US009512707B1

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

(10) **Patent No.: US 9,512,707 B1**
(45) **Date of Patent: Dec. 6, 2016**

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

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 494 days.

(21) Appl. No.: **14/018,298**

(22) Filed: **Sep. 4, 2013**

Related U.S. Application Data

(63) Continuation-in-part of application No. 13/919,240, filed on Jun. 17, 2013.

(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)

(52) **U.S. Cl.**
CPC ***E21B 45/00*** (2013.01)

(58) **Field of Classification Search**
CPC E21B 45/00; E21B 47/00; E21B 47/0002; E21B 7/04; G06Q 10/0639; G06Q 10/06395; G06T 15/00; G06T 15/005
See application file for complete search history.

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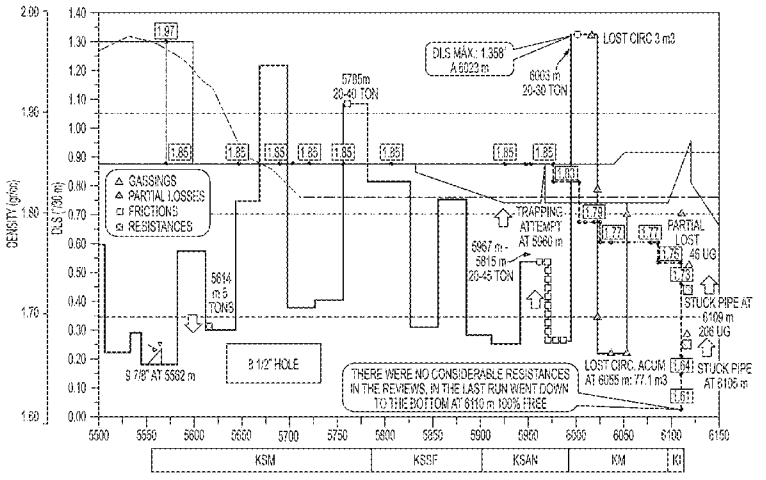
(57) **ABSTRACT**

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 expressable 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



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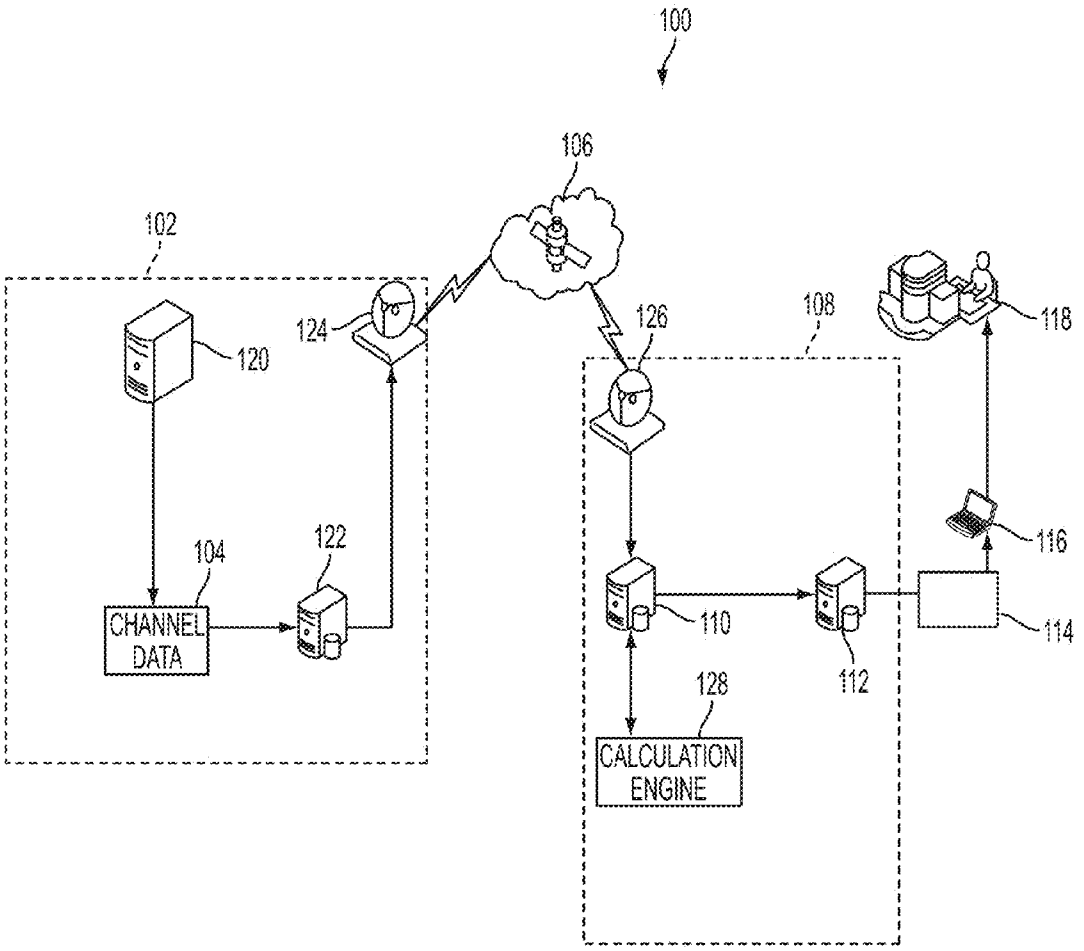
100
106
102
120
124
126
108
118
104
122
116
CHANNEL DATA
110
112
114
128
CALCULATION ENGINE

