



US011719088B2

(12) **United States Patent**
Bermudez Martinez

(10) **Patent No.:** **US 11,719,088 B2**

(45) **Date of Patent:** ***Aug. 8, 2023**

(54) **CROSS-PLOT ENGINEERING SYSTEM AND METHOD**

(71) Applicant: **Petrolink International Ltd.**, Douglas (IM)

(72) Inventor: **Rafael Angel Bermudez Martinez**, Houston, TX (US)

(73) Assignee: **Petrolink International Ltd.**, Douglas (IM)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 44 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **17/383,200**

(22) Filed: **Jul. 22, 2021**

(65) **Prior Publication Data**

US 2021/0348496 A1 Nov. 11, 2021

Related U.S. Application Data

(63) Continuation of application No. 17/063,035, filed on Oct. 5, 2020, now Pat. No. 11,105,193, which is a (Continued)

(51) **Int. Cl.**

E21B 47/00 (2012.01)

E21B 44/00 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC **E21B 47/00** (2013.01); **E21B 44/00** (2013.01); **E21B 45/00** (2013.01); **E21B 47/024** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC E21B 47/00; E21B 47/024; E21B 44/00; E21B 45/00; E21B 49/00; E21B 49/08; G06T 11/206

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,205,371 A 5/1980 Feather
4,794,535 A 12/1988 Gray et al.

(Continued)

OTHER PUBLICATIONS

Li, Y., Bjorndalen, N., and E. Kuru. "Numerical Modelling of Cuttings Transport in Horizontal Wells Using Conventional Drilling Fluids," J Can Pet Technol 46 (2007): No Pagination Specified, doi: <https://doi.org/10.2118/07-07-TN> (Year: 2007).

(Continued)

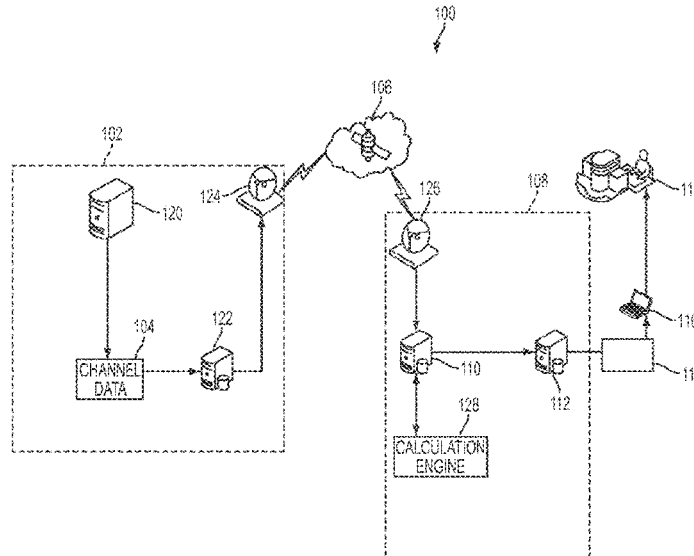
Primary Examiner — Toan M Le

(74) *Attorney, Agent, or Firm* — Bradley Arant Boult Cummings LLP

(57) **ABSTRACT**

In one embodiment, a method includes facilitating a real-time cross-plot display of drilling-performance data for a current well. The real-time cross-plot display includes a plurality of data plots represented on a common graph such that each data plot specifying at least two drilling parameters. Each data plot includes a plurality of data points such that each data point is expressible as Cartesian coordinates in terms of the at least two drilling parameters. The method further includes receiving new channel data for the current well from a wellsite computer system. In addition, the method includes creating, from the new channel data, new data points for the plurality of data plots as the new channel data is received. Moreover, the method includes updating the plurality of data plots with the new data points as the new data points are created.

20 Claims, 7 Drawing Sheets



Related U.S. Application Data

continuation of application No. 16/404,175, filed on May 6, 2019, now Pat. No. 10,830,035, which is a continuation of application No. 15/343,535, filed on Nov. 4, 2016, now Pat. No. 10,329,892, which is a continuation of application No. 14/018,298, filed on Sep. 4, 2013, now Pat. No. 9,512,707, which is a continuation-in-part of application No. 13/919,240, filed on Jun. 17, 2013, now Pat. No. 9,518,459.

(60) Provisional application No. 61/697,687, filed on Sep. 6, 2012, provisional application No. 61/660,565, filed on Jun. 15, 2012.

(51) **Int. Cl.**

E21B 45/00 (2006.01)
E21B 47/024 (2006.01)
E21B 49/00 (2006.01)
E21B 49/08 (2006.01)
G06T 11/20 (2006.01)

(52) **U.S. Cl.**

CPC **E21B 49/00** (2013.01); **E21B 49/08** (2013.01); **G06T 11/206** (2013.01)

(56)

References Cited

U.S. PATENT DOCUMENTS

5,128,866	A	7/1992	Weakley
6,109,368	A	8/2000	Goldman et al.
6,411,902	B1	6/2002	Wiltshire
6,749,029	B2	6/2004	Alft et al.
6,826,486	B1	11/2004	Malinverno
6,950,786	B1	9/2005	Sonneland et al.
7,054,750	B2	5/2006	Rodney et al.
7,066,284	B2	6/2006	Wylie et al.
7,142,986	B2	11/2006	Moran
7,225,879	B2	6/2007	Wylie et al.
7,341,117	B2	3/2008	Wylie et al.
7,542,979	B2	6/2009	Gupta et al.
7,571,777	B2	8/2009	Wylie et al.
7,606,666	B2	10/2009	Repin et al.
7,836,973	B2	11/2010	Belcher et al.
7,980,312	B1	7/2011	Hill et al.
8,011,446	B2	9/2011	Wylie et al.
8,122,975	B2	2/2012	Belcher et al.
8,316,936	B2	11/2012	Roddy et al.
8,615,374	B1	12/2013	Discenzo
9,191,266	B2	11/2015	Abraham et al.
9,512,707	B1	12/2016	Bermudez Martinez
9,518,459	B1	12/2016	Bermudez Martinez et al.
10,209,400	B2	2/2019	Bermudez Martinez et al.
10,329,892	B2	6/2019	Bermudez Martinez
10,590,761	B1	3/2020	Bermudez Martinez
10,830,035	B1*	11/2020	Bermudez Martinez
			E21B 47/00
11,105,193	B2*	8/2021	Bermudez Martinez
			E21B 45/00
2002/0073082	A1	6/2002	Duvillier et al.
2003/0074139	A1	4/2003	Poedjono
2004/0019696	A1	1/2004	Scott et al.
2004/0149431	A1	8/2004	Wylie et al.
2005/0063251	A1	3/2005	Guidry et al.
2005/0197777	A1	9/2005	Rodney et al.
2005/0209866	A1	9/2005	Veeningen et al.
2005/0241855	A1	11/2005	Wylie et al.
2005/0267899	A1	12/2005	Gupta et al.
2006/0173625	A1	8/2006	Moran
2007/0047279	A1	3/2007	Evans et al.
2007/0061081	A1	3/2007	Moran
2007/0089508	A1	4/2007	Allmendinger
2007/0185696	A1	8/2007	Moran et al.
2007/0187146	A1	8/2007	Wylie et al.
2007/0252717	A1	11/2007	Fielder

