical system comprising two independent surgical hubs that are configured to interact with one another. Each of the hubs has their own linked surgical devices and the control designation of and distribution of where data is recorded and processed. This interaction causes one or both hubs to change how they were behaving before the interaction. In one aspect, the change involves a redistribution of devices previously assigned to each of the hubs. In another aspect, the change involves establishing a master-slave arrangement between the hubs. In yet another aspect, the change can be a change in the location of the processing shared between the hubs.

FIG. **53** is a logic flow diagram of a process depicting a control program or a logic configuration for coordinating a control arrangement between surgical hubs. The process of FIG. **53** is similar in many respects to the process of FIG. **35** except that the process of FIG. **53** addresses detection of a surgical hub by another surgical hub. As illustrated in FIG. **53**, the surgical hub **106** determines **3007** the bounds of the operating room. After the initial determination, the surgical hub **106** continuously searches for or detects **3008** devices within a pairing range. If a device is detected **3010**, and if the detected device is located **3011** within the bounds of the operating room, the surgical hub **106** pairs **3012** with the device and assigns **3013** an identifier to the device. If through an initial interaction, as described below in greater detail, the surgical hub **106** determines **3039** that the device is another surgical hub, a control arrangement is established **3040** therebetween.

Referring to FIG. **54**, a robotic surgical hub **3300** enters an operating room already occupied by a surgical hub **3300**. The robotic surgical hub **3310** and the surgical hub **3300** are similar in many respects to other surgical hubs described in greater detail elsewhere herein, such as, for example, the surgical hubs **106**. For example, the robotic surgical hub **3310** includes non-contact sensors configured to measure the bounds of the operating room, as described in greater detail elsewhere herein in connection with FIGS. **33**, **34**.

As the robotic surgical hub **3310** is powered up, it determines the bounds of the operating room and begins to pair with other components of the surgical system **102** that are located within the bounds of the operating room. The robotic surgical hub **3310** pairs with a robotic advanced energy tool **3311**, a robotic stapler **3312**, a monopolar energy tool **3313**, and a robotic visualization tower **3314**, which are all located within the bounds of the operating room. The surgical hub **3300** is already paired with a handheld stapler **3301**, a handheld powered dissector **3302**, a secondary display **3303**, a surgeon interface **3304**, and a visualization tower **3305**. Since the handheld stapler **3301**, the handheld powered dissector **3302**, the secondary display **3303**, the surgeon interface **3304**, and the visualization tower **3305** are already paired with the surgical hub **3300**, such devices cannot pair with another surgical hub without permission from the surgical hub **3300**.

Further to the above, the robotic surgical hub **3310** detects and/or is detected by the surgical hub **3300**. A communication link is established between the communication modules of the surgical hubs **3300**, **3310**. The surgical hubs **3300**, **3310** then determine the nature of their interaction by determining a control arrangement therebetween. In one aspect, the control arrangement can be a master-slave arrangement. In another aspect, the control arrangement can be a peer-to-peer arrangement.

In the example of FIG. **54**, a master-slave arrangement is established. The surgical hubs **3300**, **3310** request permission from a surgical operator for the robotic surgical hub **3310** to take control of the operating room from the surgical hub **3300**. The permission can be requested through a surgeon interface or console **3304**. Once permission is granted, the robotic surgical hub **3310** requests the surgical hub **3300** to transfer control to the robotic surgical hub **3310**.

Alternatively, the surgical hubs **3300**, **3310** can negotiate the nature of their interaction without external input based on previously gathered data. For example, the surgical hubs **3300**, **3310** may collectively determine that the next surgical task requires use of a robotic system. Such determination may cause the surgical hub **3300** to autonomously surrender control of the operating room to the robotic surgical hub **3310**. Upon completion of the surgical task, the robotic surgical hub **3310** may then autonomously return the control of the operating room to surgical hub **3300**.

The outcome of the interaction between the surgical hubs **3300**, **3310** is illustrated on the right of FIG. **54**. The surgical hub **3300** has transferred control to the robotic surgical hub **3310**, which has also taken control of the surgeon interface **3304** and the secondary display **3303** from the surgical hub **3300**. The robotic surgical hub **3310** assigns new identification numbers to the newly transferred devices. The surgical hub **3300** retains control the handheld stapler **3301**, the handheld powered dissector **3302**, and visualization tower **3305**. In addition, the surgical hub **3300** performs a supporting role, wherein the processing and storage capabilities of the surgical hub **3300** are now available to the robotic surgical hub **3310**.

FIG. **55** is a logic flow diagram of a process depicting a control program or a logic configuration for coordinating a control arrangement between surgical hubs. In various aspects, two independent surgical hubs will interact with one another in a predetermined manner to assess the nature of their relationship. In one example, after establishing **3321** a communication link, the surgical hubs exchange **3322** data packets. A data packet may include type, identification number, and/or status of a surgical hub. A data packet may further include a record of devices under control of the surgical hub and/or any limited communication connections, such as data ports for other secondary operating room devices.

The control arrangement between the surgical hubs is then determined **3323** based on input from a surgical operator or autonomously between the surgical hubs. The surgical hubs may store instructions as to how to determine a control arrangement therebetween. The control arrangement between two surgical hubs may depend on the type of surgical procedure being performed. The control arrangement between two surgical hubs may depend on their types, identification information, and/or status. The control arrangement between two surgical hubs may depend on the devices paired with the surgical hubs. The surgical hubs then redistribute **3324** the devices of the surgical system **102** therebetween based upon the determined control arrangement.

In the master-slave arrangement, the record communication can be unidirectional from the slave hub to the master hub. The master hub may also require the slave hub to hand-off some of its wireless devices to consolidate communication pathways. In one aspect, the slave hub can be relegated to a relay configuration with the master hub originating all commands and recording all data. The slave hub can remain linked to the master hub for a distributed sub-processing of the master hub commands, records, and/or controls. Such interaction expands the processing capacity of the dual linked hubs beyond the capabilities of the master hub by itself.

