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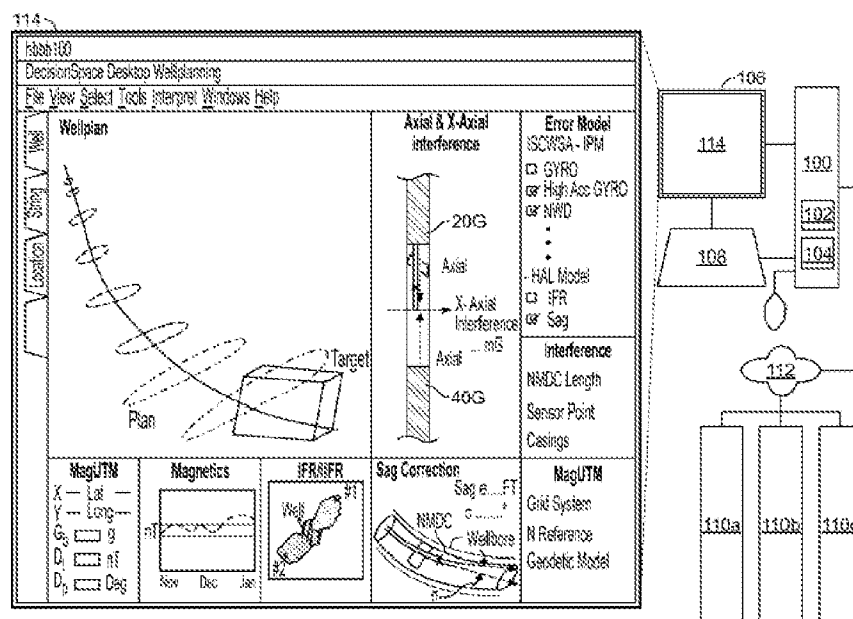
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(54)	Title	A computer-implemented well survey method
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(57)	Abstract	

In one example, an integrated well survey management and planning tool is implemented by a computer system. The tool can receive a trajectory of a proposed well from a surface to a subterranean geological target to be reached by drilling the well, and a survey plan indicating the number, position and survey type of surveys to be performed on the well while drilling the well. The tool can apply multiple error models based on the survey type for drilling the well. Each error model defines a respective uncertainty in reaching the subterranean geological target by drilling the well along the received trajectory. The tool can display, in a user interface, the received trajectory of the well and an uncertainty indicator determined by applying the multiple error models. The uncertainty indicator represents a combination of respective uncertainties defined by the multiple error models and indicates an uncertainty in drilling the well on the received trajectory.



INTEGRATED WELL SURVEY MANAGEMENT AND PLANNING TOOL

TECHNICAL FIELD

[0001] This disclosure relates to well survey management and planning.

BACKGROUND

[0002] A well plan describes the well trajectory to be followed to take a well successfully from its surface position to the end of the well trajectory. Based on factors such as an expected use of a well (e.g., observation, production, injection, or multi-purpose well), parameters (e.g., production parameters, completion requirements, well dimensions, location), an expected life of the well, and conditions of the geological target (e.g., the subterranean reservoir) to be reached by the well, and other factors, the well plan outlines well objectives to be achieved during well drilling and well use. When drilling commences based on the well plan, the well can be periodically surveyed to obtain information describing the well being drilled and the obtained information interpreted, e.g., to compare a planned position and a determined position of the well. An operator can respond to deviations between the planned position and the determined position, e.g., by adjusting the drilling operations or by re-defining the well objectives (or both).

[0003] US 2009/152005 discloses an optoisolator leadframe assembly including two aligned single pieces of emitter and receiver leadframe parts, each of which includes a rail and a plurality of leadframe units.

[0004] US 2010/241410 relates to methods for generating relative and absolute error models for a well path and to methods of combining uncertainties from multiple wells to obtain an improved error model.

DESCRIPTION OF DRAWINGS

[0005] FIG. 1 illustrates an example computer system to implement an integrated well survey management and planning tool.

[0006] FIG. 2 is a flowchart of an example process to implement the integrated well survey management and planning tool during a planning stage.

[0007] FIG. 3 illustrates an example user interface provided by the example computer system of FIG. 1 in response to implementing the integrated well survey management and planning tool.

[0008] FIG. 4 is a flowchart of an example process to implement the integrated well survey management and planning tool during an execution stage.

[0009] FIG. 5 illustrates an example schematic of the example computer system of FIG. 1.

[0010] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0011] The invention is set out in the appended set of claims.

[0012] This disclosure describes an integrated well survey management and planning tool. The tool can be implemented as a comprehensive, interactive survey management computer software application that can enable better planning and evaluation of survey strategy. The tool can bring different aspects of survey management, e.g., outputs determined by different survey tools that need to be considered during planning and executing a well into a single interactive environment. By implementing the tool, results of some analysis and actual interference effects can be viewed during the planning stage and the execution stage, respectively.

[0013] As described below, the tool can display multiple elements that affect well planning and surveying in a single interactive user interface on a display device. The interactive user interface can display the effect of a change in one parameter on other parameters, as applicable. Based on the outputs displayed in the user interface, an operator can adjust the choice of survey tools resulting in a well survey that achieves the well objectives, e.g., drill a well that reaches the intended geological target. In this manner, the tool can be implemented as an all-in-one interactive tool that can illustrate and optimize a survey for a well, platform, pad or field. For example, the tool can enable implementing as few surveys as necessary with survey tools that are as inexpensive as practicable. The tool can be implemented before or after commencing drilling operations (or both). Implementing the tool can enable operators to match the survey program with well objectives. The tool can be used to perform what-if analysis to determine the optimum length of non-magnetic material

required in the BHA and to monitor the effects of variations in the earth magnetic field, due to solar storms for instance, on survey accuracy and allow for early determination if re-surveying is needed. Also the tool allows for the instantaneous verification that the correct earth magnetic model is being used and that the input variables are correct, the same applies for the declination correction being applied. FIG. 1 illustrates an example computer system 100 to implement the integrated well survey management and planning tool. In some implementations, the tool can be implemented as a computer software application including computer instructions stored on a computer-readable medium 102 and executable by data processing apparatus 104 (e.g., one or more computer processors). The computer system 100 can be connected to a display device 106 and to one or more input devices 108 (e.g., a mouse, a keyboard, a touchscreen, a stylus, an audio input device, or other input devices). In some implementations, the computer system 100 can be a desktop computer, a laptop computer, a tablet computer, a smartphone, a personal digital assistant, a client computer of a server-client computer system, or other computer system.