2007/0284147	A1	12/2007	Moran
2008/0060846	A1	3/2008	Belcher et al.
2008/0071817	A1	3/2008	Gaurav et al.
2008/0087423	A1	4/2008	Wylie et al.
2008/0156977	A1	7/2008	Jeffryes
2008/0179094	A1	7/2008	Repin et al.
2008/0181230	A1	7/2008	Hitt et al.
2008/0184269	A1	7/2008	Avery et al.
2008/0208475	A1	8/2008	Karr et al.
2008/0262810	A1	10/2008	Moran et al.
2008/0294606	A1	11/2008	Moran et al.
2009/0077008	A1	3/2009	Francis
2009/0090555	A1	4/2009	Boone et al.
2009/0132458	A1	5/2009	Edwards et al.
2009/0152005	A1	6/2009	Chapman et al.
2009/0159336	A1	6/2009	Boone
2009/0182472	A1	7/2009	Singh et al.
2009/0234584	A1	9/2009	Casey et al.
2009/0254569	A1	10/2009	Paulk et al.
2009/0294174	A1	12/2009	Harmer et al.
2009/0308601	A1	12/2009	Poe, Jr. et al.
2009/0308616	A1	12/2009	Wylie et al.
2010/0005111	A1	1/2010	Bal et al.
2010/0179963	A1	7/2010	Conner et al.
2010/0191511	A1	7/2010	Hsu et al.
2010/0204972	A1	8/2010	Hsu et al.
2010/0217530	A1	8/2010	Boone
2010/0259415	A1	10/2010	Strachan et al.
2011/0106856	A2	5/2011	Paulk et al.
2011/0114387	A1	5/2011	Belcher et al.
2011/0132662	A1	6/2011	Dennis
2011/0166843	A1	7/2011	Hsu et al.
2011/0170373	A1	7/2011	Hsu et al.
2011/0174541	A1	7/2011	Strachan et al.
2011/0175899	A1	7/2011	Bittar et al.
2011/0253445	A1	10/2011	Hannegan et al.
2012/0072578	A1	3/2012	Alam
2012/0197898	A1	8/2012	Pandey et al.
2013/0013677	A1	1/2013	Engstrom et al.
2013/0135115	A1	5/2013	Johnson et al.
2013/0144531	A1	6/2013	Johnston
2013/0254416	A1	9/2013	Abraham et al.
2015/0347565	A1	12/2015	Abraham et al.
2016/0281490	A1	9/2016	Samuel
2016/0281498	A1	9/2016	Nguyen et al.
2017/0051601	A1	2/2017	Bermudez Martinez
2017/0052282	A1	2/2017	Bermudez Martinez et al.
2019/0146118	A1	5/2019	Bermudez Martinez et al.
2019/0213205	A1	7/2019	Abraham et al.
2019/0376385	A1	12/2019	Bermudez Martinez

OTHER PUBLICATIONS

DrillingFormulas.Com, Critical Flow Rate—Drilling Hydraulics, May 15, 2012—6:30 am, <https://www.drillingformulas.com/critical-flow-rate-drilling-hydraulics/> (Year: 2012).

DrillingFormulas.Com, Power Law Constants (n and K) Calculation, Apr. 16, 2012—12:10 pm, <https://www.drillingformulas.com/power-law-constants-n-and-k-calculation/> (Year: 2012).

DrillingFormulas.Com, Effective Viscosity Calculation, Apr. 30, 2012—16:16 pm, <https://www.drillingformulas.com/effective-viscosity-calculation/> (Year: 2012).

U.S. Appl. No. 14/477,444, Bermudez Martinez.

U.S. Appl. No. 15/446,761, Gonzalez.

Halliburton / Landmark Software & Services, “Drillworks® User Guide”, Oct. 2009.

Martínez, R.B., Petrolink Services, Inc., and Olán, C.I., Petrolink Services, Inc., “Improving Real-Time Drilling Optimization Applying Engineering Performance From Offset Wells.” SPWLA 53rd Annual Logging Symposium, Jun. 16-20, 2012.

Khudiri, M.M. and Shehry, M.A., Saudi Aramco, and Curtis, J.D., Petrolink International, “Data Architecture of Real-Time Drilling and Completions Information at Saudi Aramco,” SPE 116848, 2008 SPE Russian Oil & Gas Technical Conference and Exhibition, Moscow, Russia, Oct. 28-30, 2008.

Pérez-Téllez, C., Rodríguez, R., and Ramírez, I., PEMEX Drilling Business Unit, and Bermúdez-Martínez, R.A., and Palavicini-

(56)

References Cited

OTHER PUBLICATIONS

Cham, C.A., Petrolink Services Inc., "Applying a Real-Time Engineering Methodology to Drill Ahead of Potential Undesirable Events;" OTC 23180, Offshore Technology Conference, Houston, Texas, USA, Apr. 30-May 3, 2012.

González, Edgar, "U.S. Appl. No. 15/446,761," filed Mar. 1, 2017.
Bermudez Martinez, Rafael Angel, "U.S. Appl. No. 14/477,444," filed Sep. 4, 2014.

Mclaren, et al., "Improving the Value of Real-Time Drilling Data to Aid Collaboration, Drilling Optimization, and Decision Making," Nov. 11-14, 2007, 2007 SPE Annual Technical Conference and Exhibition, Anaheim, CA, pp. 1-13.

One_Petro_Search_Results, Mar. 9, 2021, 6 pp. (Year: 2021).

Yoshida, Chikao, et al.; "An Investigative Study of Recent Technologies Used for Prediction, Detection, and Evaluation of Abnormal Formation Pressure and Fracture Pressure in North and South America"; IADC/SPE Asia Pacific Drilling Technology Conference; Kuala Lumpur, Malaysia; Sep. 1996; pp. 131-151.

One Petro Search Results; dated Jun. 14, 2021; 10 pages.

Fontenot et al., John E., "An Improved Method for Calculating Swab and Surge Pressures and Circulating Pressures in a Drilling Well," SPE J. 14 (1974); pp. 451-462. doi: <https://doi.org/10.2118/4521-PA> (Year: 1974).

Whittaker, A., Swab and Surge, In: Whittaker, A. (eds), "Theory and Applications of Drilling Fluid Hydraulics", The EXLOG Series of Petroleum Geology and Engineering Handbooks, vol. 1, pp. 1-210, Springer, Dordrecht, https://doi.org/10.1007/978-94-009-5303-1_8 (Year: 1985).