In a peer-to-peer arrangement, each surgical hub may retain control of its devices. In one aspect, the surgical hubs may cooperate in controlling a surgical instrument. In one aspect, an operator of the surgical instrument may designate the surgical hub that will control the surgical instrument at the time of its use.

Referring generally to FIGS. **56**-**61**, the interaction between surgical hubs can be extended beyond the bounds of the operating room. In various aspects, surgical hubs in separate operating rooms may interact with one another within predefined limits. Depending on their relative proximity, surgical hubs in separate operating rooms may interact through any suitable wired or wireless data communication network such as Bluetooth and WiFi. As used here, a "data communication network" represents any number of physical, virtual, or logical components, including hardware, software, firmware, and/or processing logic configured to support data communication between an originating component and a destination component, where data communication is carried out in accordance with one or more designated communication protocols over one or more designated communication media.

In various aspects, a first surgical operator in a first operating room may wish to consult a second surgical operator in a second operating room, such as in case of an emergency. A temporary communication link may be established between the surgical hubs of the first and second operating room to facilitate the consult while the first and second surgical operators remain in their respective operating rooms.

The surgical operator being consulted can be presented with a consult request through the surgical hub in his/her operating room. If the surgical operator accepts, he/she will have access to all the data compiled by the surgical hub requesting the consult. The surgical operator may access all previously stored data, including a full history of the procedure. In addition, a livestream of the surgical site at the requesting operating room can be transmitted through the surgical hubs to a display at the receiving operating room.

When a consult request begins, the receiving surgical hub begins to record all received information in a temporarily storage location, which can be a dedicated portion of the storage array of the surgical hub. At the end of the consult, the temporary storage location is purged from all the information. In one aspect, during a consult, the surgical hub records all accessible data, including blood pressure, ventilation data, oxygen stats, generator settings and uses, and all patient electronic data. The recorded data will likely be more than the data stored by the surgical hub during normal operation, which is helpful in providing the surgical operator being consulted with as much information as possible for the consult.

Referring to FIG. **56**, a non-limiting example of an interaction between surgical hubs in different operating rooms is depicted. FIG. **56** depicts an operating room OR **1** that includes a surgical system **3400** supporting a thoracic segmentectomy and a second operating room OR **3** that includes a surgical system **3410** supporting a colorectal procedure. The surgical system **3400** includes surgical hub **3401**, surgical hub **3402**, and robotic surgical hub **3403**. The surgical system **3400** further includes a personal interface **3406**, a primary display **3408**, and secondary displays **3404**, **3405**. The surgical system **3410** includes a surgical hub **3411** and a secondary display **3412**. For clarity, several components of the surgical systems **3400**, **3410** are removed.

In the example of FIG. **56**, the surgical operator of OR **3** is requesting a consult from the surgical operator of OR **1**. A surgical hub **3411** of the OR **3** transmits the consult request to one of the surgical hubs of the OR **1**, such as the surgical hub **3401**. In OR **1**, the surgical hub **3401** presents the request at a personal interface **3406** held by the surgical operator. The consult is regarding selecting an optimal location of a colon transection. The surgical operator of OR **1**, through a personal interface **3406**, recommends an optimal location for the transection site that avoids a highly vascular section of the colon. The recommendation is transmitted in real time through the surgical hubs **3401**, **3411**. Accordingly, the surgical operator is able to respond to the consult request in real time without having to leave the sterile field of his own operating room. The surgical operator requesting the consult also did not have to leave the sterile field of OR **3**.

If the surgical hub **3401** is not in communication with the personal interface **3406**, it may relay the message to another surgical hub such as, for example, the surgical hub **3402** or the robotic surgical hub **3403**. Alternatively, the surgical hub **3401** may request control of the personal interface **3406** from another surgical hub.

In any event, if the surgical operator of OR **1** decides to accept the consult request, a livestream, or frames, of a surgical site **3413** of the colorectal procedure of OR **3** is transmitted to OR **1** through a connection established between the surgical hubs **3401**, **3411**, for example. FIG. **57** illustrates a livestream of the surgical site **3413** displayed on a secondary display of OR **3**. The surgical hubs **3401**, **3411** cooperate to transmit the livestream of the surgical site of OR **3** to the personal interface **3406** of the OR **1**, as illustrated in FIG. **58**.

Referring to FIGS. **59-61**, the surgical operator may expand the laparoscopic livestream from OR **3** onto the primary display **3405** in OR **1**, for example, through the controls of the personal interface **3406**. The personal interface **3406** allows the surgical operator to select a destination for the livestream by presenting the surgical operator with icons that represent the displays that are available in OR **1**, as illustrated in FIG. **60**. Other navigation controls **3407** are available to the surgical operator through the personal interface **3406**, as illustrated in FIG. **61**. For example, the personal interface **3406** includes navigation controls for adjusting the livestream of the surgical site of OR **3** in OR **1** by the surgical operator moving his or her fingers on the livestream displayed on the personal interface **3406**. To visualize the high vasculature regions, the consulted surgical operator may change the view of the livestream from OR **3** through the personal interface **3406** to an advanced imaging screen. The surgical operator may then manipulate the image in multiple planes to see the vascularization using a wide-angle multi-spectral view, for example.

As illustrated in FIG. **61**, the surgical operator also has access to an array of relevant information **3420**, such as, for example, heart rate, blood pressure, ventilation data, oxygen stats, generator settings and uses, and all patient electronic data of the patient in OR **3**.

Situational Awareness

Situational awareness is the ability of some aspects of a surgical system to determine or infer information related to a surgical procedure from data received from databases and/or instruments. The information can include the type of procedure being undertaken, the type of tissue being operated on, or the body cavity that is the subject of the procedure. With the contextual information related to the surgical procedure, the surgical system can, for example, improve the manner in which it controls the modular devices (e.g., a robotic arm and/or robotic surgical tool) that are connected to it and provide contextualized information or suggestions to the surgeon during the course of the surgical procedure.