FIG. 1

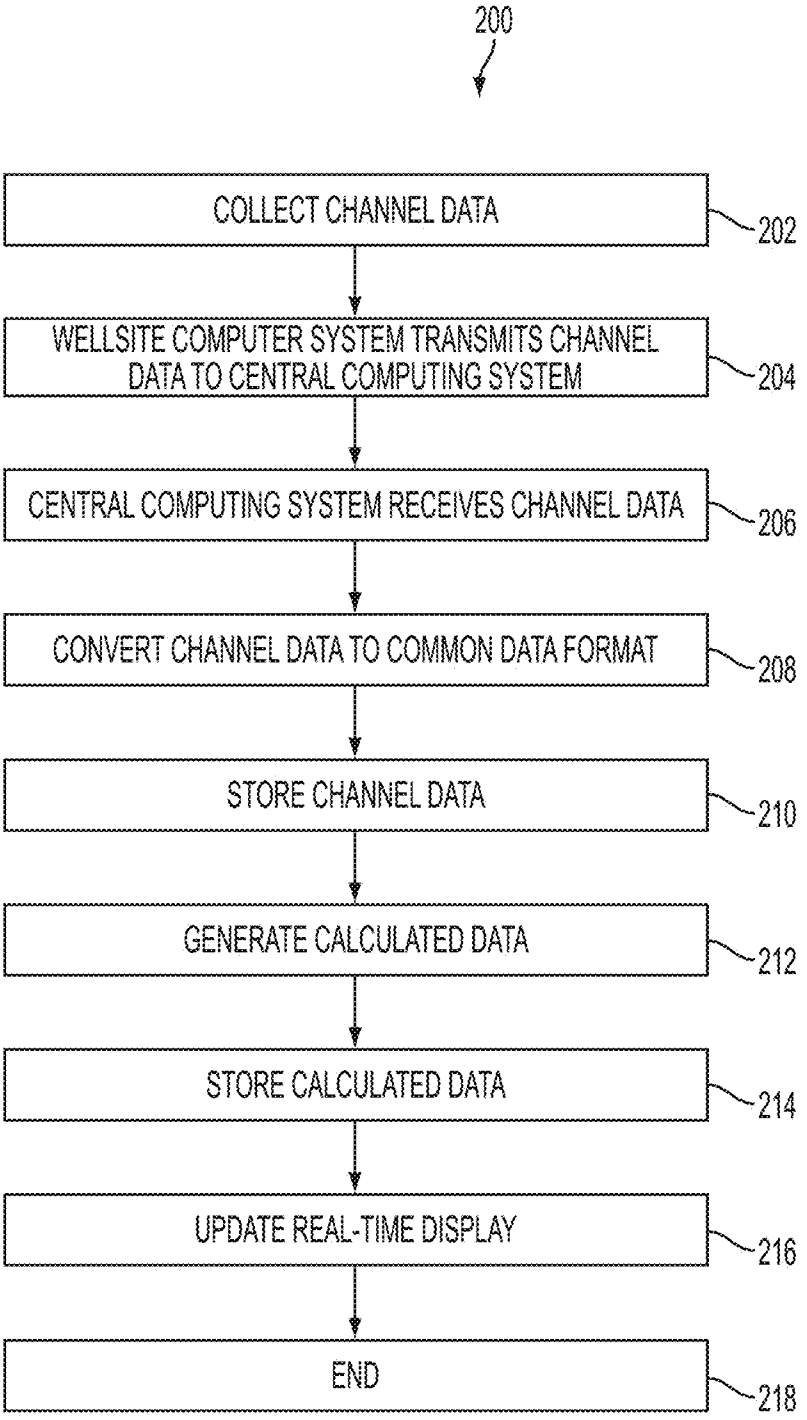
200
COLLECT CHANNEL DATA
202
WELLSITE COMPUTER SYSTEM TRANSMITS CHANNEL DATA TO CENTRAL COMPUTING SYSTEM
204
CENTRAL COMPUTING SYSTEM RECEIVES CHANNEL DATA
206
CONVERT CHANNEL DATA TO COMMON DATA FORMAT
208
STORE CHANNEL DATA
210
GENERATE CALCULATED DATA
212
STORE CALCULATED DATA
214
UPDATE REAL-TIME DISPLAY
216
END
218