* cited by examiner

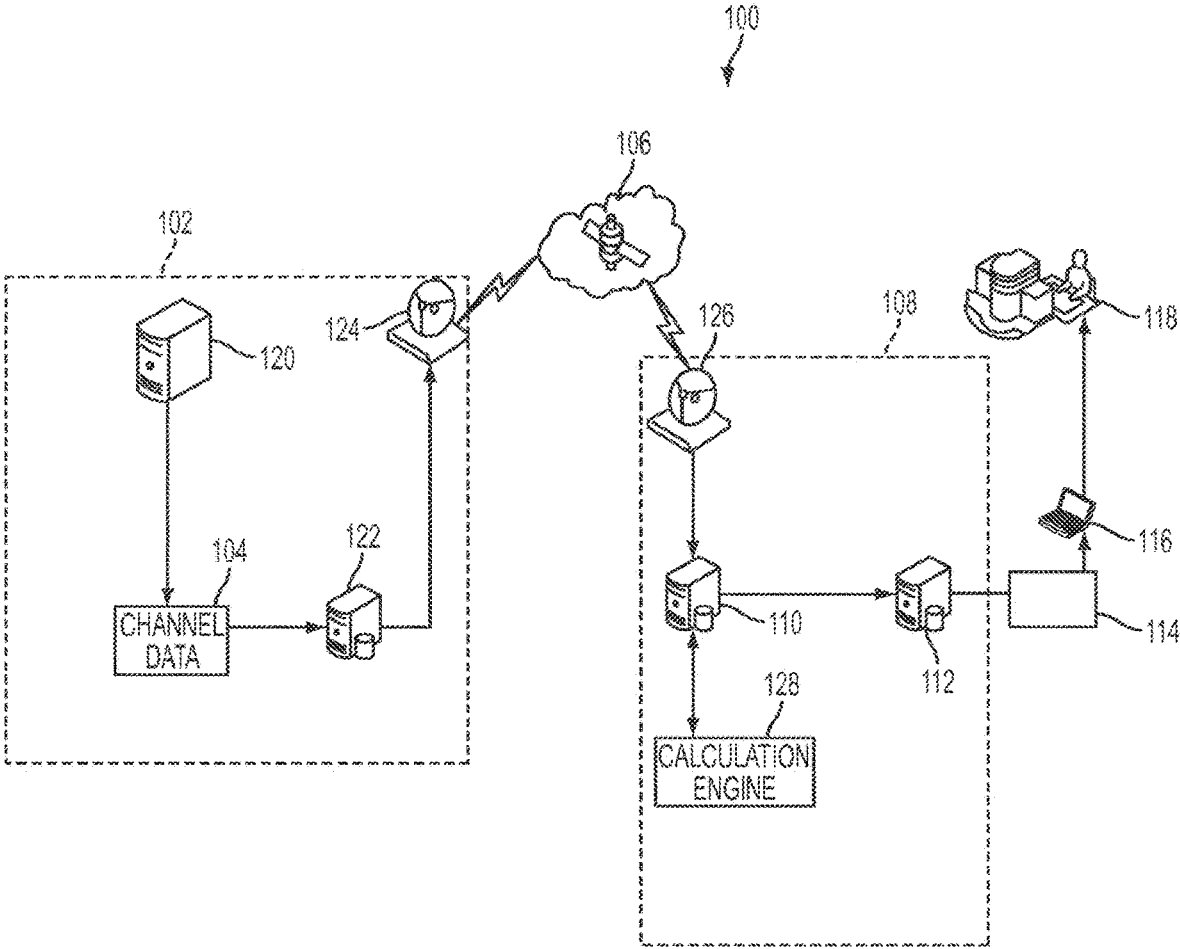


FIG. 1

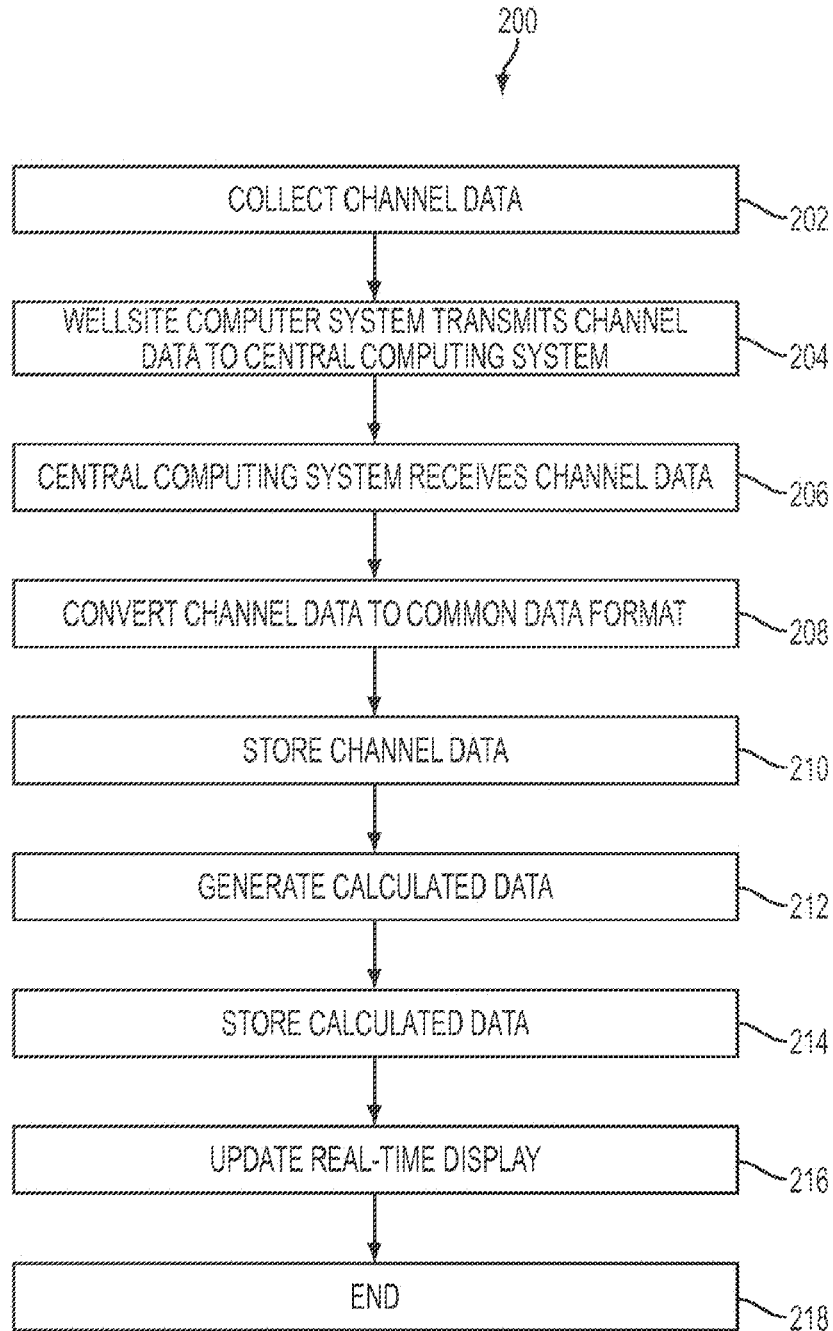


FIG. 2

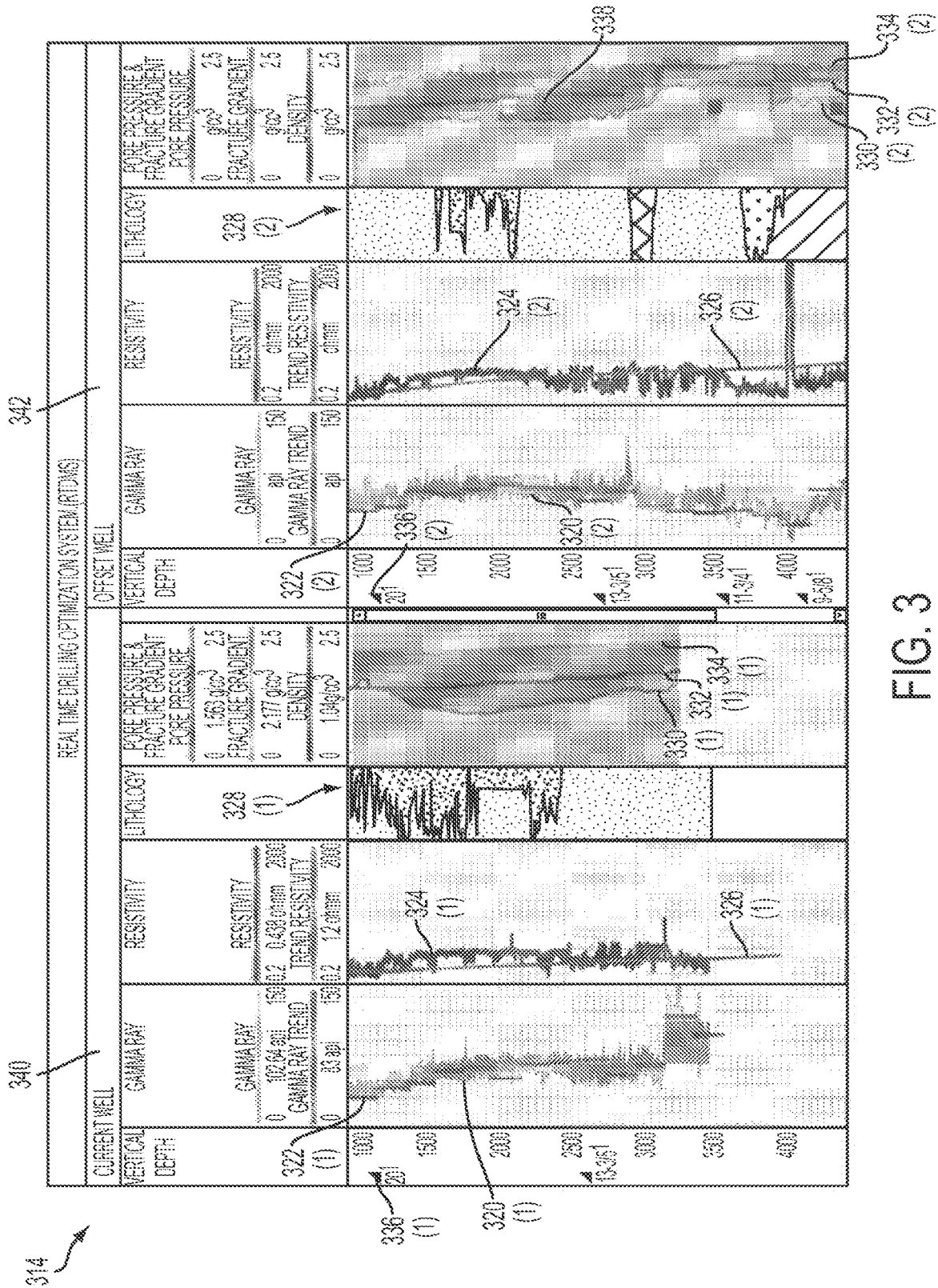


FIG. 3

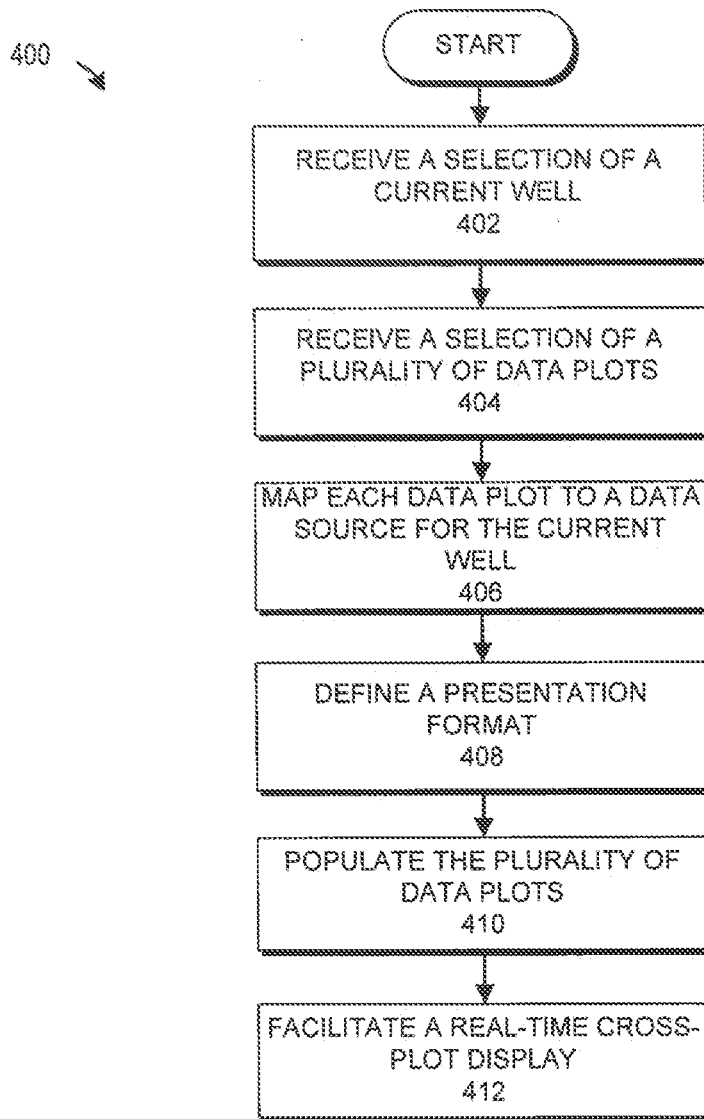


FIG. 4

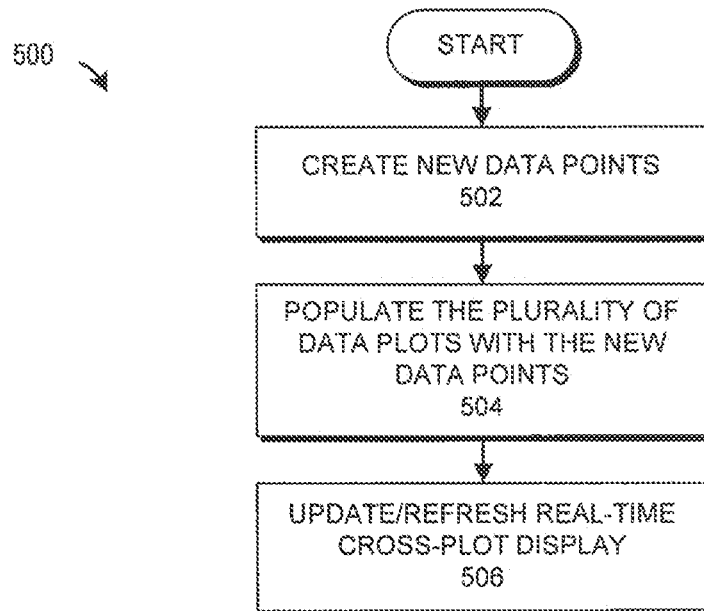


FIG. 5

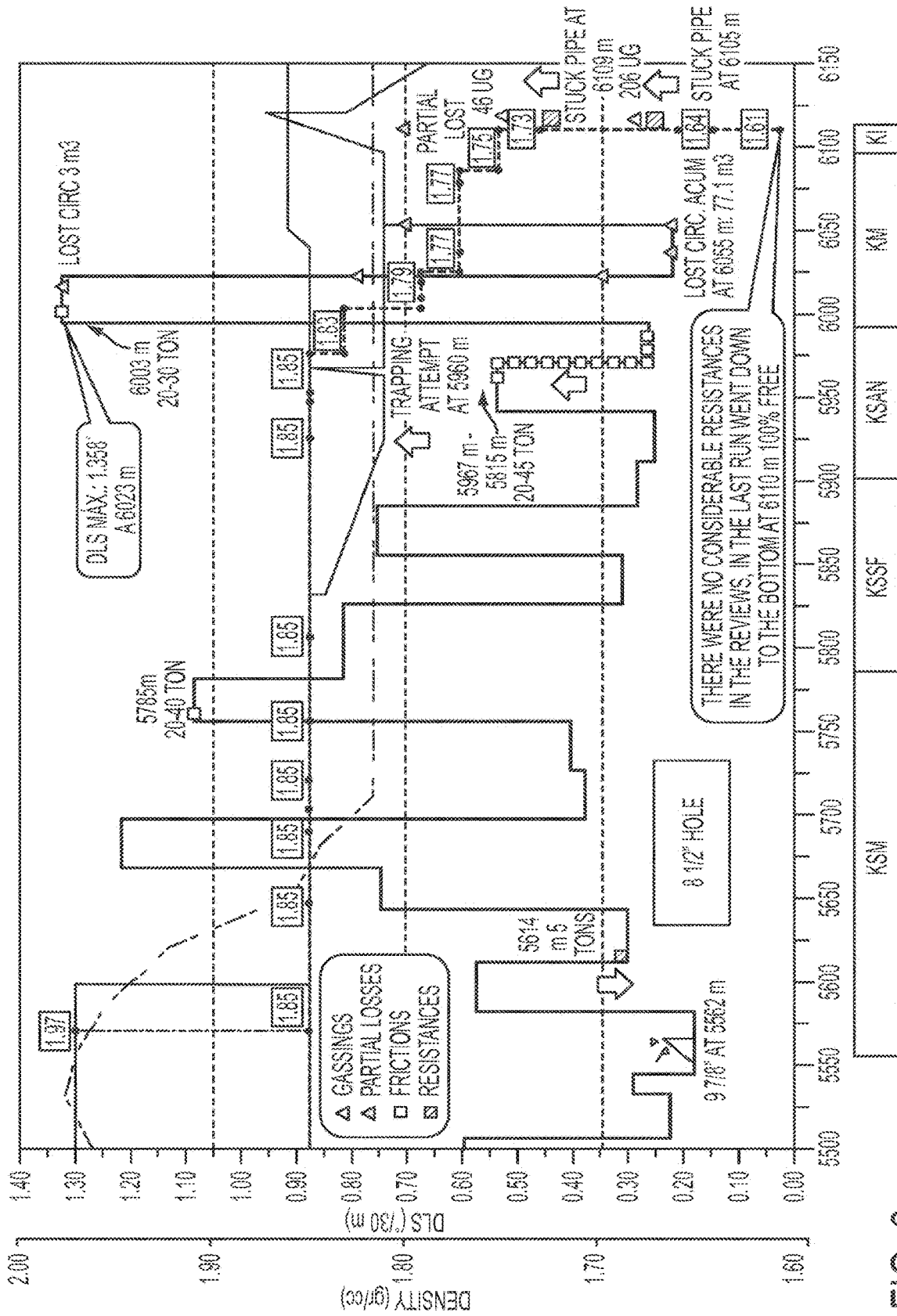


FIG. 6

CROSS-PLOT ENGINEERING SYSTEM AND METHOD**CROSS-REFERENCE TO RELATED APPLICATIONS**

This patent application is a continuation of U.S. patent application Ser. No. 17/063,035, filed on Oct. 5, 2020. U.S. patent application Ser. No. 17/063,035 is a continuation of U.S. patent application Ser. No. 16/404,175, filed on May 6, 2019, now U.S. Pat. No. 10,830,035. U.S. patent application Ser. No. 16/404,175 is a continuation of U.S. patent application Ser. No. 15/343,535, filed on Nov. 4, 2016, now U.S. Pat. No. 10,329,892. U.S. patent application Ser. No. 15/343,535 is a continuation of Ser. No. 14/018,298, filed on Sep. 4, 2013, now U.S. Pat. No. 9,512,707. U.S. patent application Ser. No. 14/018,298 is a continuation-in-part of U.S. patent application Ser. No. 13/919,240, filed on Jun. 17, 2013, now U.S. Pat. No. 9,518,459. U.S. patent application Ser. No. 13/919,240 claims priority from U.S. Provisional Application No. 61/660,565, filed on Jun. 15, 2012. U.S. patent application Ser. No. 14/018,298 claims priority from U.S. Provisional Application No. 61/697,687, filed on Sep. 6, 2012. U.S. patent application Ser. Nos. 17/063,035, 16/404,175, 15/343,535, 14/018,298, 13/919,240, 61/660,565, 61/697,687 are hereby incorporated by reference in their entirety.