Referring now to FIG. **62**, a timeline **5200** depicting situational awareness of a hub, such as the surgical hub **106** or **206**, for example, is depicted. The timeline **5200** is an illustrative surgical procedure and the contextual information that the surgical hub **106**, **206** can derive from the data received from the data sources at each step in the surgical procedure. The timeline **5200** depicts the typical steps that would be taken by the nurses, surgeons, and other medical personnel during the course of a lung segmentectomy procedure, beginning with setting up the operating theater and ending with transferring the patient to a post-operative recovery room.

The situationally aware surgical hub **106**, **206** receives data from the data sources throughout the course of the surgical procedure, including data generated each time medical personnel utilize a modular device that is paired with the surgical hub **106**, **206**. The surgical hub **106**, **206** can receive this data from the paired modular devices and other data sources and continually derive inferences (i.e., contextual information) about the ongoing procedure as new data is received, such as which step of the procedure is being performed at any given time. The situational awareness system of the surgical hub **106**, **206** is able to, for example, record data pertaining to the procedure for generating reports, verify the steps being taken by the medical personnel, provide data or prompts (e.g., via a display screen) that may be pertinent for the particular procedural step, adjust modular devices based on the context (e.g., activate monitors, adjust the field of view of the medical imaging device, or change the energy level of an ultrasonic surgical instrument or RF electrosurgical instrument), and take any other such action described above.

As the first step S**202** in this illustrative procedure, the hospital staff members retrieve the patient's EMR from the hospital's EMR database. Based on select patient data in the EMR, the surgical hub **106**, **206** determines that the procedure to be performed is a thoracic procedure.

In the second step S**204**, the staff members scan the incoming medical supplies for the procedure. The surgical hub **106**, **206** cross-references the scanned supplies with a list of supplies that are utilized in various types of procedures and confirms that the mix of supplies corresponds to a thoracic procedure. Further, the surgical hub **106**, **206** is also able to determine that the procedure is not a wedge procedure (because the incoming supplies either lack certain supplies that are necessary for a thoracic wedge procedure or do not otherwise correspond to a thoracic wedge procedure).

In the third step S**206**, the medical personnel scan the patient band via a scanner that is communicably connected to the surgical hub **106**, **206**. The surgical hub **106**, **206** can then confirm the patient's identity based on the scanned data.

In the fourth step S**208**, the medical staff turns on the auxiliary equipment. The auxiliary equipment being utilized can vary according to the type of surgical procedure and the techniques to be used by the surgeon, but in this illustrative case, they include a smoke evacuator, insufflator, and medical imaging device. When activated, the auxiliary equipment that are modular devices can automatically pair with the surgical hub **106**, **206** that is located within a particular vicinity of the modular devices as part of their initialization process. The surgical hub **106**, **206** can then derive contextual information about the surgical procedure by detecting the types of modular devices that pair with it during this pre-operative or initialization phase. In this particular example, the surgical hub **106**, **206** determines that the surgical procedure is a VATS procedure based on this particular combination of paired modular devices. Based on the combination of the data from the patient's EMR, the list of medical supplies to be used in the procedure, and the type of modular devices that connect to the hub, the surgical hub **106**, **206** can generally infer the specific procedure that the surgical team will be performing. Once the surgical hub **106**, **206** knows what specific procedure is being performed, the surgical hub **106**, **206** can then retrieve the steps of that procedure from a memory or from the cloud and then cross-reference the data it subsequently receives from the connected data sources (e.g., modular devices and patient monitoring devices) to infer what step of the surgical procedure the surgical team is performing.

In the fifth step S**210**, the staff members attach the EKG electrodes and other patient monitoring devices to the patient. The EKG electrodes and other patient monitoring devices are able to pair with the surgical hub **106**, **206**. As the surgical hub **106**, **206** begins receiving data from the patient monitoring devices, the surgical hub **106**, **206** thus confirms that the patient is in the operating theater.

In the sixth step S**212**, the medical personnel induce anesthesia in the patient. The surgical hub **106**, **206** can infer that the patient is under anesthesia based on data from the modular devices and/or patient monitoring devices, including EKG data, blood pressure data, ventilator data, or combinations thereof, for example. Upon completion of the sixth step S**212**, the pre-operative portion of the lung segmentectomy procedure is completed and the operative portion begins.

In the seventh step S**214**, the patient's lung that is being operated on is collapsed (while ventilation is switched to the contralateral lung). The surgical hub **106**, **206** can infer from the ventilator data that the patient's lung has been collapsed, for example. The surgical hub **106**, **206** can infer that the operative portion of the procedure has commenced, as it can compare the detection of the patient's lung collapsing to the expected steps of the procedure (which can be accessed or retrieved previously) and thereby determine that collapsing the lung is the first operative step in this particular procedure.

In the eighth step S**216**, the medical imaging device (e.g., a scope) is inserted and video from the medical imaging device is initiated. The surgical hub **106**, **206** receives the medical imaging device data (i.e., video or image data) through its connection to the medical imaging device. Upon receipt of the medical imaging device data, the surgical hub **106**, **206** can determine that the laparoscopic portion of the surgical procedure has commenced. Further, the surgical hub **106**, **206** can determine that the particular procedure being performed is a segmentectomy, as opposed to a lobectomy (note that a wedge procedure has already been discounted by the surgical hub **106**, **206** based on data received at the second step S**204** of the procedure). The data from the medical imaging device **124** (FIG. **2**) can be utilized to determine contextual information regarding the type of procedure being performed in a number of different ways, including by determining the angle at which the medical imaging device is oriented with respect to the visualization of the patient's anatomy, monitoring the number of medical imaging devices being utilized (i.e., that are activated and paired with the surgical hub **106**, **206**), and monitoring the types of visualization devices utilized. For example, one technique for performing a VATS lobectomy places the camera in the lower anterior corner of the patient's chest cavity above the diaphragm, whereas one technique for performing a VATS segmentectomy places the camera in an anterior intercostal position relative to the segmental fissure. Using pattern recognition or machine learning techniques, for example, the situational awareness system can be trained to recognize the positioning of the medical imaging device according to the visualization of the patient's anatomy. As another example, one technique for performing a VATS lobectomy utilizes a single medical imaging device, whereas another technique for performing a VATS segmentectomy utilizes multiple cameras. As yet another example, one technique for performing a VATS segmentectomy utilizes an infrared light source (which can be communicably coupled to the surgical hub as part of the visualization system) to visualize the segmental fissure, which is not utilized in a VATS lobectomy. By tracking any or all of this data from the medical imaging device, the surgical hub **106**, **206** can thereby determine the specific type of surgical procedure being performed and/or the technique being used for a particular type of surgical procedure.