FIG. 2

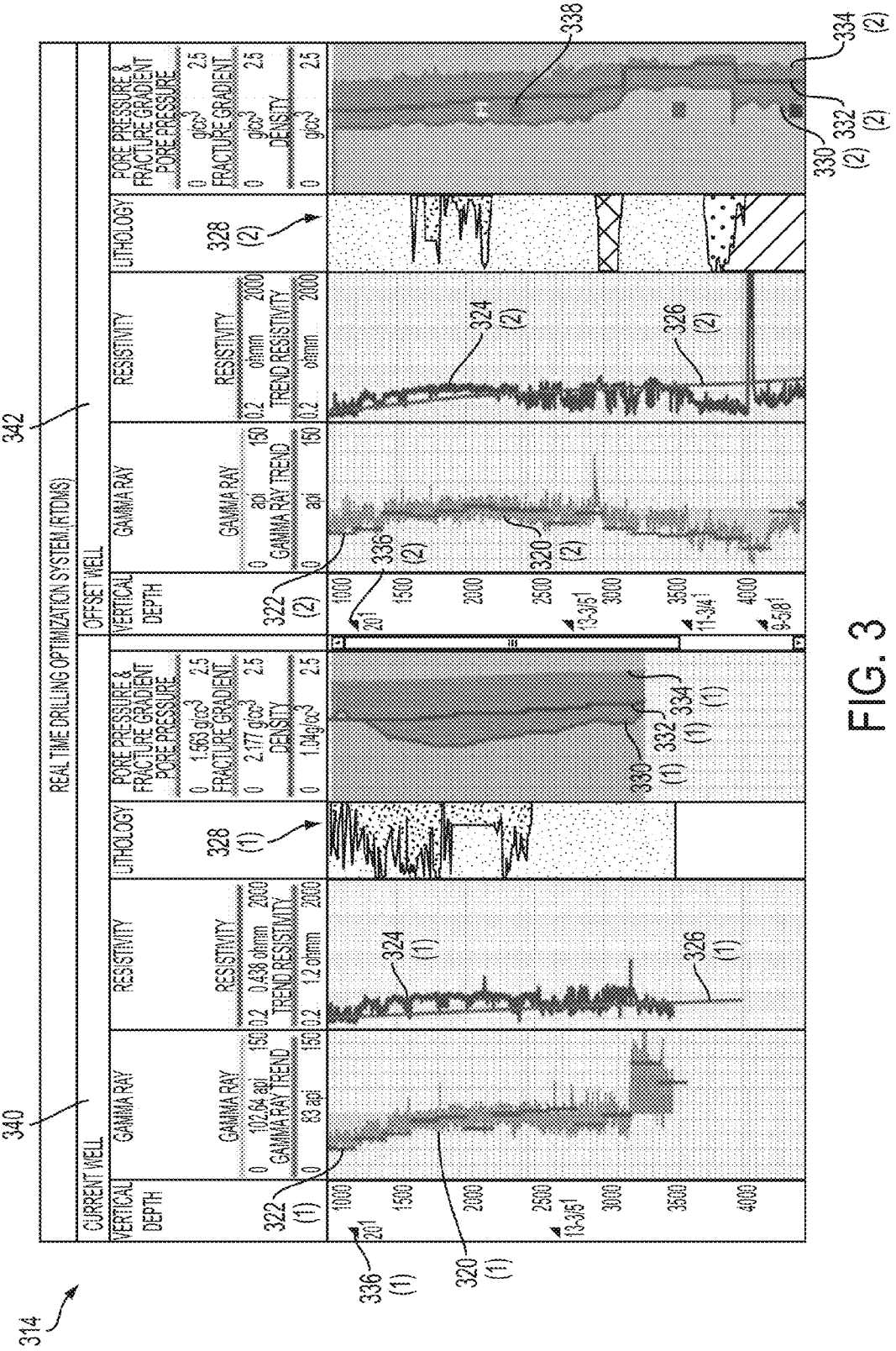
314
340
342
REAL TIME DRILLING OPTIMIZATION SYSTEM (RTDMS)
CURRENT WELL
OFFSET WELL
VERTICAL DEPTH
GAMMA RAY
RESISTIVITY
LITHOLOGY
PORE PRESSURE & FRACTURE GRADIENT
PORE PRESSURE
FRACTURE GRADIENT
DENSITY
GAMMA RAY TREND
TREND RESISTIVITY
322 (1)
322 (2)
324 (1)
324 (2)
326 (1)
326 (2)
328 (1)
328 (2)
330 (1)
330 (2)
332 (1)
332 (2)
334 (1)
334 (2)
336 (1)
336 (2)
338
320 (1)
320 (2)