[0014] The computer system 100 can be connected to one or more well survey and planning computer systems (e.g., a first computer system 110a, a second computer system 110b, a third computer system 110c) over one or more wired or wireless networks 112 (e.g., a local area network, a wide area network, the Internet). Each well survey and planning computer system can execute a respective well survey and planning computer software application that receives survey information obtained from survey tools connected to each well survey and planning computer system. The computer system 100 can receive the survey information from the well survey and planning computer software applications over the one or more wired or wireless networks 112. In some implementations, the one or more well survey and planning computer systems can be implemented as entities that are separate from the computer system 100 that implements the integrated well survey management and planning tool. Alternatively, the computer system 100 can implement the computer software applications implemented by each of the one or more well survey and planning computer systems.

[0015] FIG. 2 is a flowchart of a process 200 to implement the integrated well survey management and planning tool during a planning stage, i.e., before drilling commences. In some implementations, the computer system 100 can implement the process 200. At 202, the computer system 100 can receive multiple parameters. For example, the parameters can describe a location and a shape of a well and can be received, e.g., from a well operator. At 206, the computer system 100 can receive a survey plan indicating the number, position and survey type of surveys to be performed on the well while drilling the well.

[0016] At 204, the computer system 100 can receive a trajectory of the well from a surface to a subterranean geological target to be reached by drilling the well. For example, an operator can provide the trajectory as an input to the computer system 100. Alternatively, another computer system, which stores the trajectory, can provide the trajectory as an input to the computer system 100. At 208, the computer system 100 can receive a selection of a survey tool from among multiple survey tools. A survey tool can be a physical type of surveying tool that can be carried into the well. For example, the tool can be carried into the well on a wire (e.g., a wireline, e-line, or other tool) or tubing. The survey tool can measure the location in three-dimensional space of the well. For example, either the computer system 100 or one or more of the well survey and planning computer systems (or both) can be connected to the survey tool that surveys the well to be drilled along the received trajectory. In some implementations, the computer system 100 can also receive the number, position and survey type of surveys to be performed on the well while drilling the well.

[0017] At 210, the computer system 100 can apply multiple error models to the survey tool. An error model can be implemented as a computer software application as computer instructions stored on the computer-readable medium 102 and executable by the data processing apparatus 104. Each error model can define a respective uncertainty in reaching the subterranean geological target by drilling the well along the received trajectory. Some error models can determine the respective uncertainty by accounting for influences of different error sources. In some implementations, the computer system 100 can receive the error models, e.g., as inputs from an operator or from another computer system (or both). At 212, the

computer system 100 can display, in a user interface 114 (e.g., displayed in the display device 106), the multiple parameters, the received trajectory of the well, an identifier identifying the survey tool and an uncertainty indicator determined by applying the one or more error models. The uncertainty indicator indicates an uncertainty in drilling the well on the received trajectory.

[0018] The uncertainty indicator represents a combination of respective uncertainties defined by the multiple error models. In other words, the uncertainty indicator is an uncertainty of the well that represents a combination of uncertainties of each survey and spacing between the surveys. For example, each of multiple survey tools that are (or can be) implemented during a well survey is associated with a respective uncertainty. The uncertainty indicator described in this disclosure represents a combination of the multiple uncertainties associated with the multiple survey tools. The computer system 100 can determine the uncertainty indicator based, in part, on the locations of the survey tools. The uncertainty represented by the uncertainty indicator is more than the uncertainty in the accuracy of the tool itself. The uncertainty in the accuracy of the tool is determined by errors in the tool's ability to make measurements. In addition to the uncertainty of the tool, the uncertainty for the well represented by the uncertainty indicator represents an uncertainty in drilling the well along the target trajectory without being able to see the three-dimensional drilling space, i.e., without survey points and using measurements made by the survey tools during the previous survey. The uncertainty represented by the uncertainty indicator can increase as a time between successive surveys increases because the possible error builds. In some implementations, the uncertainty indicator can be determined based on the intended well trajectory and the survey tools that will be used (and the locations of the survey tools). The operator can then plan more or fewer survey points, different survey points, different survey tools (or combinations of them) based on a confidence (provided by the uncertainty indicator) that the well will hit the geological target.

[0019] In this manner, the computer system 100 can provide the user interface 114 as a comprehensive, interactive survey management module. The operator can use the user interface 114 to evaluate an effect of different numbers, positions and survey types of surveys that affect the uncertainty indicator. The operator can also

use the user interface 114 to evaluate an effect of different error models and combinations of error models, measurement corrections (e.g., sag correction), drill string configuration (e.g., the NMDC), well configurations and factors including well location and drilling time of the year. For example, the computer system 100 can provide each of the factors that affect the uncertainty indicator as a selectable option in the user interface 114. The operator can create combinations of selectable options (e.g., a combination of a first error model, a first correction, a first drill string configuration, a first location, a first drilling time, another combination of first and second error models, no correction, a second drill string configuration, the first location, a second drilling time, or other combinations) to determine the uncertainty indicator. In this manner, the operator can select/unselect available options and determine an effect on the uncertainty indicator. The operator can use the tool implemented by the computer system 100 to determine a survey program (i.e., the number, position and survey types) that will enable the operator to drill a well that will reach the geological target.