In the ninth step S**218**, the surgical team begins the dissection step of the procedure. The surgical hub **106**, **206** can infer that the surgeon is in the process of dissecting to mobilize the patient's lung because it receives data from the RF or ultrasonic generator indicating that an energy instrument is being fired. The surgical hub **106**, **206** can cross-reference the received data with the retrieved steps of the surgical procedure to determine that an energy instrument being fired at this point in the process (i.e., after the completion of the previously discussed steps of the procedure) corresponds to the dissection step. In certain instances, the energy instrument can be an energy tool mounted to a robotic arm of a robotic surgical system.

In the tenth step S**220**, the surgical team proceeds to the ligation step of the procedure. The surgical hub **106**, **206** can infer that the surgeon is ligating arteries and veins because it receives data from the surgical stapling and cutting instrument indicating that the instrument is being fired. Similarly to the prior step, the surgical hub **106**, **206** can derive this inference by cross-referencing the receipt of data from the surgical stapling and cutting instrument with the retrieved steps in the process. In certain instances, the surgical instrument can be a surgical tool mounted to a robotic arm of a robotic surgical system.

In the eleventh step S**222**, the segmentectomy portion of the procedure is performed. The surgical hub **106**, **206** can infer that the surgeon is transecting the parenchyma based on data from the surgical stapling and cutting instrument, including data from its cartridge. The cartridge data can correspond to the size or type of staple being fired by the instrument, for example. As different types of staples are utilized for different types of tissues, the cartridge data can thus indicate the type of tissue being stapled and/or transected. In this case, the type of staple being fired is utilized for parenchyma (or other similar tissue types), which allows the surgical hub **106**, **206** to infer that the segmentectomy portion of the procedure is being performed.

In the twelfth step S**224**, the node dissection step is then performed. The surgical hub **106**, **206** can infer that the surgical team is dissecting the node and performing a leak test based on data received from the generator indicating that an RF or ultrasonic instrument is being fired. For this particular procedure, an RF or ultrasonic instrument being utilized after parenchyma was transected corresponds to the node dissection step, which allows the surgical hub **106**, **206** to make this inference. It should be noted that surgeons regularly switch back and forth between surgical stapling/cutting instruments and surgical energy (i.e., RF or ultrasonic) instruments depending upon the particular step in the procedure because different instruments are better adapted for particular tasks. Therefore, the particular sequence in which the stapling/cutting instruments and surgical energy instruments are used can indicate what step of the procedure the surgeon is performing. Moreover, in certain instances, robotic tools can be utilized for one or more steps in a surgical procedure and/or handheld surgical instruments can be utilized for one or more steps in a surgical procedure. The surgeon(s) can alternate between robotic tools and handheld surgical instruments and/or can use the devices concurrently, for example. Upon completion of the twelfth step S**224**, the incisions are closed up and the post-operative portion of the procedure begins.

In the thirteenth step S**226**, the patient's anesthesia is reversed. The surgical hub **106**, **206** can infer that the patient is emerging from the anesthesia based on the ventilator data (i.e., the patient's breathing rate begins increasing), for example.

Lastly, in the fourteenth step S**228**, the medical personnel remove the various patient monitoring devices from the patient. The surgical hub **106**, **206** can thus infer that the patient is being transferred to a recovery room when the hub loses EKG, BP, and other data from the patient monitoring devices. As can be seen from the description of this illustrative procedure, the surgical hub **106**, **206** can determine or infer when each step of a given surgical procedure is taking place according to data received from the various data sources that are communicably coupled to the surgical hub **106**, **206**.

Situational awareness is further described in U.S. Provisional Patent Application Ser. No. 62/611,341, entitled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, which is incorporated by reference herein in its entirety. In certain instances, operation of a robotic surgical system, including the various robotic surgical systems disclosed herein, for example, can be controlled by the surgical hub **106**, **206** based on its situational awareness and/or feedback from the components thereof and/or based on information from the cloud **102**.

Various aspects of the subject matter described herein are set out in the following numbered examples.

Example 1

A surgical hub configured to transmit generator data associated with a surgical procedure from a generator of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs, the surgical hub, comprising: a processor; and a memory coupled to the processor, the memory storing instructions executable by the processor to: receive generator data from the generator, wherein the generator data is structured into a data packet comprising at least two of the following fields: a field that indicates a source of the data; a unique time stamp; a field indicating an energy mode of the generator; a field indicating a power output of the generator; and a field indicating a duration of the power output of the generator; encrypt the generator data; generate a message authentication code based on the generator data; generate a datagram comprising the encrypted generator data, the generated message authentication code, a source identifier and a destination identifier; and transmit the datagram to a cloud-based system, wherein the datagram allows for the cloud-based system to: decrypt the encrypted generator data of the transmitted datagram; verify the integrity of the generator data based on the message authentication code; authenticate the surgical hub as the source of the datagram; and validate a transmission path followed by the datagram between the surgical hub and the cloud-based system.

Example 2

The surgical hub of Example 1, wherein generating the datagram comprises: generating a datagram header, wherein the datagram header is structured to comprise: a field indicating an IP address associated with the surgical hub; and a field indicating an IP address associated with the cloud-based system; and generating a datagram payload, wherein the datagram payload is structured to comprise the encrypted generator data and the generated message authentication code.

Example 3

The surgical hub of Examples 2, wherein the datagram header is further structured to comprise: a field indicating a transmission path designating at least one IP address associated with at least one intermediate network component through which the datagram is to pass as the datagram is transmitted from the IP address associated with the surgical hub to the IP address associated with the cloud-based system.