FIG. 3

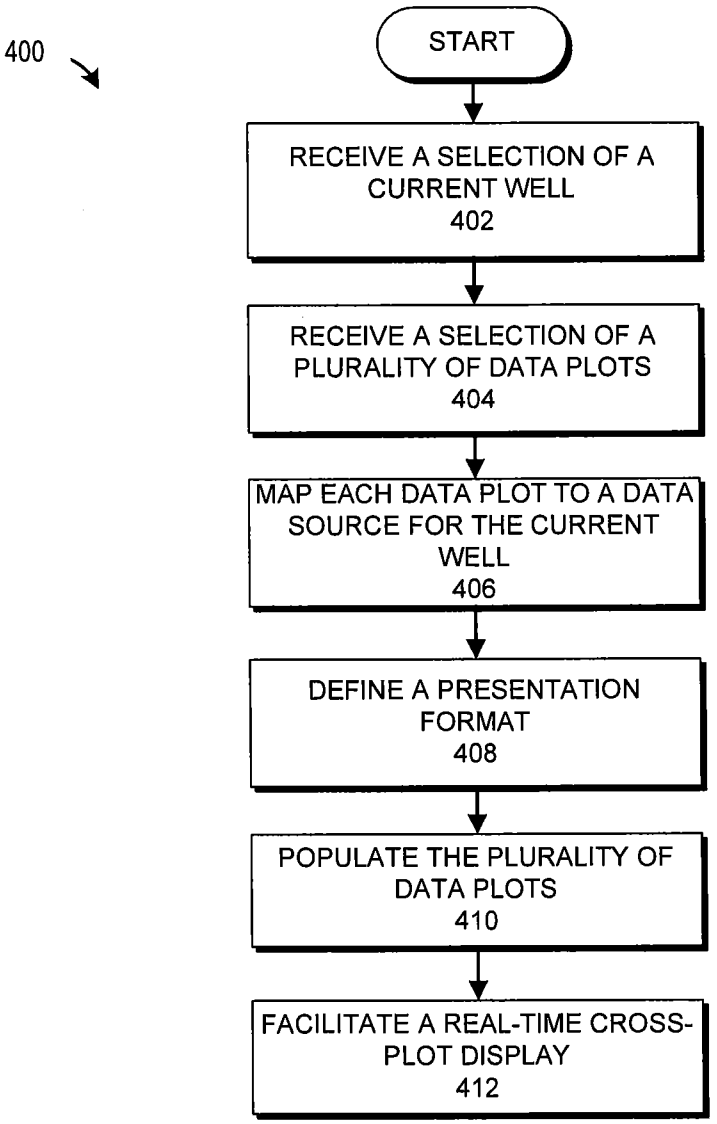
400
START
RECEIVE A SELECTION OF A CURRENT WELL
402
RECEIVE A SELECTION OF A PLURALITY OF DATA PLOTS
404
MAP EACH DATA PLOT TO A DATA SOURCE FOR THE CURRENT WELL
406
DEFINE A PRESENTATION FORMAT
408
POPULATE THE PLURALITY OF DATA PLOTS
410
FACILITATE A REAL-TIME CROSS-PLOT DISPLAY
412