[0020] In the planning stage, the computer system 100 can receive the multiple parameters, receive the trajectory of the well, receive the selection of the survey tool, apply the one or more error models and display the multiple well survey parameters before the well is drilled along the received trajectory. In an execution stage, the computer system 100 can additionally receive actual drilling data and show the trajectory based on actual drilling data, as described below.

[0021] FIG. 3 is an example of the user interface 114 provided by the computer system 100 in response to executing the integrated well survey management and planning tool. The user interface 114 includes multiple regions. In each region, the computer system 100 displays either an input to or an output of the integrated well survey management and planning tool implemented by the computer system 100. In some implementations, the user interface 114 includes a region 304 in which the computer system 100 displays multiple parameters, e.g., a length of a non-magnetic drill collar (NMDC) to be positioned in the well, a sensor position in the NMDC at which a survey tool is to be positioned, and casing information describing at least one of a casing size, distance, or direction from the sensor position. The computer system 100 can receive the multiple parameters, which can also include a location and a

shape of the well, either from an operator of the computer system 100 or from one of the well survey and planning computer systems.

[0022] The user interface 114 includes a region 308 in which the computer system 100 displays the trajectory of the well from the surface to the subterranean geological target based, in part, on the parameters. In the region 308, the computer system 100 can also display the uncertainty indicator described above. In some implementations, the computer system 100 can display the uncertainty indicator as including multiple ellipses, each occupying a different area. As described above, each ellipse represents a combination of uncertainties associated with different multiple survey tools. A change in an uncertainty associated with information obtained by one of the survey tools affects an uncertainty associated with information obtained by another of the survey tools. Each ellipse of the multiple ellipses accounts for the different uncertainties associated with the different survey tools. For example, an area occupied by each ellipse is a measure of uncertainty in drilling on the target trajectory at a respective depth that cannot be visualized by relying on survey points obtained from the survey tools during a previous survey. In addition, each ellipse is associated with a respective depth of the well from the surface to the subterranean geological target. The computer system 100 can display the multiple ellipses at multiple respective depths along the trajectory in the region 308 of the user interface 114.

[0023] In some implementations, the computer system 100 can determine a confidence level for each ellipse that represents a confidence that an actual trajectory of the drilled well will match the predicted trajectory. The computer system 100 can determine the confidence level for each ellipse based, in part, on uncertainties associated with the information obtained by the survey tools, as described above. The computer system 100 can additionally determine an uncertainty threshold at a respective depth that represents an acceptable deviation between the actual and predicted trajectories. The uncertainty threshold is a potential uncertainty that is so great that the target trajectory could possibly miss the geological target. The computer system 100 can also determine whether the possible actual trajectory will reach the geological target. The computer system 100 can determine that a first ellipse at a first depth does not satisfy an uncertainty threshold at that depth. In response, the computer system 100 can display the first ellipse in the region 308 in a

manner that is visually distinguishable from a second ellipse that satisfies the uncertainty threshold at a second depth. For example, the computer system 100 can display ellipses that satisfy respective uncertainty thresholds in a color (e.g., green) and ellipses that do not satisfy the respective uncertainty thresholds in another color (e.g., red).

[0024] In some implementations, multiple survey tools can be available and can be connected to (e.g., operated by) the well survey and planning computer systems. The operator of the computer system 100 can select one or more survey tools, which can include, e.g., a single shock magnetic survey tool, a MWD magnetic survey tool with multi-shock type survey, or other survey tools. If the inaccuracies determined for the survey tools are higher than acceptable thresholds, then additional corrections can be applied. The corrections can include, e.g., SAG corrections to correct errors in the alignment of the survey tool, corrections to correct errors associated with the presence of magnetic components in the drill string, corrections due to earth's magnetic field based on geographic location (e.g., closer to the north or south poles), and other corrections.

[0025] As described above, the computer system 100 can receive a selection of one or more survey tools, e.g., from a user of the computer system 100 or from one or more of the well survey and planning computer systems. In addition, the computer system 100 can receive one or more error models to be applied to the selected survey tool through the user interface 114. For example, the user interface 114 can include a region 302 in which the computer system 100 displays multiple error models including, e.g., at least one of an interpolation in-field referencing (IIFR) model, an in-field referencing (IFR) model, and a measurement while drilling (MWD) model. In this region, the user interface 114 can also include a correction applied to the readings, e.g., a sag correction. A user of the computer system 100 can select one or more of the error models through the user interface 114. The computer system 100 can apply the selected one or more error models to the selected survey tool. In some implementations, the computer system 100 can include an "Accuracy" field that specifies an acceptable deviation (e.g., 1-sigma, 2-sigma, 3-sigma) in the region 302. The computer system 100 can apply the selected one or more error models to the

selected survey tool to determine that the errors fall within the deviation specified in the “Accuracy” field.

[0026] In some implementations, the multiple parameters can include a geographic location at which the well is to be drilled and a drilling time, i.e., a time of the year when drilling operations are to be performed. A well survey and planning computer system can implement a geodetic model that can determine the earth’s gravitational field and magnetic field strength at the location and at the drilling time. The user interface 114 can include a region 306 in which the computer system 100 displays an identifier identifying the geodetic model. The user interface 114 can also include a region 312 in which the computer system 100 can display the earth’s gravitational field strength and magnetic field strength, and a dip angle of the magnetic field.