Example 4

The surgical hub of any one of Examples 1-3, wherein the instructions are further executable by the processor to: receive a receipt message from the cloud-based system in response to the transmitted datagram, wherein the receipt message indicates at least one of: the integrity of the generator data, decrypted from the transmitted datagram, has been verified by the cloud-based system; the surgical hub has been authenticated as the source of the datagram by the cloud-based system; or the transmission path followed by the transmitted datagram between the surgical hub and the cloud-based system has been validated by the cloud-based system.

Example 5

The surgical hub of any one of Examples 1-4, wherein the instructions are further executable by the processor to: send a message to the cloud-based system, wherein the message requests recommendation generator data associated with a particular surgical procedure; receive a response datagram from the cloud-based system, wherein the response datagram comprises encrypted recommendation generator data and a response message authentication code; decrypt the encrypted recommendation generator data of the response datagram, wherein the recommendation generator data is structured into a response data packet comprising at least one of the following fields: a field indicating an energy mode of the generator for the particular surgical procedure; a field indicating a power output of the generator for the particular surgical procedure; or a field indicating a duration of the power output of the generator for the particular surgical procedure; verify the integrity of the recommendation generator data based on the response message authentication code; and send the recommendation generator data to the generator for implementation, via a generator module, during the particular surgical procedure.

Example 6

The surgical hub of Example 5, wherein the recommendation generator data is based on generator data associated with the particular surgical procedure as securely transmitted by the plurality of surgical hubs to the cloud-based system over time.

Example 7

The surgical hub of Example 1, wherein generating the message authentication code comprises: calculating the message authentication code based on a key, a hash function and one of the received generator data or the encrypted generator data.

Example 8

The surgical hub of Example 7, wherein the key is a secret key and the hash algorithm is a message authentication code algorithm, and wherein calculating the message authentication code comprises processing the encrypted generator data through the message authentication code algorithm using the secret key.

Example 9

The surgical hub of any one of Examples 7-8, wherein the key is a secret key and the hash algorithm is a message authentication code algorithm, and wherein calculating the message authentication code comprises processing the received generator data through the message authentication code algorithm using the secret key.

Example 10

The surgical hub of Example 1, wherein encrypting the generator data comprises encrypting the received generator data using a shared secret or a public key associated with the cloud-based system.

Example 11

A surgical hub configured to transmit generator data associated with a surgical procedure from a generator of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs, the surgical hub, comprising: a control circuit configured to: receive generator data from the generator, wherein the generator data is structured into a data packet comprising at least two of the following fields: a field that indicates a source of the data; a unique time stamp; a field indicating an energy mode of the generator; a field indicating a power output of the generator; and a field indicating a duration of the power output of the generator; encrypt the generator data; generate a message authentication code based on the generator data; generate a datagram comprising the encrypted generator data, the generated message authentication code, a source identifier and a destination identifier; and transmit the datagram to a cloud-based system, wherein the datagram allows for the cloud-based system to: decrypt the encrypted generator data of the transmitted datagram; verify the integrity of the generator data based on the message authentication code; authenticate the surgical hub as the source of the datagram; and validate a transmission path followed by the datagram between the surgical hub and the cloud-based system.

Example 12

The surgical hub of Example 11, wherein the control circuit is further configured to: send a message to the cloud-based system, wherein the message requests recommendation generator data associated with a particular surgical procedure; receive a response datagram from the cloud-based system, wherein the response datagram comprises encrypted recommendation generator data and a response message authentication code; decrypt the encrypted recommendation generator data of the response datagram, wherein the recommendation generator data is structured into a response data packet comprising at least one of the following fields: a field indicating an energy mode of the generator for the particular surgical procedure; a field indicating a power output of the generator for the particular surgical procedure; or a field indicating a duration of the power output of the generator for the particular surgical procedure; verify the integrity of the recommendation generator data based on the response message authentication code; and send the recommendation generator data to the generator for implementation, via a generator module, during the particular surgical procedure.

Example 13

The surgical hub of any one of Examples 11-12, wherein the recommendation generator data is based on generator data associated with the particular surgical procedure as securely transmitted by the plurality of surgical hubs to the cloud-based system over time.

Example 14

A surgical hub configured to prioritize surgical data associated with a surgical procedure from a surgical device of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs, the surgical hub comprising: a processor; and a memory coupled to the processor, the memory storing instructions executable by the processor to: capture surgical data, wherein the surgical data comprises data associated with the surgical device; time-stamp the captured surgical data; identify a failure event; identify a time period associated with the failure event; isolate failure event surgical data from surgical data not associated with the failure event based on the identified time period; chronologize the failure event surgical data by time-stamp; encrypt the chronologized failure event surgical data; generate a datagram comprising the encrypted failure event surgical data, wherein the datagram is structured to include a field which includes a flag that prioritizes the encrypted failure event surgical data over other encrypted data of the datagram; transmit the datagram to the cloud-based system, wherein the datagram allows for the cloud-based system to: decrypt the encrypted failure event surgical data; focus analysis on the failure event surgical data rather than surgical data not associated with the failure event; and flag the surgical device associated with the failure event for at least one of: removal from an operating room; return to a manufacturer; future inoperability in the cloud-based system; or a download update to prevent failure events.

Example 15

The surgical hub of Example 14, wherein the surgical device comprises an end effector including a staple cartridge, wherein the captured surgical data comprises snapshots taken via an endoscope of the surgical hub during a stapling portion of a surgical procedure, and wherein identifying the failure event comprises comparing, via an imaging module of the surgical hub, the snapshots to images conveying correctly fired staples to detect at least one of a misfired staple or evidence of a misfired staple.

Example 16

The surgical hub of any one of Examples 14-15, wherein the instructions are further executable by the processor to: download a program from the cloud-based system for execution by the surgical device, wherein execution of the program modifies the surgical device to prevent misfired staples.