FIG. 4

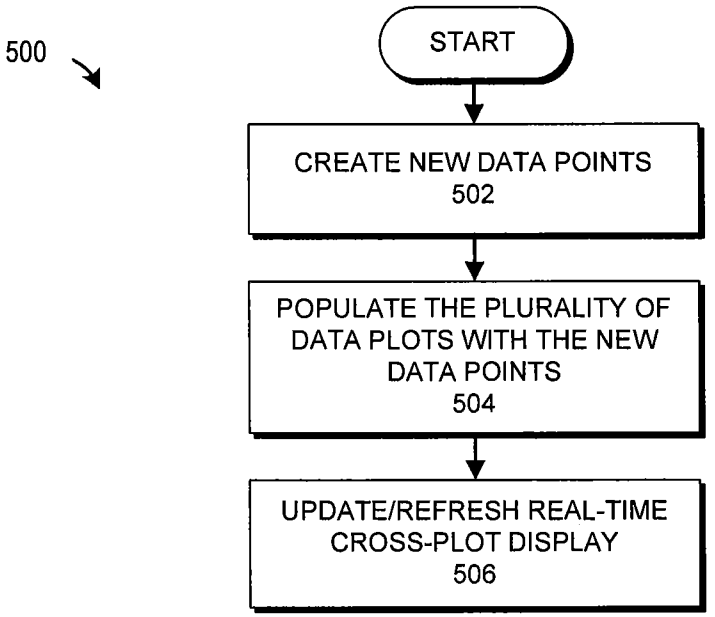
500
START
CREATE NEW DATA POINTS
502
POPULATE THE PLURALITY OF DATA PLOTS WITH THE NEW DATA POINTS
504
UPDATE/REFRESH REAL-TIME CROSS-PLOT DISPLAY
506