[0027] In some implementations, the multiple parameters can include magnetics representing variations in the earth’s magnetic field due to solar effects during the drilling time. The user interface 114 can include a region 314 in which the computer system 100 displays the magnetics during the drilling time. For example, one of the well survey and planning computer systems can determine and provide the magnetics to the computer system 100 for display in the region 314. The computer system 100 can display a plot of the magnetics over a time that includes the drilling time in the region 314. Either the computer system 100 or a well survey and planning computer system can compare the magnetics with a threshold magnetics for drilling the well. In some implementations, the computer system 100 can display the magnetics at a particular time that satisfy the threshold magnetics to be visually distinguishable from magnetics at a different time that does not satisfy the threshold magnetics. For example, the computer system 100 can display the magnetics that satisfy the threshold magnetics in a first color (e.g., green) and the magnetics that do not satisfy the threshold magnetics in a second, different color (e.g., red). Moreover, some of the survey tools measure orientation relative to the earth’s magnetic field. The computer system 100 can account for the effect of the magnetics on the readings of the magnetic survey tools.

[0028] Additional survey and planning information that the computer system 100 can display in the user interface 114 can include an image of a SAG correction

for the well (e.g., in a region 318), an axial and cross-axial interference (e.g., in a region 310) representing a disturbance in a magnetic field due to low magnetic permeability components in the well, and an output of the IFR/IIFR error models (e.g., in a region 316). As described above, the user interface 114 is interactive. For example, when the computer system 100 receives a change to an uncertainty defined by an error model (or any input to the integrated well survey management and planning tool) that results in a change to an uncertainty defined by another error model, the computer system 100 can automatically and without user intervention update the uncertainty indicator (or any other aspect of the well plan or survey displayed in the user interface 114). The computer system 100 can display the updated uncertainty indicator in the user interface 114. An operator of the computer system 100 can make changes and see, e.g., in real time or near real time, an effect of the changes on the ellipse. In this manner, the operator can create different scenarios while designing the well survey plan.

[0029] The techniques described above related to implementing the integrated well survey management and planning tool during the planning stage of well. After drilling has commenced, one or more survey tools can be implemented to monitor the drilling operation as described below with reference to FIG. 4. The computer system 100 can implement the integrated well survey management and planning tool to receive information determined by the one or more survey tools, and, in real time, update appropriate regions in the user interface 114. By doing so, the operator can compare the actual drilling information with the predicted drilling information, and make adjustments as necessary, e.g., to the drilling conditions, the survey tools, the error models (or combinations of them). In addition, the operator can visualize an effect of the actual drilled well on the ellipses. For example, if the as-drilled well lands at a center of a predicted ellipse, the subsequent ellipses over undrilled portions will not be as large as predicted.

[0030] FIG. 4 is a flowchart of an example process to implement the integrated well survey management and planning tool during an execution stage. In some implementations, the computer system 100 can implement the process 400. At 402, the computer system 100 can receive survey data describing a well being drilled. For example, after the well drilling has commenced, a survey tool positioned at a

location between the surface and the geological target to be reached by drilling the well can be implemented to obtain survey data that includes a trajectory of the well being drilled. The survey tool can be moved to different locations in the well. For example, after drilling for a certain period, drilling can be stopped and the survey tool, which can be near the drill bit, can be operated to take a survey. As described above, the computer system 100 can receive a target trajectory along the well to be drilled to the geological target. At 404, the computer system 100 can determine an uncertainty indicator indicating an uncertainty in drilling the well on a target trajectory. For example, the computer system 100 can determine the uncertainty indicator based at least in part on the survey data and the target trajectory. The uncertainty indicator can indicate an uncertainty (e.g., a confidence measure) in reaching the geological target by drilling the well along the target trajectory.

[0031] At 406, the computer system 100 can display the uncertainty indicator in a user interface, e.g., in the user interface 114. As described above, in certain (but not all) instances, the computer system 100 can have previously determined an uncertainty indicator for the well during a planning stage, i.e., before drilling commences. By implementing process 400, the computer system 100 can determine a revised uncertainty indicator for the well based, in part, on survey data that describe the well being drilled. The revised uncertainty indicator measured during the drilling stage, therefore, is an update to the uncertainty indicator determined during the planning stage. In some implementations, the computer system 100 can receive at least a portion of a measured trajectory (i.e., the actual trajectory) of the well being drilled and compare the portion of the measured trajectory with the target trajectory determined during the planning stage. The computer system 100 can determine the revised uncertainty indicator based on the comparison. For example, upon determining that the as-drilled well lands at or near a center of an ellipse, then the computer system 100 can determine that the uncertainty that the well will land in a subsequent ellipse in an undrilled portion is low. Consequently, the computer system 100 can determine the revised ellipse to be smaller than a current ellipse. Alternatively, upon determining that the as-drilled well lands at or near a periphery of the ellipse, the computer system 100 can determine the revised ellipse to be larger than or at least the same size as the current ellipse.

[0032] The uncertainty indicator determined during the drilling stage, like the uncertainty indicator determined during the planning stage, can include multiple ellipses, each occupying a different area. Each ellipse is associated with a respective depth of the well from the surface to the subterranean geological target. One or more of the ellipses represents an uncertainty associated with a portion of the well that has not yet been drilled. The computer system 100 can display the multiple ellipses at multiple respective depths of the well in the user interface. In some implementations, the computer system 100 can replace an ellipse at a depth determined during the planning stage with another ellipse at the depth determined during the drilling stage. In this manner, the computer system 100 can replace one or more ellipses at respective one or more depths based on the survey data and the target trajectory. In some situations, the computer system 100 can determine that an ellipse determined during the planning stage matches (e.g., occupies the same area as) an ellipse determined during the drilling stage. In such situations, the computer system 100 may not replace the ellipse determined during the planning stage.