Example 17

The surgical hub of any one of Examples 14-16, wherein the surgical device comprises an end effector including a temperature sensor, wherein the captured surgical data comprises at least one temperature detected by the temperature sensor during a tissue sealing portion of a surgical procedure, and wherein identifying the failure event comprises comparing the at least one detected temperature to a temperature or a range of temperatures associated with that surgical procedure to detect an inadequate sealing temperature.

Example 18

The surgical hub of Example 17, wherein the instructions are further executable by the processor to: download a program from the cloud-based system for execution by the surgical device, wherein execution of the program modifies the surgical device to prevent inadequate sealing temperatures.

Example 19

The surgical hub of Example 14, wherein the identified time period includes a period of time prior to the failure event being identified.

Example 20

The surgical hub of any one of Examples 14-18, wherein the instructions are further executable by the processor to: receive an action message from the cloud-based system, wherein the action message indicates the surgical device as flagged for at least one of: removal from the operating room; return to the manufacturer; future inoperability in the cloud-based system; or the download update to prevent failure events; and provide a notification, via at least one of a user interface of the surgical hub or a user interface of the surgical device, to perform an action associated with the action message.

While several forms have been illustrated and described, it is not the intention of the applicant to restrict or limit the scope of the appended claims to such detail. Numerous modifications, variations, changes, substitutions, combinations, and equivalents to those forms may be implemented and will occur to those skilled in the art without departing from the scope of the present disclosure. Moreover, the structure of each element associated with the described forms can be alternatively described as a means for providing the function performed by the element. Also, where materials are disclosed for certain components, other materials may be used. It is therefore to be understood that the foregoing description and the appended claims are intended to cover all such modifications, combinations, and variations as falling within the scope of the disclosed forms. The appended claims are intended to cover all such modifications, variations, changes, substitutions, modifications, and equivalents.

The foregoing detailed description has set forth various forms of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, and/or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. Those skilled in the art will recognize that some aspects of the forms disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skilled in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein are capable of being distributed as one or more program products in a variety of forms and that an illustrative form of the subject matter described herein applies regardless of the particular type of signal-bearing medium used to actually carry out the distribution.

Instructions used to program logic to perform various disclosed aspects can be stored within a memory in the system, such as DRAM, cache, flash memory, or other storage. Furthermore, the instructions can be distributed via a network or by way of other computer-readable media. Thus a machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer), but is not limited to, floppy diskettes, optical disks, CD-ROMs, magneto-optical disks, ROM, RAM, EPROM, EEPROM, magnetic or optical cards, flash memory, or tangible, machine-readable storage used in the transmission of information over the Internet via electrical, optical, acoustical, or other forms of propagated signals (e.g., carrier waves, infrared signals, digital signals). Accordingly, the non-transitory computer-readable medium includes any type of tangible machine-readable medium suitable for storing or transmitting electronic instructions or information in a form readable by a machine (e.g., a computer).

As used in any aspect herein, the term “control circuit” may refer to, for example, hardwired circuitry, programmable circuitry (e.g., a computer processor comprising one or more individual instruction processing cores, processing unit, processor, microcontroller, microcontroller unit, controller, DSP, PLD, programmable logic array (PLA), or FPGA), state machine circuitry, firmware that stores instructions executed by programmable circuitry, and any combination thereof. The control circuit may, collectively or individually, be embodied as circuitry that forms part of a larger system, for example, an integrated circuit, an application-specific integrated circuit (ASIC), a system on-chip (SoC), desktop computers, laptop computers, tablet computers, servers, smart phones, etc. Accordingly, as used herein, “control circuit” includes, but is not limited to, electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application-specific integrated circuit, electrical circuitry forming a general-purpose computing device configured by a computer program (e.g., a general-purpose computer configured by a computer program which at least partially carries out processes and/or devices described herein, or a microprocessor configured by a computer program which at least partially carries out processes and/or devices described herein), electrical circuitry forming a memory device (e.g., forms of random access memory), and/or electrical circuitry forming a communications device (e.g., a modem, communications switch, or optical-electrical equipment). Those having skill in the art will recognize that the subject matter described herein may be implemented in an analog or digital fashion or some combination thereof.

As used in any aspect herein, the term "logic" may refer to an app, software, firmware, and/or circuitry configured to perform any of the aforementioned operations. Software may be embodied as a software package, code, instructions, instruction sets, and/or data recorded on non-transitory computer-readable storage medium. Firmware may be embodied as code, instructions, instruction sets, and/or data that are hard-coded (e.g., non-volatile) in memory devices.

As used in any aspect herein, the terms "component," "system," "module," and the like can refer to a computer-related entity, either hardware, a combination of hardware and software, software, or software in execution.

As used in any aspect herein, an "algorithm" refers to a self-consistent sequence of steps leading to a desired result, where a "step" refers to a manipulation of physical quantities and/or logic states which may, though need not necessarily, take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It is common usage to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like. These and similar terms may be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities and/or states.

A network may include a packet-switched network. The communication devices may be capable of communicating with each other using a selected packet-switched network communications protocol. One example communications protocol may include an Ethernet communications protocol which may be capable permitting communication using a Transmission Control Protocol/IP. The Ethernet protocol may comply or be compatible with the Ethernet standard published by the Institute of Electrical and Electronics Engineers (IEEE) titled "IEEE 802.3 Standard," published in December 2008 and/or later versions of this standard. Alternatively or additionally, the communication devices may be capable of communicating with each other using an X.25 communications protocol. The X.25 communications protocol may comply or be compatible with a standard promulgated by the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T). Alternatively or additionally, the communication devices may be capable of communicating with each other using a frame relay communications protocol. The frame relay communications protocol may comply or be compatible with a standard promulgated by Consultative Committee for International Telegraph and Telephone (CCITT) and/or the American National Standards Institute (ANSI). Alternatively or additionally, the transceivers may be capable of communicating with each other using an Asynchronous Transfer Mode (ATM) communications protocol. The ATM communications protocol may comply or be compatible with an ATM standard published by the ATM Forum, titled "ATM-MPLS Network Interworking 2.0," published August 2001, and/or later versions of this standard. Of course, different and/or after-developed connection-oriented network communication protocols are equally contemplated herein.