FIG. 5

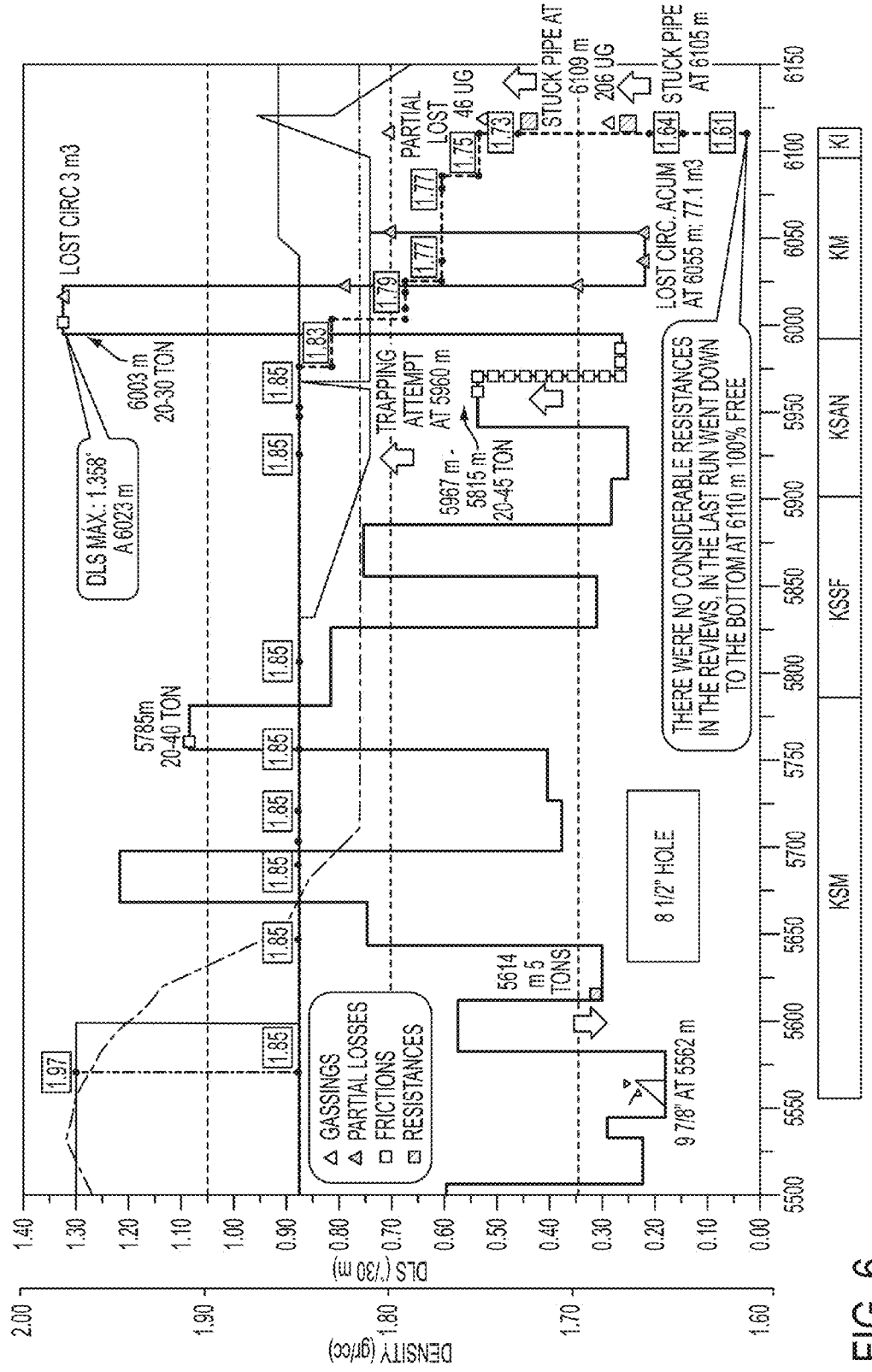
DENSITY (gr/cc)
DLS (°/30 m)
GASSINGS
PARTIAL LOSSES
FRICTIONS
RESISTANCES
LOST CIRC 3 m3
DLS MAX.: 1.358°
A 6023 m
6003 m
20-30 TON
5785m
20-40 TON
TRAPPING
ATTEMPT
AT 5960 m
5967 m -
5815 m
20-45 TON
5614
m 5
TONS
9 7/8" AT 5562 m
8 1/2" HOLE
PARTIAL
LOST
46 UG
STUCK PIPE AT
6109 m
206 UG
LOST CIRC. ACUM
AT 6055 m: 77.1 m3
STUCK PIPE
AT 6105 m
THERE WERE NO CONSIDERABLE RESISTANCES
IN THE REVIEWS, IN THE LAST RUN WENT DOWN
TO THE BOTTOM AT 6110 m 100% FREE
KSM
KSSF
KSAN
KM
KI