[0033] In response to viewing ellipses associated with the revised uncertainty indicator, an operator may change aspects of a survey plan, e.g., to adjust the target trajectory from the as-drilled well and the plan such that the newly updated ellipses land at the geological target. At 408, the computer system 100 can receive a change to the survey plan that indicates the number, position and survey type of surveys to be performed on the well while drilling the well. As described above, the change can be responsive to the uncertainty indicated by the revised uncertainty indicator. For example, upon viewing the revised uncertainty indicator, an operator can determine to change the number, position, survey type, error models (or a combination) that was previously defined in the survey plan. The operator can, e.g., select a survey tool that the operator had not selected during the planning stage before drilling commenced. In some implementations, the computer system 100 can display, in the user interface, multiple survey tools from among which the operator can make one or more selections.

[0034] At 410, the computer system 100 can apply multiple error models based on the received change to the survey plan. Each error model defines a respective uncertainty in reaching the subterranean geological target by drilling the

well. The uncertainty is based on a survey performed while the well is being drilled as well as the remaining target trajectory. The revised uncertainty indicator represents a combination of the respective uncertainties defined by the multiple error models. A change to an uncertainty defined by one of the error models can affect an uncertainty defined by another of the error models and the revised uncertainty indicator itself. At 412, the computer system 100 can determine such a change to the uncertainty indicator, and, at 414 display the revised uncertainty indicator in the user interface 114.

[0035] After the operator has adjusted the survey plan, well drilling can continue. The computer system 100 can continue to receive the survey data and determine the uncertainty indicator. For example, the computer system 100 can receive the data in real time (or near real time) or concurrently with the well drilling (or both). Based on a change or changes to the uncertainty indicator (e.g., if the uncertainty indicator fails to satisfy an uncertainty threshold), the operator can provide changes to the survey plan resulting in the computer system 100 revising the uncertainty indicator. In this manner, during the drilling stage, the computer system 100 can be implemented as a tool that the operator can use to monitor and adjust drilling operations to reach the geological target by implementing as few and as inexpensive survey tools as practicable.

[0036] FIG. 5 illustrates a schematic of the example computer system 100 of FIG. 1. The example computer system 100 can be located at or near one or more wells and/or at a remote location. The example computer system 100 includes a data processing apparatus 104 (e.g., one or more processors), a computer-readable medium 102 (e.g., a memory), and input/output controllers 170 communicably coupled by a bus 165. The computer-readable medium can include, for example, a random access memory (RAM), a storage device (e.g., a writable read-only memory (ROM) and/or others), a hard disk, and/or another type of storage medium. The computer system 100 can be preprogrammed and/or it can be programmed (and reprogrammed) by loading a program from another source (e.g., from a CD-ROM, from another computer device through a data network, and/or in another manner). The input/output controller 170 is coupled to input/output devices (e.g., the display device 106, input devices 108, and/or other input/output devices) and to a network 112. The

input/output devices receive and transmit data in analog or digital form over communication links such as a serial link, wireless link (e.g., infrared, radio frequency, and/or others), parallel link, and/or another type of link.

[0037] The network 112 can include any type of data communication network. For example, the network 112 can include a wireless and/or a wired network, a Local Area Network (LAN), a Wide Area Network (WAN), a private network, a public network (such as the Internet), a WiFi network, a network that includes a satellite link, and/or another type of data communication network.

CLAIMS

1. A computer-implemented well survey method for determining an uncertainty in reaching a subterranean geological target by drilling a proposed well along a received trajectory

characterized in that the method comprises:

receiving a trajectory of a proposed well from a surface to a subterranean geological target to be reached by drilling the proposed well;

receiving a survey plan indicating the number, position and survey type of surveys to be performed on the proposed well while drilling the proposed well;

receiving a selection of a survey tool, from among a plurality of survey tools, that is to survey the proposed well while drilling the proposed well;

displaying, in a user interface (114), a plurality of error models including at least one of an interpolation in-field referencing (IIFR) model, an in-field referencing (IFR) model, a measurement while drilling (MWD) model, or a sag correction model;

applying the plurality of error models based on the survey type for drilling the well, each error model defining a respective uncertainty in reaching the subterranean geological target by drilling the well along the received trajectory by accounting for influences of different error sources; and

displaying in the user interface (114)

the received trajectory of the well; and

an uncertainty indicator determined by applying the plurality of error models;

wherein the uncertainty indicator represents a combination of respective uncertainties defined by the plurality of error models;

the uncertainty indicator indicates an uncertainty in drilling the proposed well on the received trajectory; and

a change in uncertainty defined by one of the plurality of error models effects an uncertainty of at least another of the plurality of error models as well as the displayed uncertainty indicator of an uncertainty in drilling the proposed well on the received trajectory.

2. The method of claim 1, wherein the uncertainty indicator includes a plurality of ellipses, each occupying a different area, each ellipse associated with a respective depth of the well from the surface to the subterranean geological target, the method further comprising displaying the plurality of ellipses at a plurality of respective depths in the user interface (114).

3. The method of claim 2, further comprising:

determining that a first ellipse does not satisfy an uncertainty threshold at a respective depth;
and

displaying the first ellipse in the user interface (114) in a manner that is visually distinguishable from a second ellipse that satisfies the uncertainty threshold at a respective depth.

4. The method of claim 1, further comprising receiving a selection of a survey tool from among a plurality of survey tools, the survey tool to be implemented to survey the well to be drilled along the received trajectory.

5. The method of claim 1, further comprising receiving the trajectory of the well, receiving the survey plan, and applying the plurality of error models before drilling the well along the received trajectory.