Unless specifically stated otherwise as apparent from the foregoing disclosure, it is appreciated that, throughout the foregoing disclosure, discussions using terms such as "processing," "computing," "calculating," "determining," "displaying," or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission, or display devices.

One or more components may be referred to herein as "configured to," "configurable to," "operable/operative to," "adapted/adaptable," "able to," "conformable/conformed to," etc. Those skilled in the art will recognize that "configured to" can generally encompass active-state components, inactive-state components, and/or standby-state components, unless context requires otherwise.

The terms "proximal" and "distal" are used herein with reference to a clinician manipulating the handle portion of the surgical instrument. The term "proximal" refers to the portion closest to the clinician, and the term "distal" refers to the portion located away from the clinician. It will be further appreciated that, for convenience and clarity, spatial terms such as "vertical," "horizontal," "up," and "down" may be used herein with respect to the drawings. However, surgical instruments are used in many orientations and positions, and these terms are not intended to be limiting and/or absolute.

Those skilled in the art will recognize that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims), are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including, but not limited to"; the term "having" should be interpreted as "having at least"; the term "includes" should be interpreted as "includes, but is not limited to"). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation, no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to claims containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations.

In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means at least two recitations or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general, such a construction is intended in the sense that one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include, but not be limited to, systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general, such a construction is intended in the sense that one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include, but not be limited to, systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together). It will be further understood by those within the art that typically a disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms, unless context dictates otherwise. For example, the phrase "A or B" will be typically understood to include the possibilities of "A" or "B" or "A and B."

With respect to the appended claims, those skilled in the art will appreciate that recited operations therein may generally be performed in any order. Also, although various operational flow diagrams are presented in a sequence(s), it should be understood that the various operations may be performed in other orders than those which are illustrated or may be performed concurrently. Examples of such alternate orderings may include overlapping, interleaved, interrupted, reordered, incremental, preparatory, supplemental, simultaneous, reverse, or other variant orderings, unless context dictates otherwise. Furthermore, terms like "responsive to," "related to," or other past-tense adjectives are generally not intended to exclude such variants, unless context dictates otherwise.

It is worthy to note that any reference to "one aspect," "an aspect," "an exemplification," "one exemplification," and the like means that a particular feature, structure, or characteristic described in connection with the aspect is included in at least one aspect. Thus, appearances of the phrases "in one aspect," "in an aspect," "in an exemplification," and "in one exemplification" in various places throughout the specification are not necessarily all referring to the same aspect. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more aspects.

Any patent application, patent, non-patent publication, or other disclosure material referred to in this specification and/or listed in any Application Data Sheet is incorporated by reference herein, to the extent that the incorporated materials are not inconsistent herewith. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

In summary, numerous benefits have been described which result from employing the concepts described herein. The foregoing description of the one or more forms has been presented for purposes of illustration and description. It is not intended to be exhaustive or limiting to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The one or more forms were chosen and described in order to illustrate principles and practical application to thereby enable one of ordinary skill in the art to utilize the various forms and with various modifications as are suited to the particular use contemplated. It is intended that the claims submitted herewith define the overall scope.

The invention claimed is:

1. A surgical hub configured to transmit generator data associated with a surgical procedure from a generator of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs, the surgical hub, comprising:

- a processor; and
- a memory coupled to the processor, the memory storing instructions executable by the processor to:
  - receive generator data from the generator, wherein the generator data is structured into a data packet comprising at least two of the following fields:
    - a field that indicates a source of the generator data;
    - a unique time stamp;
    - a field indicating an energy mode of the generator;
    - a field indicating a power output of the generator; and
    - a field indicating a duration of the power output of the generator;
  - encrypt the generator data;
  - generate a message authentication code based on the generator data;
  - generate a datagram comprising: the encrypted generator data, the generated message authentication code, a source identifier, and a destination identifier; and
  - transmit the datagram to the cloud-based system, wherein the datagram allows for the cloud-based system to:
    - decrypt the encrypted generator data of the transmitted datagram;
    - verify integrity of the generator data based on the message authentication code;
    - authenticate the surgical hub as a source of the datagram; and
    - validate a transmission path followed by the datagram between the surgical hub and the cloud-based system.

2. The surgical hub of claim **1**, wherein generating the datagram comprises:

- generating a datagram header, wherein the datagram header is structured to comprise:
  - a field indicating an IP address associated with the surgical hub; and
  - a field indicating an IP address associated with the cloud-based system; and
- generating a datagram payload, wherein the datagram payload is structured to comprise the encrypted generator data and the generated message authentication code.

3. The surgical hub of claim **2**, wherein the datagram header is further structured to comprise:

- a field indicating a transmission path designating at least one IP address associated with at least one intermediate network component through which the datagram is to pass as the datagram is transmitted from the IP address associated with the surgical hub to the IP address associated with the cloud-based system.

4. The surgical hub of claim **1**, wherein the instructions are further executable by the processor to:

receive a receipt message from the cloud-based system in response to the transmitted datagram, wherein the receipt message indicates at least one of:

the integrity of the generator data, decrypted from the transmitted datagram, has been verified by the cloud-based system;

the surgical hub has been authenticated as the source of the datagram by the cloud-based system; or

the transmission path followed by the transmitted datagram between the surgical hub and the cloud-based system has been validated by the cloud-based system.

5. The surgical hub of claim **1**, wherein the instructions are further executable by the processor to:

send a message to the cloud-based system, wherein the message requests recommendation generator data associated with a particular surgical procedure;

receive a response datagram from the cloud-based system, wherein the response datagram comprises encrypted recommendation generator data and a response message authentication code;

decrypt the encrypted recommendation generator data of the response datagram, wherein the recommendation generator data is structured into a response data packet comprising at least one of the following fields:

a field indicating an energy mode of the generator for the particular surgical procedure;

a field indicating a power output of the generator for the particular surgical procedure; or

a field indicating a duration of the power output of the generator for the particular surgical procedure;

verify integrity of the recommendation generator data based on the response message authentication code; and

send the recommendation generator data to the generator for implementation, via a generator module, during the particular surgical procedure.