FIG. 6

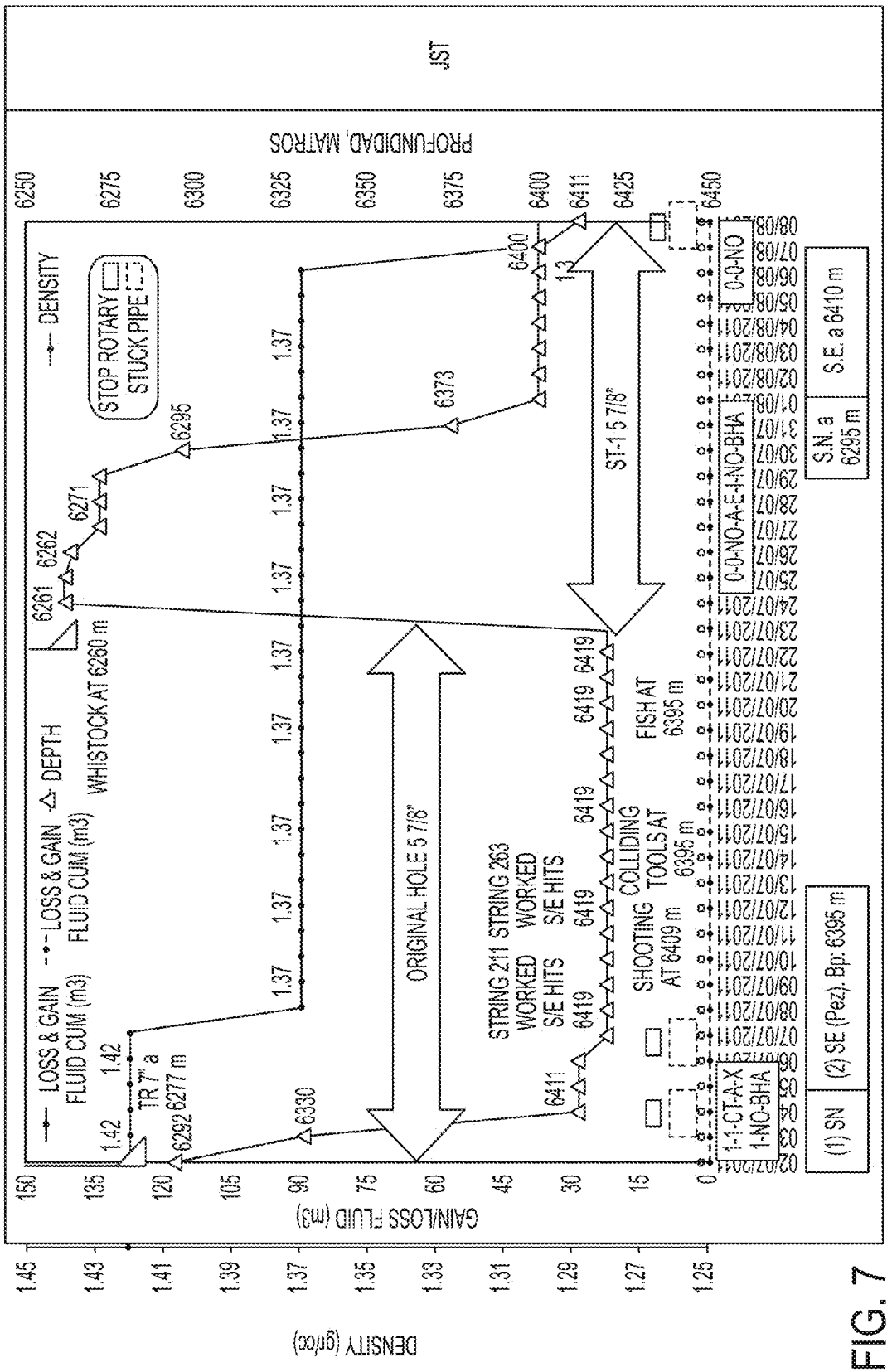
PROFUNDIDAD, MATROS
DENSITY
LOSS & GAIN
FLUID CUM (m3)
LOSS & GAIN
FLUID CUM (m3)
DEPTH
WHISTOCK AT 6260 m
STOP ROTARY
STUCK PIPE
TR 7" a 6277 m
ORIGINAL HOLE 5 7/8"
STRING 211 STRING 263
WORKED WORKED
S/E HITS S/E HITS
SHOOTING COLLIDING
AT 6409 m TOOLS AT 6395 m
FISH AT 6395 m
ST-1 5 7/8"
S.N. a 6295 m
S.E. a 6410 m
1-1-CT-A-X
1-NO-BHA
0-0-NO-A-E-I-NO-BHA
0-0-NO
(1) SN
(2) SE (Pez). Bp: 6395 m
GAIN/LOSS FLUID (m3)
DENSITY (gr/cc)

FIG. 7

CROSS-PLOT ENGINEERING SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation-in-part of U.S. patent application Ser. No. 13/919,240, filed on Jun. 17, 2013. 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. This patent application claims priority from U.S. Provisional Application No. 61/697,687, filed on Sep. 6, 2012. U.S. patent application Ser. No. 13/919,240, U.S. Provisional Application No. 61/660,565, and U.S. Provisional Application No. 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 expressable 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 expressable 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 expressable 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 WITS0) 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**.