6. A computer-implemented well survey method for determining an uncertainty in reaching a subterranean geological target by drilling a proposed well along a received trajectory

characterized in that the method comprises:

receiving a plurality of parameters that describe a location and a shape of the proposed well including a length of a non-magnetic drill collar (NMDC) to be positioned in the well, a sensor position in the NMDC at which a survey tool is to be positioned, and casing information describing at least one of a casing size, distance, or direction from the sensor position;

receiving a trajectory of the proposed well from a surface to a subterranean geological target to be reached by drilling the proposed well;

receiving a survey plan indicating the number, position and survey type of surveys to be performed on the proposed well while drilling the proposed well;

receiving a selection of a survey tool, from among a plurality of survey tools, that is to survey the proposed well while drilling the proposed well;

applying a plurality of error models based on the survey type for drilling the well, each error model defining a respective uncertainty in reaching the subterranean geological target by drilling the well along the received trajectory by accounting for influences of different error sources;

displaying in a user interface (114);

the plurality of parameters describing the proposed well;

the received trajectory of the proposed well; and

an uncertainty indicator determined by applying the plurality of error models:

wherein the uncertainty indicator represents a combination of respective uncertainties defined by the plurality of error models;

the uncertainty indicator indicates an uncertainty in drilling the proposed well on the received trajectory; and

a change in uncertainty defined by one of the plurality of error models effects an uncertainty of at least another of the plurality of error models as well as the displayed uncertainty indicator of an uncertainty in drilling the proposed well on the received trajectory.

7. A computer-implemented well survey method for determining an uncertainty in reaching a subterranean geological target by drilling a proposed well along a received trajectory

characterized in that the method comprises:

receiving a trajectory of the proposed well from a surface to a subterranean geological target to be reached by drilling the proposed well;

receiving a survey plan indicating the number, position and survey type of surveys to be performed on the proposed well while drilling the proposed well;

receiving an earth's gravitational field and magnetic field strength at a geographic location at which the well is to be drilled at a drilling time determined based on a geodetic model used to determine the earth's gravitational field, and magnetic dipping;

receiving a selection of a survey tool, from among a plurality of survey tools, that is to survey the proposed well while drilling the proposed well;

applying a plurality of error models based on the survey type for drilling the well, each error model defining a respective uncertainty in reaching the subterranean geological target by drilling the well along the received trajectory by accounting for influences of different error sources;

displaying in a user interface (114);

an identifier identifying the geodetic model, the earth's gravitational field strength and magnetic field strength, and a dip angle of the magnetic field;

the received trajectory of the proposed well; and

an uncertainty indicator determined by applying the plurality of error models;

wherein the uncertainty indicator represents a combination of respective uncertainties defined by the plurality of error models;

the uncertainty indicator indicates an uncertainty in drilling the proposed well on the received trajectory; and

a change in uncertainty defined by one of the plurality of error models effects an uncertainty of at least another of the plurality of error models as well as the displayed uncertainty indicator of an uncertainty in drilling the proposed well on the received trajectory.

8. The method of claim 7, further comprising receiving magnetics representing variations in the earth's magnetic field due to solar effects during the drilling time, the method further comprising displaying, in the user interface (114), the magnetics during the drilling time.

9. The method of claim 8, wherein displaying, in the user interface (114), the magnetics during the drilling time comprises:

displaying a plot of the magnetics over time that comprises the drilling time;

comparing the magnetics with a threshold magnetics for drilling the well;

displaying the magnetics that satisfy the threshold magnetics in a first color and the magnetics that do not satisfy the threshold magnetics in a second color that is different from the first color.

10. The method of claim 1, further comprising displaying, in the user interface (114), an image of a sag correction for the well.

11. The method of claim 1, further comprising displaying, in the user interface (114), axial and cross-axial interference representing a disturbance in a magnetic field due to low magnetic permeability components in the well.

12. The method of claim 1, further comprising:

receiving a change to an uncertainty defined by a first error model of the plurality of error models, the change resulting in a change to an uncertainty defined by a second error model of the plurality of error models;

in response to receiving the change, automatically and without user intervention:

updating the uncertainty indicator determined by applying the plurality of error models including the first error model and the second error model; and

displaying the updated uncertainty indicator in the user interface (114).

13. A computer-readable medium (102) characterized in that it comprises instructions which, when executed by a computer, cause the computer to carry out the method of claim 1.

14. The medium (102) of claim 13, wherein the uncertainty indicator includes a plurality of ellipses, each occupying a different area, each ellipse associated with a respective depth of the well from the surface to the subterranean geological target, the operations further comprising displaying the plurality of ellipses at a plurality of respective depths in the user interface (114).

15. The medium of claim 14, the operations further comprising:

determining that a first ellipse does not satisfy an uncertainty threshold at a respective depth; and

displaying the first ellipse in the user interface (114) in a color that is different from a color of a second ellipse that satisfies the uncertainty threshold at a respective depth.

16. The medium (102) of claim 13, the operations further comprising receiving the trajectory of the well, receiving the survey plan, and applying the plurality of error models before drilling the well along the received trajectory.

17. A system characterized in that it comprises:

data processing apparatus (104); and

a computer-readable medium (102) comprising instructions which, when executed by the data processing apparatus (104), cause the data processing apparatus (104) to carry out the method of claim 1.

18. A system characterized in that it comprises:

data processing apparatus (104); and

a computer-readable medium (102) comprising instructions which, when executed by the data processing apparatus (104), cause the data processing apparatus (104) to carry out the method of claim 7.

19. A system characterized in that it comprises:

data processing apparatus (104); and

a computer-readable medium (102) comprising instructions which, when executed by the data processing apparatus (104), cause the data processing apparatus (104) to carry out the method of claim 6.