6. The surgical hub of claim **5**, wherein the recommendation generator data is based on generator data associated with the particular surgical procedure as securely transmitted by the plurality of surgical hubs to the cloud-based system over time.

7. The surgical hub of claim **1**, wherein generating the message authentication code comprises:

calculating the message authentication code based on a key, a hash function and one of the received generator data or the encrypted generator data.

8. The surgical hub of claim **7**, wherein the key is a secret key and the hash function is a message authentication code algorithm, and wherein calculating the message authentication code comprises processing the encrypted generator data through the message authentication code algorithm using the secret key.

9. The surgical hub of claim **7**, wherein the key is a secret key and the hash function is a message authentication code algorithm, and wherein calculating the message authentication code comprises processing the received generator data through the message authentication code algorithm using the secret key.

10. The surgical hub of claim **1**, wherein encrypting the generator data comprises encrypting the received generator data using a shared secret or a public key associated with the cloud-based system.

11. A surgical hub configured to transmit generator data associated with a surgical procedure from a generator of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs, the surgical hub, comprising:

a control circuit configured to:

receive generator data from the generator, wherein the generator data is structured into a data packet comprising at least two of the following fields:

a field that indicates a source of the generator data;

a unique time stamp;

a field indicating an energy mode of the generator;

a field indicating a power output of the generator; and

a field indicating a duration of the power output of the generator;

encrypt the generator data;

generate a message authentication code based on the generator data;

generate a datagram comprising the encrypted generator data, the generated message authentication code, a source identifier and a destination identifier; and

transmit the datagram to a cloud-based system, wherein the datagram allows for the cloud-based system to:

decrypt the encrypted generator data of the transmitted datagram;

verify integrity of the generator data based on the message authentication code;

authenticate the surgical hub as a source of the datagram; and

validate a transmission path followed by the datagram between the surgical hub and the cloud-based system.

12. The surgical hub of claim **11**, wherein the control circuit is further configured to:

send a message to the cloud-based system, wherein the message requests recommendation generator data associated with a particular surgical procedure;

receive a response datagram from the cloud-based system, wherein the response datagram comprises encrypted recommendation generator data and a response message authentication code;

decrypt the encrypted recommendation generator data of the response datagram, wherein the recommendation generator data is structured into a response data packet comprising at least one of the following fields:

a field indicating an energy mode of the generator for the particular surgical procedure;

a field indicating a power output of the generator for the particular surgical procedure; or

a field indicating a duration of the power output of the generator for the particular surgical procedure;

verify integrity of the recommendation generator data based on the response message authentication code; and

send the recommendation generator data to the generator for implementation, via a generator module, during the particular surgical procedure.

13. The surgical hub of claim **12**, wherein the recommendation generator data is based on generator data associated with the particular surgical procedure as securely transmitted by the plurality of surgical hubs to the cloud-based system over time.

14. A surgical hub configured to prioritize surgical data associated with a surgical procedure from a surgical device of the surgical hub to a cloud-based system communicatively coupled to a plurality of surgical hubs, the surgical hub comprising:

a processor; and

a memory coupled to the processor, the memory storing instructions executable by the processor to:

capture surgical data, wherein the surgical data comprises data associated with the surgical device;

time-stamp the captured surgical data;

identify a failure event;

identify a time period associated with the failure event;

isolate failure event surgical data from surgical data not associated with the failure event based on the identified time period;

chronologize the failure event surgical data by time-stamp;

encrypt the chronologized failure event surgical data;

generate a datagram comprising the encrypted chronologized failure event surgical data, wherein the datagram is structured to include a field which includes a flag that prioritizes the encrypted chronologized failure event surgical data over other encrypted data of the datagram;

transmit the datagram to the cloud-based system, wherein the datagram allows for the cloud-based system to:

decrypt the encrypted chronologized failure event surgical data;

focus analysis on the failure event surgical data rather than surgical data not associated with the failure event; and

flag the surgical device associated with the failure event for at least one of:

removal from an operating room;

return to a manufacturer;

future inoperability in the cloud-based system; or

a download update to prevent failure events.

15. The surgical hub of claim **14**, wherein the surgical device comprises an end effector including a staple cartridge, wherein the captured surgical data comprises snapshots taken via an endoscope of the surgical hub during a stapling portion of a surgical procedure, and wherein identifying the failure event comprises comparing, via an imaging module of the surgical hub, the snapshots to images conveying correctly fired staples to detect at least one of a misfired staple or evidence of a misfired staple.

16. The surgical hub of claim **15**, wherein the instructions are further executable by the processor to:

download a program from the cloud-based system for execution by the surgical device, wherein execution of the program modifies the surgical device to prevent misfired staples.

17. The surgical hub of claim **14**, wherein the surgical device comprises an end effector including a temperature sensor, wherein the captured surgical data comprises at least one temperature detected by the temperature sensor during a tissue sealing portion of a surgical procedure, and wherein identifying the failure event comprises comparing the at least one detected temperature to a temperature or a range of temperatures associated with that surgical procedure to detect an inadequate sealing temperature.

18. The surgical hub of claim **17**, wherein the instructions are further executable by the processor to:

download a program from the cloud-based system for execution by the surgical device, wherein execution of the program modifies the surgical device to prevent inadequate sealing temperatures.

19. The surgical hub of claim **14**, wherein the identified time period includes a period of time prior to the failure event being identified.

20. The surgical hub of claim **14**, wherein the instructions are further executable by the processor to:

receive an action message from the cloud-based system, wherein the action message indicates the surgical device as flagged for at least one of:

removal from the operating room;

return to the manufacturer;

future inoperability in the cloud-based system; or

the download update to prevent failure events; and

provide a notification, via at least one of a user interface of the surgical hub or a user interface of the surgical device, to perform an action associated with the action message.

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