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 comparatives 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:

on a central computing system comprising a server computer, collecting channel data from a plurality of channels in real-time as the channel data is generated, the channel data comprising measured physical properties determined by sensors in use at a site of a current well;

the central computing system providing over a network interface a real-time cross-plot display of drilling-performance data for the current well;

wherein the drilling-performance data comprises a plurality of data plots represented on a common graph, each data plot specifying at least two drilling parameters;

wherein each data plot comprises a plurality of data points determined in real-time over a progression of time as the channel data is received, each data point expressable as Cartesian coordinates in terms of the at least two drilling parameters;

for each channel of the plurality of channels, in real-time as the channel data is received, the central computing system:

creating, from the channel data, new data points for the plurality of data plots;

populating the plurality of data plots with the new data points as the new data points are created; and

updating the provided real-time cross-plot display with the populated plurality of data plots.

2. The method of claim **1**, wherein, for each of the plurality of data plots, the central computing system maps the at least two drilling parameters to data sources for the current well.

3. The method of claim **1**, comprising:

as the channel data is received:

the central computing system retrieving input data comprising historical drilling-performance data for an offset well relative to the current well; and

the central computing system computing calculated data for the current well based on the channel data and the input data; and

wherein, for at least one data plot of the plurality of data plots, a drilling parameter of the at least two drilling parameters comprises the calculated data.

4. The method of claim **1**, wherein the drilling-performance data comprises casing-point data for the current well and an offset well.

5. The method of claim **1**, wherein the plurality of data plots comprises at least one drilling-event data plot 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:

at least one server computer, wherein the at least one server computer is operable to perform a method comprising:

collecting channel data from a plurality of channels in real-time as the channel data is generated, the channel data comprising measured physical properties determined by sensors in use at a site of a current well;

providing over a network interface a real-time cross-plot display of drilling-performance data for the current well;

wherein the drilling-performance data comprises a plurality of data plots represented on a common graph, each data plot specifying at least two drilling parameters;

wherein each data plot comprises a plurality of data points determined in real-time over a progression of time as the channel data is received, each data point expressable as Cartesian coordinates in terms of the at least two drilling parameters;

for each channel of the plurality of channels, in real-time as the channel data is received:

creating, from the channel data, new data points for the plurality of data plots;

populating the plurality of data plots with the new data points as the new data points are created; and

updating the provided real-time cross-plot display with the populated plurality of data plots.

11. The system of claim **10**, wherein, for each of the plurality of data plots, the at least one server computer maps the at least two drilling parameters to data sources for the current well.

12. The system of claim **10**, the method comprising:

as the channel data is received:

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, for at least one data plot of the plurality of data plots, a drilling parameter of the at least two drilling parameters comprises the calculated data.

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

14. The method of claim **10**, wherein the plurality of data plots comprises at least one drilling-event data plot 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.

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 non-transitory computer-usable medium having computer-readable program code embodied therein, the computer-readable program code adapted to be executed to implement a method comprising:

collecting channel data from a plurality of channels in real-time as the channel data is generated, the channel data comprising measured physical properties determined by sensors in use at a site of a current well;

providing over a network interface a real-time cross-plot display of drilling-performance data for the current well;

wherein the drilling-performance data comprises a plurality of data plots represented on a common graph, each data plot specifying at least two drilling parameters;

wherein each data plot comprises a plurality of data points determined in real-time over a progression of time as the channel data is received, each data point expressable as Cartesian coordinates in terms of the at least two drilling parameters;

for each channel of the plurality of channels, in real-time as the channel data is received:

creating, from the channel data, new data points for the plurality of data plots;

populating the plurality of data plots with the new data points as the new data points are created; and

updating the provided real-time cross-plot display with the populated plurality of data plots.

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

as the channel data is received:

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, for at least one data plot of the plurality of data plots, a drilling parameter of the at least two drilling parameters comprises the calculated data.

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