BACKGROUND**Technical Field**

The present invention relates generally to drilling analytics and more particularly, but not by way of limitation, to systems and methods for enabling real-time drilling-performance analysis.

History of Related Art

Over the years, the world of drilling has become increasingly technical. Drilling professionals constantly search for engineering solutions to achieve profitable production targets efficiently. Thus, the oil-and-gas industry continues to develop new drilling-engineering techniques to facilitate the understanding of geological and physical phenomena that occur during drilling operations worldwide. However, it is difficult to present information in a timely and comprehensive manner, for example, to a drilling engineer, so that appropriate decisions can be made.

SUMMARY OF THE INVENTION

In one embodiment, a method includes, on a central computing system comprising at least one server computer, facilitating a real-time cross-plot display of drilling-performance data for a current well. The real-time cross-plot display includes a plurality of data plots represented on a common graph such that each data plot specifies at least two drilling parameters. Each data plot comprises a plurality of data points such that each data point is expressible as Cartesian coordinates in terms of the at least two drilling parameters. The method also includes the central computing system receiving new channel data for the current well from a wellsite computer system. In addition, the method includes the central computing system creating, from the new channel data, new data points for the plurality of data plots as the new channel data is received. Furthermore, the method

includes the central computing system updating the plurality of data plots with the new data points as the new data points are created.

In one embodiment, a system includes at least one server computer. The at least one server computer is operable to perform a method. The method includes facilitating a real-time cross-plot display of drilling-performance data for a current well. The real-time cross-plot display comprises a plurality of data plots represented on a common graph such that each data plot specifying at least two drilling parameters. Each data plot includes a plurality of data points such that each data point is expressible as Cartesian coordinates in terms of the at least two drilling parameters. The method further includes receiving new channel data for the current well from a wellsite computer system. In addition, the method includes creating, from the new channel data, new data points for the plurality of data plots as the new channel data is received. Moreover, the method includes updating the plurality of data plots with the new data points as the new data points are created.

In one embodiment, a computer-program product includes a computer-usable medium having computer-readable program code embodied therein. The computer-readable program code is adapted to be executed to implement a method. The method includes facilitating a real-time cross-plot display of drilling-performance data for a current well. The real-time cross-plot display comprises a plurality of data plots represented on a common graph such that each data plot specifying at least two drilling parameters. Each data plot includes a plurality of data points such that each data point is expressible as Cartesian coordinates in terms of the at least two drilling parameters. The method further includes receiving new channel data for the current well from a wellsite computer system. In addition, the method includes creating, from the new channel data, new data points for the plurality of data plots as the new channel data is received. Moreover, the method includes updating the plurality of data plots with the new data points as the new data points are created.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the method and apparatus of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

FIG. 1 illustrates a system for facilitating real-time drilling-performance analysis;

FIG. 2 illustrates a process for performing real-time drilling analysis;

FIG. 3 illustrates an example of real-time drilling-performance analysis via a real-time display;

FIG. 4 illustrates a process for creating a cross plot;

FIG. 5 illustrates a process for updating a real-time cross-plot display; and

FIGS. 6-7 illustrate examples of real-time cross-plot displays.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS OF THE INVENTION

In various embodiments, a real-time cross-plot display can integrate a plurality of data plots that depict selected drilling parameters and/or drilling events for a given well. In certain embodiments, the real-time cross-plot display can be created when drilling operations commence for a given well and be continuously updated from that point forward.

For purposes of this patent application, drilling parameters can include any type or segmentation of channel data, input data, calculated data, and combinations thereof. For example, the drilling parameters can relate to depth, date, densities, geological formation, volume loss and gain, casing points, offset well casing points, trajectory analysis (e.g., inclination, azimuth, etc.), fluid properties (plastic viscosity, yield point, etc.), standard pipe pressure (SPP), rate of penetration (ROP), equivalent circulating density (ECD), gallons per minute (GPM), weight on bit (WOB), torque, hook load, and/or the like. In addition, trapping, drag, friction, resistance, and technical comments can be integrated while drilling advances meter by meter, thereby allowing simultaneous identification of a drilling technical condition that is different from what is expected (e.g., a drilling event). In a typical embodiment, drilling-performance cross plots can be shown in real-time on a real-time display (i.e., a real-time cross-plot display).

In various embodiments, cross-plots can be defined and used as needed for a given well. In these embodiments, each cross plot can include a selection of drilling parameters and drilling events, a defined presentation format, and a defined period of time (e.g., from a time when drilling begins). The presentation format can specify, for example, how and where the drilling parameters and drilling events are graphically presented. In addition, in various embodiments, a drilling professional such as, for example, a drilling engineer, can create a custom cross-plot by selecting drilling parameters and drilling events and specifying a presentation format.

In addition, in various embodiments, real-time drilling-performance analytics such as, for example, pore pressure and fracture gradient, can be facilitated by leveraging historical drilling-performance data from offset wells. As one of ordinary skill in the art will appreciate, an offset well is a pre-existing well that is in close proximity to the current well. For example, an offset well can be located adjacently to the current well according to spacing rules defined by applicable law. However, it should be appreciated that immediate adjacency need not be required.

FIG. 1 illustrates a system 100 for facilitating real-time drilling-performance analysis. The system 100 includes a wellsite computer system 102, a central computing system 108, and a communications network 106. The wellsite computer system 102 includes a collection server 120, a remote-integration server 122, and a network link 124. The central computing system 108 includes a main server 110, a repository server 112, and a network link 126. It should be appreciated that the depicted configurations of the central computing system 108 and the wellsite computer system 102 are illustrative in nature. The central computing system 108 and the wellsite computer system can each include any number of physical or virtual server computers and databases. For example, in various embodiments, the remote-integration server 122 may be omitted or have its functionality integrated into the collection server 120. Other modifications and rearrangements will be apparent to one of ordinary skill in the art after reviewing inventive principles contained herein.

In a typical embodiment, the wellsite computer system 102 is located at or near a wellsite for a current well and communicates with the central computing system 108 over the communications network 106. The communications network 106 may include, for example, satellite communication between the network link 124 of the wellsite computer system 102 and the network link 126 of the central computing system 108. Thus, the network link 124 and the

network link 126 can be, for example, satellite links. For simplicity of description, communication between the wellsite computer system 102 and the central computing system 108 may be described below without specific reference to the network link 124, the network link 126, and the communications network 106.

Using, for example, logging while drilling (LWD), the collection server 120 receives and/or generates channel data 104 (e.g., in WITSO) via data received from sensors that are in use at the wellsite. A given sensor or other source of data is referred to herein as a "channel." Data from a channel may be referred to as "channel data," which term is inclusive of both raw data and metadata. The raw data includes, for example, measured data determined by the sensor or source. The measured data can include, for example, resistivity, porosity, permeability, density, and gamma-ray data. The metadata includes information about the raw data such as, for example, time, depth, identification information for the channel, and the like. The collection server 120 transmits the channel data 104 to the remote-integration server 122, which communicates the channel data 104 to the central computing system 108 in real-time.