PATENTKRAV

1. Datamaskinimplementert fremgangsmåte for brønnundersøkelse for å bestemme en usikkerhet i å nå et underjordisk geologisk mål ved å bore en foreslått brønn langs en mottatt bane

karakterisert ved at fremgangsmåten omfatter:

å motta en bane for en foreslått brønn fra en overflate til et underjordisk geologisk mål som skal nås ved å bore den foreslåtte brønnen;

å motta en undersøkelsesplan som indikerer antall, posisjon og undersøkelsestype av undersøkelser som skal utføres på den foreslåtte brønnen mens den foreslåtte brønnen bores;

å motta et utvalg av et undersøkelsesverktøy, fra et mangfold av undersøkelsesverktøy, som skal undersøke den foreslåtte brønnen mens den foreslåtte brønnen bores;

å vise, i et brukergrensesnitt (114), et mangfold av feilmodeller inkludert minst én av en modell for en interpolasjon i felt-referanse (IIFR), en modell for en i felt-referanse (IFR), en modell for måling under boring (MWD) eller en nedhengskorreksjonsmodell;

å bruke mangfoldet av feilmodeller basert på undersøkelsestypen for boring av brønnen, idet hver feilmodell definerer en respektive usikkerhet å nå det underjordiske geologiske målet ved å bore brønnen langs den mottatte banen ved å ta hensyn til påvirkninger fra forskjellige feilkilder; og

å vise i brukergrensesnittet (114)

den mottatte banen til brønnen; og

en usikkerhetsindikator bestemt ved å bruke mangfoldet av feilmodeller;

hvor i usikkerhetsindikatoren representerer en kombinasjon av respektive usikkerheter definert av mangfoldet av feilmodeller;

usikkerhetsindikatoren indikerer en usikkerhet ved boring av den foreslåtte brønnen på den mottatte banen; og

en endring i usikkerhet definert av ett av mangfoldet av feilmodeller påvirker en usikkerhet for minst et annet av mangfoldet av feilmodeller, så vel som den viste usikkerhetsindikatoren for en usikkerhet ved boring av den foreslåtte brønnen på den mottatte banen.

2. Fremgangsmåten ifølge krav 1, hvor i usikkerhetsindikatoren inkluderer et mangfold av ellipser, som hver opptar et forskjellig område, hver ellipse forbundet med en respektive dybde av brønnen fra

overflaten til det underjordiske geologiske målet, fremgangsmåten videre omfattende å vise mangfoldet av ellipser ved et mangfold av respektive dybder i brukergrensesnittet (114).

3. Fremgangsmåten ifølge krav 2, videre omfattende:

å bestemme at en første ellipse ikke tilfredsstiller en usikkerhetsterskel ved en respektive dybde; og

å vise den første ellipsen i brukergrensesnittet (114) på en måte som visuelt kan skilles fra en andre ellipse som tilfredsstiller usikkerhetsterskelen ved en respektive dybde.

4. Fremgangsmåten ifølge krav 1, videre omfattende å motta et utvalg av et undersøkelsesverktøy fra et mangfold av undersøkelsesverktøy, undersøkelsesverktøyet skal implementeres for å undersøke brønnen som skal bores langs den mottatte banen.

5. Fremgangsmåten ifølge krav 1, videre omfattende å motta banen til brønnen, å motta undersøkelsesplanen, og å bruke mangfoldet av feilmodeller før boring av brønnen langs den mottatte banen.

6. Datamaskinimplementert fremgangsmåte for brønnundersøkelse for å bestemme en usikkerhet i å nå et underjordisk geologisk mål ved å bore en foreslått brønn langs en mottatt bane
k a r a k t e r i s e r t ved at fremgangsmåten omfatter:

å motta et mangfold av parametere som beskriver en lokasjon og en form av den foreslåtte brønnen, inkludert en lengde av et ikke-magnetisk vektør (NMDC) som skal posisjoneres i brønnen, en sensorposisjon i NMDC hvor et undersøkelsesverktøy skal posisjoneres, og fôringsrørinformasjon som beskriver minst én av en fôringsrørstørrelse, avstand eller retning fra sensorposisjonen;

å motta en bane for den foreslåtte brønnen fra en overflate til et underjordisk geologisk mål som skal nås ved å bore den foreslåtte brønnen;

å motta en undersøkelsesplan som indikerer antall, posisjon og undersøkelsestype av undersøkelser som skal utføres på den foreslåtte brønnen mens den foreslåtte brønnen bores;

å motta et utvalg av et undersøkelsesverktøy, fra et mangfold av undersøkelsesverktøy, som skal undersøke den foreslåtte brønnen mens den foreslåtte brønnen bores;

å bruke et mangfold av feilmodeller basert på undersøkelsestypen for boring av brønnen, idet hver feilmodell definerer en respektive usikkerhet i å nå det underjordiske geologiske målet ved å bore brønnen langs den mottatte banen ved å ta hensyn til påvirkninger fra forskjellige feilkilder;

å vise i et brukergrensesnitt (114);

mangfoldet av parametere som beskriver den foreslåtte brønnen;

den mottatte banen til den foreslåtte brønnen; og

en usikkerhetsindikator bestemt ved å bruke mangfoldet av feilmodeller:

hvori usikkerhetsindikatoren representerer en kombinasjon av respektive usikkerheter definert av mangfoldet av feilmodeller;

usikkerhetsindikatoren indikerer en usikkerhet ved boring av den foreslåtte brønnen på den mottatte banen; og

en endring i usikkerhet definert av ett av mangfoldet av feilmodeller påvirker en usikkerhet for minst et annet av mangfoldet av feilmodeller så vel som den viste usikkerhetsindikatoren for en usikkerhet ved boring av den foreslåtte brønnen på den mottatte banen.