On the central computing system 108, the main server 110 receives the channel data 104 from the wellsite computer system 102 and converts the channel data 104 to a common data format. The conversion of channel data to a common data format is described in detail in U.S. patent application Ser. No. 13/829,590, which application is hereby incorporated by reference. As shown, the main server 110 has a calculation engine 128 resident thereon. Via the calculation engine 128, the main server 110 generates calculated data in real-time based on the channel data 104. The calculation engine 128 can be, for example, a software application that implements algorithms to generate the calculated data. Based on gamma-ray and resistivity data and other input data described with respect to FIG. 3, the calculated data can include, for example, pore pressure and a fracture gradient.

The calculation engine 128 can also maintain settings that are utilized for generating the calculated data. For example, implementation of Eaton and/or Mathews-and-Kelly algorithms may require certain parameters such as an Eaton exponent, a matrix stress coefficient, and a Poisson ratio. In a typical embodiment, the settings maintained on the main server 110 specify values for such parameters. If the value to be used for a given parameter is not constant across all wells (e.g. varying based on geography or well-specific data), the settings further specify rules for selecting or calculating the value, as applicable. The settings permit the calculation engine 128 to acquire necessary parameters without the need for individual configuration for each well.

The repository server 112 stores and maintains the channel data 104 and any calculated data according to the common data format. Storage and maintenance of data according to the common data format is described in detail in U.S. patent application Ser. No. 13/829,590, which application is incorporated by reference above. In a typical embodiment, the repository server 112 stores channel data from a plurality of wellsite computer systems located at a plurality of wellsites in this fashion. In addition, the repository server 112 typically maintains historical drilling-performance data (e.g., channel data, calculated data, etc.) for offset wells relative to the current well.

The repository server 112 facilitates a real-time display 114 of drilling-performance data related to the wellsite. In a typical embodiment, the real-time display 114 is provided via a network such as, for example, the Internet, via a web interface. The real-time display 114 is typically shown and

updated in real time on a computing device **116** as the channel data **104** is received. For example, in certain embodiments, the real-time display **114** can include gamma-ray and resistivity data for a formation being drilled. An example of these embodiments will be described with respect to FIGS. **2** and **3**. As described with respect to FIGS. **2** and **3**, the real-time display **114** can allow engineering personnel **118** to perform real-time drilling analysis for the wellsite.

By way of further example, in various embodiments, the real-time display **114** can be a real-time cross-plot display. In these embodiments, the real-time display **114** is operable to show, on a common graph, a cross-plot that integrates a plurality of data plots. The cross-plot generally includes at least one horizontal axis and at least one vertical axis. Each data plot of the cross-plot generally specifies at least two drilling parameters such that one drilling parameter is associated with a horizontal axis of the cross-plot and one drilling parameter is associated with a vertical axis of the cross-plot. In that way, each data plot represents a set of data points that can be expressed, for example, as Cartesian coordinates in terms of the at least two drilling parameters.

For example, if a given data plot specifies fluid gain/loss and time as the at least two drilling parameters, data points of the given data plot could be expressed as Cartesian coordinates in terms of a fluid gain/loss value and a time (e.g., day, time, hour) at which the fluid gain/loss value was collected. It should be appreciated that the cross-plot can include more than one horizontal axis and/or more than one vertical axis. In various embodiments, the inclusion of multiple horizontal axes and/or multiple vertical axes further facilitates the presentation of disparate drilling-performance data. Examples of a real-time cross-plot display will be described with respect to FIGS. **4-7**.

For purposes of illustration, examples of equations that can be used to compute calculated data will now be described. In some embodiments, pore pressure (Pp) can be computed using the Eaton method as embodied in Equation 1 below, where S represents stress (i.e. pressure exerted by the weight of the rocks and contained fluids thereabove in units of, e.g., g/cc), PPN represents normal pore pressure according to a hydrostatic gradient, Ro represents observed resistivity, Rn represents normal resistivity, and x represents an Eaton exponent.

$$Pp = S - (S - PPN) \left(\frac{Ro}{Rn} \right)^x \quad \text{Equation 1}$$

For purposes of this example, S, PPN, Ro, and Rn are input data for calculating pore pressure. In particular, S and Ro are examples of parameters that can be provided by channel data for the current well. The Eaton exponent (x) is an example of a parameter that can be retrieved from settings maintained by the calculation engine **128** of FIG. **1**. In some embodiments, PPN can also be retrieved from settings maintained by the calculation engine **128**. In a typical embodiment, Rn is obtained using historical drilling-performance data for an offset well. In this fashion, pore pressure for the current well can be calculated in real-time by retrieving resistivity data for the offset well. A specific example will be described with respect to FIG. **3**.

In various embodiments, a fracture gradient (Fg) can be computed using the Eaton method as embodied in Equation

2 below, where Pp and S represent pore pressure and stress, respectively, as described above and v represents a Poisson ratio.

$$Fg = Pp + (S - Pp) \left(\frac{v}{1 - v} \right) \quad \text{Equation 2}$$

For purposes of the example of Equation 2, stress (S), pore pressure (Pp) and the Poisson ratio (v) are input data for calculating a fracture gradient for a current well. Pp can be computed as described with respect to Equation 1 above. Stress (S) can also be obtained as described with respect to Equation 1. The Poisson ratio (v) is an example of an input value that can be retrieved from settings maintained by the calculation engine **128** as described with respect to FIG. **1**.

In various embodiments, a fracture gradient (Fg) can also be computed using the Matthews and Kelly method as embodied in Equation 3 below, where Pp and S represent pore pressure and stress, respectively, as described above and κ_i represents a matrix stress coefficient.

$$Fg = Pp + (S - Pp) \kappa_i \quad \text{Equation 3}$$

For purposes of the example of Equation 3, stress (S), pore pressure (P) and the matrix stress coefficient (κ_i) are input data for calculating a fracture gradient for a current well. The pore pressure (Pp) and stress (S) can be obtained as described with respect to Equation 2. κ_i is an example of an input value that can be retrieved from settings maintained by the calculation engine **128** as described with respect to FIG. **1**.

FIG. **2** illustrates a process **200** for performing real-time drilling analysis using the system **100** of FIG. **1**. At step **202**, the wellsite computer system **102** collects the channel data **104** in real-time from sensors via, for example, LWD. The channel data **104** is received in an initial data format such as, for example, WITS0. From step **202**, the process **200** proceeds to step **204**. At step **204**, the wellsite computer system **102** transmits the channel data **104** to the central computing system **108** via the communications network **106**. From step **204**, the process **200** proceeds to step **206**. At step **206**, the central computing system **108** receives the channel data from the wellsite computer system **102**. From step **206**, the process **200** proceeds to step **208**.

At step **208**, the central computing system **108** converts the channel data **104** to a common data format. From step **208**, the process **200** proceeds to step **210**. At step **210**, the channel data **104** is stored on the central computing system **108** according to the common data format. From step **210**, the process **200** proceeds to step **212**. At step **212**, the calculation engine **128** generates calculated data based on the channel data **104**, settings, and other input data described with respect to FIG. **3**. As described above, the calculation engine **128** may be, for example, a software application that implements algorithms to generate the calculated data. From step **212**, the process **200** proceeds to step **214**.

At step **214**, the central computing system **108** stores the calculated data. For example, the calculated data can be stored on the repository server **112**. From step **214**, the process **200** proceeds to step **216**. At step **216**, the central computing system **108** updates the real-time display **114** to include selected data such as, for example, all or part of the channel data **104** and all or part of the calculated data. Examples of the real-time display **114** will be described in greater detail with respect to FIGS. **3-7**. From step **216**, the process **200** proceeds to step **218**. At step **218**, the process **200** ends.

FIG. 3 illustrates an example of real-time drilling-performance analysis via a real-time display 314. To facilitate comparative analysis, for example, by a drilling engineer, the real-time display 314 depicts drilling-performance data for both a current well 340 and an offset well 342 relative to true vertical depth (TVD). In a typical embodiment, the offset well 342 is pre-selected and associated with the current well 340 due to its geographic proximity to the current well 340. In various embodiments, the pre-selection can be made by drilling personnel such as a drilling engineer and stored by a repository server such as the repository server 112 of FIG. 1.

The drilling-performance data depicted by the real-time display 314 can include, inter alia, selected channel data, input data, calculated data, casing-point data, and event data. The selected channel data includes, for example, channel data from a well site that is received at a central computing system, converted to a common data format, and stored as described with respect to FIGS. 1 and 2. The input data is additional data that is received, for example, from a drilling engineer or from other data stored within a repository such as a repository maintained by the repository server 112 of FIG. 1. The calculated data is data that is calculated, for example, by a calculation engine such as the calculation engine 128 of FIG. 1. The casing-point data includes information related to the placement and size of casing utilized in a given well. The event data is data related to certain detected events at a well such as, for example, a stuck pipe, lost circulation, or a kick (i.e., undesired influx of formation fluid into the wellbore).

With respect to the current well 340, the real-time display 314 shows selected channel data, input data, calculated data, and casing-point data. In particular, the selected channel data for the current well 340 includes gamma-ray data 320(1), resistivity data 324(1), lithography 328(1), and fluid density 332(1). The input data for the current well 340 includes gamma-ray trend lines 322(1) (also referred to herein as shale lines) and a resistivity-trend line 326(1) (also referred to herein as a normal compaction trend). The calculated data for the current well 340 includes pore pressure 330(1) and fracture gradient 334(1). The casing-point data includes one or more casing points 336(1) (which are updated in real time).

With respect to the offset well 342, the real-time display 314 shows selected channel data, input data, calculated data, casing-point data, and event data. It should be appreciated that all such data for the offset well 342 is generally historical drilling-performance data (as opposed to real-time data for the current well 340). In particular, the selected channel data for the offset well 342 includes gamma-ray data 320(2), resistivity data 324(2), lithography 328(2), and fluid density 332(2). The input data for the offset well 342 includes gamma-ray trend lines 322(2) (also referred to herein as shale lines) and a resistivity-trend line 326(2) (also referred to herein as a normal compaction trend). The calculated data for the current well 340 includes pore pressure 330(2) and fracture gradient 334(2). The casing-point data includes one or more casing points 336(2). The event data for the offset well 342 includes one or more drilling events 338.

With respect to the current well 340, acquisition of the input data will now be described. As mentioned above, the selected channel data for the current well 340 is displayed and refreshed in real-time as such data is received by a central computing system such as, for example, the central computing system 108 of FIG. 1. As the selected channel data is received, the central computing system 108 gathers

the input data, i.e., the gamma-ray trend lines 322(1) and the resistivity-trend line 326(1). In a typical embodiment, the gamma-ray trend lines 322(1) are traced by drilling personnel such as, for example, a drilling, geological or geophysical engineer, who determines points of shale. Shale, as one of ordinary skill in the art will appreciate, generally emit more gamma rays than other sedimentary rocks. The gamma-ray trend lines 322(1) generally connect points of shale and represent an average of the gamma-ray data 320(1) between those shale points (i.e. spanning that trend line). For example, in various embodiments, a drilling engineer may be prompted at configurable points in time to trace the gamma-ray trend lines.

The resistivity-trend line 326(1) is typically acquired automatically from historical drilling-performance data for the offset well 342. In that way, the resistivity-trend line 326(2) (i.e., the normal compaction trend for the offset well 342) serves as the resistivity-trend line 326(1). The resistivity-trend line 326(2) is a normalization of the resistivity data 324 for the offset well 342.

The calculated data for the current well 340 is generated by a central computing system such as, for example, the central computing system 108 of FIG. 1, based on the selected channel data and the input data for the current well 340. In a typical embodiment, the calculated data for the current well 340 has defined relationships, established on the central computing system 108 of FIG. 1, with the selected channel data and the input data. Particularly, the gamma-ray data 320(1), the gamma-ray trend lines 322(1), the resistivity data 324(1), and the resistivity-trend line 326(1) are leveraged by a calculation engine such as, for example, the calculation engine 128, to compute the pore pressure 330(1) and the fracture gradient 334(1) in real time. In that way, published algorithms such as those developed by Eaton and Matthews and Kelly may be used in real time to compute the pore pressure 330(1) and the fracture gradient 334(1).

Moreover, the real-time display 314 also enables other types of real-time drilling-performance analyses. As one example of real-time drilling-performance analysis, the real-time display 314 enables drilling personnel such as, for example, drilling engineers, to perform real-time geopressure analysis. Drilling engineers are able to compare the pore pressure 330(1) and the fracture gradient 334(1) for the current well 340 with the pore pressure 330(2) and the fracture gradient 334(2) for the offset well. This real-time geopressure analysis allows drilling engineers to compare trends and anticipate changes based on the offset well 342. The geopressure analysis can also be correlated with the one or more drilling events 338, as described further below.

Further real-time drilling-performance analysis is enabled by the one or more drilling events 338. Each of the one or more drilling events 338 is typically plotted at a depth at which a defined adverse drilling event occurred in the offset well 342. The one or more drilling events 338 can include, for example, stuck pipes, lost circulation, kicks, and the like. As a result of the geographic proximity between the current well 340 and the offset well 342, circumstances that led to the one or more drilling events 338 are often likely to reoccur at similar depths in the current well 340. Therefore, the real-time display 314 allows drilling personnel to anticipate and plan for the one or more drilling events 338. In a typical embodiment, when the depth of the current well 340 is within a preconfigured distance of the depth at which one of the one or more drilling events 338 occurred (e.g., 500 feet), an alert is generated and presented to responsible personnel. The alert can be, for example, a beep or alarm. Responsive to the alert, the responsible personnel may

perform, for example, the real-time geopressure analysis described above so that it can be determined if the pore pressure **330(1)** is trending similarly to the pore pressure **330(2)**. Corrective action such as an adjustment in the fluid density **332(1)** may be taken.

As another example of real-time drilling-performance analysis, the real-time display **314** further enables casing-point prediction. As described above, the real-time display **314** shows the one or more casing points **336(1)** for the current well **340** and the one or more casing points **336(2)** for the offset well **342**. Using data from the one or more casing points **336(2)**, drilling personnel are able to predict both size and placement for future casing points for the current well **340**.

A further example of real-time drilling-performance analysis enabled by the real-time display **314** relates to density analysis. As described above, the real-time display **314** displays both the fluid density **332(1)** for the current well **340** and the fluid density **332(2)** for the offset well **342**. By reviewing and comparing density trends, drilling personnel such as, for example, drilling engineers, are able to determine if the fluid density **332(1)** for the current well **340** should be increased, decreased, or maintained.

In a typical embodiment, the real-time display **314** can be customized based on the desires of drilling engineers. For example, the selected channel data can include more, less, or different channel data than described above. Likewise, the calculated data can have defined relationships with other channel data and/or input data for purposes of performing different calculations in real time.

FIG. 4 illustrates a process **400** for creating a cross plot using the system **100** of FIG. 1. At step **402**, the central computing system **108** receives a selection of one or more wells from a user such as, for example, a drilling engineer. In a typical embodiment, the selection is of a current well (e.g., a well that is being drilled). From step **402**, the process **400** proceeds to step **404**.

At step **404**, the central computing system **108** receives a selection of a plurality of data plots for the current well from the user. Each data plot generally specifies at least two drilling parameters such that one drilling parameter can be associated with a horizontal axis and one drilling parameter can be associated with a vertical axis. The at least two drilling parameters can correspond, for example, to depth, date, densities, geological formation, volume loss and gain, casing points, calculated data (e.g. pore pressure), input data, etc.

In some cases, a given data plot of the plurality of data plots can be a drilling-event data plot. The drilling-event data plot can correspond to one or more types of drilling events such as, for example, the one or more drilling events **338** of FIG. 3. The one or more drilling events can include, for example, stuck pipes, lost circulation, kicks, and the like. The at least two drilling parameters of the drilling-event data plot can include any of the drilling parameters described above. However, the drilling-event data plot will generally only include data points when, for example, a specified Boolean condition defining the event is met (e.g., stuck pipe, lost circulation, kicks, etc.). The one or more drilling events can be actual events that have been detected via new channel data for the current well. The one or more drilling events can also be historical drilling events for an offset well that are plotted, for example, at a depth at which such event occurred in the offset well. In that way, the one or more drilling events can facilitate alerting as described with respect to FIG. 3. From step **404**, the process **400** proceeds to step **406**.

At step **406**, the central computing system **108** maps each data plot to data sources for the current well. As described above, each of the plurality of data plots generally specifies at least two drilling parameters. The mapping can include specifying which data fields form the basis for each drilling parameter. The drilling parameters may directly correspond to particular fields of channel data, calculated data, and/or the like. In that way, when, for example, new channel data for a current well is received, the central computing system **108** can at that time create new data points for the plurality of data plots. In some embodiments, the step **406** may be omitted when, for example, all drilling parameters are pre-mapped to channel data prior to the user's selection of the plurality of data plots. From step **406**, the process **400** proceeds to step **408**.

At step **408**, the central computing system **108** defines a presentation format for the cross plot. In a typical embodiment, the presentation format encompasses specification of, for example, measurement units, data precision/scaling of the cross-plot, presentation attributes (e.g., color, layout, etc.), and/or the like. In various embodiments, the presentation format can be defined responsive to manual configuration by the user, technical personnel acting at the instruction of the user, and/or the like. The presentation format can also be defined based on pre-existing templates. It should be appreciated that different ones of the plurality of data plots may share a drilling parameter (e.g., time). In such cases, certain ones of the plurality of data plots may share an axis of the cross-plot. From step **408**, the process **400** proceeds to step **410**.

At step **410**, the central computing system **108** populates the plurality of data plots with data points for the current well. From step **410**, the process **400** proceeds to step **412**. At step **412**, the central computing system facilitates a real-time cross-plot display of the cross-plot in a fashion similar to that described above with respect to FIG. 2. The real-time cross-plot display can be viewed, for example, by a drilling engineer. In various embodiments, the real-time cross-plot display can be updated with technical comments of a user such as, for example, the drilling engineer. The technical comments can include drilling analysis of the user, be inserted at an appropriate place on the cross-plot, and be persistently stored as part of the cross-plot. The technical comments can then be viewed by whomever accesses the real-time cross-plot display. After step **412**, the process **400** ends.

FIG. 5 illustrates a process **500** for updating a real-time cross-plot display using the system **100** of FIG. 1. The real-time cross-plot display includes a plurality of data plots and can be created, for example, as described with respect to FIG. 4. The process **500** begins at step **502**. At step **502**, the central computing system **108** creates new data points for the plurality of data plots. The new data points can be based on channel data, calculated data, and/or input data as described above. From step **502**, the process **500** proceeds to step **504**. At step **504**, the central computing system **108** populates the plurality of data plots with the new data points. From step **504**, the process **500** proceeds to step **506**. At step **506**, the central computing system **108** updates/refreshes the real-time cross-plot display. After step **506**, the process **500** ends.

FIGS. 6-7 illustrate examples of real-time cross-plot displays. The real-time cross-plot displays of FIGS. 6-7 can be created as described with respect to FIG. 4. In various embodiments, the real-time cross-plot displays of FIGS. 6-7 can also be updated in real-time as described with respect to FIGS. 2 and 5.

11

Real-time drilling performance analyses such as those described above allow drilling personnel such as, for example, drilling, geological, or geophysical engineers, to reduce non-productive time (NPT). Alerts, recommendations, and real-time displays such as those described above allow drilling personnel to perform better analyses more quickly and more efficiently using, for example, a single systematic slide provided by a real-time cross-plot display. The automation provided by a system such as, for example, the system 100 of FIG. 1, frees drilling personnel from manually gathering information necessary to analyze and make decisions regarding the drilling performance of a well. For example, in various embodiments, real-time cross-plot displays such as those described above can allow establishment of historical and comparative analysis for different phases along a given well such as: 17½", 12¼", 8½", 6½" and 5". Therefore, real-time cross-plot displays can be tailored to the objective of the well. Thus, technical analyses and risk detections can be performed in a timely manner and the drilling process can be optimized.

Although various embodiments of the method and apparatus of the present invention have been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it will be understood that the invention is not limited to the embodiments disclosed, but is capable of numerous rearrangements, modifications and substitutions without departing from the spirit of the invention as set forth herein.

What is claimed is:

1. A method comprising, by a computer system: receiving channel data in real-time as the channel data is generated, the channel data comprising measured physical properties determined by one or more sensors in use at a site of a current well; providing, over a network interface, a real-time cross-plot display for the current well, wherein the real-time cross-plot display comprises a first data plot and a second data plot, wherein the first data plot and the second data plot each comprise a plurality of data points determined in real-time over a progression of time as the channel data is received; in real-time as the channel data is received: creating, via the channel data, a first new data point for the first data plot; creating via the channel data, a second new data point for the second data plot; updating the first data plot with the first new data point; and updating the second data plot with the second new data point.
2. The method of claim 1, wherein the computer system maps at least two drilling parameters to data sources for the current well.
3. The method of claim 1, comprising, by the computer system: retrieving input data comprising historical drilling-performance data for an offset well relative to the current well; and computing calculated data for the current well based on the channel data and the input data; and wherein at least one of the first data plot and the second data plot comprises the calculated data.
4. The method of claim 1, wherein the first data plot comprises casing-point data for the current well and an offset well.

12

5. The method of claim 1, wherein the second data plot comprises at least one drilling-event relating to one or more adverse drilling events.

6. The method of claim 5, wherein the one or more adverse drilling events are selected from the group consisting of stuck pipe, lost circulation, and kick.

7. The method of claim 5, wherein the one or more adverse drilling events are events that previously occurred with respect to an offset well relative to the current well.

8. The method of claim 7, comprising generating an alert when a depth of the current well is within a preconfigured distance of a depth at which the one or more adverse drilling events occurred.

9. The method of claim 1, comprising: receiving a technical comment from a user; and inserting the technical comment into the real-time cross-plot display.

10. A system comprising a processor and memory, wherein the processor and memory in combination are operable to implement a method comprising:

receiving channel data in real-time as the channel data is generated, the channel data comprising measured physical properties determined by one or more sensors in use at a site of a current well;

providing, over a network interface, a real-time cross-plot display for the current well, wherein the real-time cross-plot display comprises a first data plot and a second data plot, wherein the first data plot and the second data plot each comprise a plurality of data points determined in real-time over a progression of time as the channel data is received;

in real-time as the channel data is received: creating, via the channel data, a first new data point for the first data plot; creating via the channel data, a second new data point for the second data plot; updating the first data plot with the first new data point; and updating the second data plot with the second new data point.

11. The system of claim 10, wherein at least two drilling parameters are mapped to data sources for the current well.

12. The system of claim 10, the method comprising: retrieving input data comprising historical drilling-performance data for an offset well relative to the current well; computing calculated data for the current well based on the channel data and the input data; and wherein at least one of the first data plot and the second data plot comprises the calculated data.

13. The system of claim 10, wherein the first data plot comprises casing-point data for the current well and an offset well.

14. The method of claim 10, wherein the second data plot comprises at least one drilling-event relating to one or more adverse drilling events.

15. The system of claim 14, wherein the one or more adverse drilling events are selected from the group consisting of stuck pipe, lost circulation, and kick.

16. The system of claim 14, wherein the one or more adverse drilling events are events that previously occurred with respect to an offset well relative to the current well.

17. The system of claim 16, the method comprising generating an alert when a depth of the current well is within a preconfigured distance of a depth at which the one or more adverse drilling events occurred.

13

18. The system of claim 10, wherein the method comprises:

- receiving a technical comment from a user; and
- inserting the technical comment into the real-time cross-plot display.

19. A computer-program product comprising a computer-usable medium having computer-readable program code embodied therein, the computer-readable program code adapted to be executed to implement a method comprising:

- receiving channel data in real-time as the channel data is generated, the channel data comprising measured physical properties determined by one or more sensors in use at a site of a current well;

providing, over a network interface, a real-time cross-plot display for the current well, wherein the real-time cross-plot display comprises a first data plot and a second data plot, wherein the first data plot and the second data plot each comprise a plurality of data points determined in real-time over a progression of time as the channel data is received;

14

in real-time as the channel data is received:

- creating, via the channel data, a first new data point for the first data plot;
- creating via the channel data, a second new data point for the second data plot;
- updating the first data plot with the first new data point; and
- updating the second data plot with the second new data point.

20. The computer-program product of claim 19, wherein the method comprises:

- retrieving input data comprising historical drilling-performance data for an offset well relative to the current well; and
 - computing calculated data for the current well based on the channel data and the input data; and
- wherein at least one of the first data plot and the second data plot comprises the calculated data.

* * * * *