7. Datamaskinimplementert fremgangsmåte for brønnundersøkelse for å bestemme en usikkerhet i å nå et underjordisk geologisk mål ved å bore en foreslått brønn langs en mottatt bane

k a r a k t e r i s e r t ved at fremgangsmåten omfatter:

å motta en bane for den foreslåtte brønnen fra en overflate til et underjordisk geologisk mål som skal nås ved å bore den foreslåtte brønnen;

å motta en undersøkelsesplan som indikerer antall, posisjon og undersøkelsestype av undersøkelser som skal utføres på den foreslåtte brønnen mens den foreslåtte brønnen bores;

å motta en jords gravitasjonsfelt og magnetfeltstyrke ved en geografisk lokasjon der brønnen skal bores på et boretidspunkt bestemt basert på en geodetisk modell anvendt til å bestemme jordens gravitasjonsfelt, og magnetisk inklinasjon;

å motta et utvalg av et undersøkelsesverktøy, fra et mangfold av undersøkelsesverktøy, som skal undersøke den foreslåtte brønnen mens den foreslåtte brønnen bores;

å bruke et mangfold av feilmodeller basert på undersøkelsestypen for boring av brønnen, idet hver feilmodell definerer en respektive usikkerhet i å nå det underjordiske geologiske målet ved å bore brønnen langs den mottatte banen ved å ta hensyn til påvirkninger fra forskjellige feilkilder;

å vise i et brukergrensesnitt (114);

en identifikator som identifiserer den geodetiske modellen, jordens gravitasjonsfeltstyrke og magnetfeltstyrke, og en fallvinkel for magnetfeltet;

den mottatte banen til den foreslåtte brønnen; og

en usikkerhetsindikator bestemt ved å bruke mangfoldet av feilmodeller;

hvor i usikkerhetsindikatoren representerer en kombinasjon av respektive usikkerheter definert av mangfoldet av feilmodeller;

usikkerhetsindikatoren indikerer en usikkerhet ved boring av den foreslåtte brønnen på den mottatte banen; og

en endring i usikkerhet definert av ett av mangfoldet av feilmodeller påvirker en usikkerhet for minst et annet av mangfoldet av feilmodeller så vel som den viste usikkerhetsindikatoren for en usikkerhet ved boring av den foreslåtte brønnen på den mottatte banen.

8. Fremgangsmåten ifølge krav 7, videre omfattende å motta magnetikk som representerer variasjoner i jordens magnetfelt som følge av soleffekter under boretiden, fremgangsmåten videre omfattende å vise, i brukergrensesnittet (114), magnetikken under boretiden.

9. Fremgangsmåten ifølge krav 8, hvor i å vise, i brukergrensesnittet (114), magnetikken under boretiden omfatter:

å vise et plott av magnetikken over tid som omfatter boretiden;

å sammenligne magnetikken med en terskelmagnetikk for boring av brønnen;

å vise magnetikken som tilfredsstiller terskelmagnetikken i en første farge og magnetikken som ikke tilfredsstiller terskelmagnetikken i en andre farge som er forskjellig fra den første fargen.

10. Fremgangsmåten ifølge krav 1, videre omfattende å vise, i brukergrensesnittet (114), et bilde av en nedhengskorreksjon for brønnen.

11. Fremgangsmåten ifølge krav 1, videre omfattende å vise, i brukergrensesnittet (114), aksial og kryssaksial interferens som representerer en forstyrrelse i et magnetfelt som følge av komponenter med lav magnetisk permeabilitet i brønnen.

12. Fremgangsmåten ifølge krav 1, videre omfattende:

å motta en endring for en usikkerhet definert av en første feilmodell av mangfoldet av feilmodeller, endringen resulterer i en endring for en usikkerhet definert av en andre feilmodell av mangfoldet av feilmodeller;

som respons på mottak av endringen, automatisk og uten brukerintervensjon:

å oppdatere usikkerhetsindikatoren bestemt ved å bruke mangfoldet av feilmodeller inkludert den første feilmodellen og den andre feilmodellen; og

å vise den oppdaterte usikkerhetsindikatoren i brukergrensesnittet (114).

13. Datamaskinlesbart medium (102), k a r a k t e r i s e r t ved at det omfatter instruksjoner som, når de utføres av en datamaskin, får datamaskinen til å utføre fremgangsmåten ifølge krav 1.

14. Mediet (102) ifølge krav 13, hvori usikkerhetsindikatoren inkluderer et mangfold av ellipser, som hver opptar et forskjellig område, hver ellipse forbundet med en respektive dybde av brønnen fra overflaten til det underjordiske geologiske målet, operasjonene videre omfattende å vise mangfoldet av ellipser ved et mangfold av respektive dybder i brukergrensesnittet (114).

15. Mediet ifølge krav 14, operasjonene videre omfattende:

å bestemme at en første ellipse ikke tilfredsstiller en usikkerhetsterskel ved en respektive dybde; og

å vise den første ellipsen i brukergrensesnittet (114) i en farge som er forskjellig fra en farge til en andre ellipse som tilfredsstiller usikkerhetsterskelen ved en respektive dybde.

16. Mediet (102) ifølge krav 13, operasjonene videre omfattende å motta banen til brønnen, motta undersøkelsesplanen og bruke mangfoldet av feilmodeller før boring av brønnen langs den mottatte banen.

17. System, k a r a k t e r i s e r t ved at det omfatter:

et databehandlingsapparat (104); og

et datamaskinlesbart medium (102), omfattende instruksjoner som, når de utføres av databehandlingsapparatet (104), får databehandlingsapparatet (104) til å utføre fremgangsmåten ifølge krav 1.

18. System, k a r a k t e r i s e r t ved at det omfatter:

et databehandlingsapparat (104); og

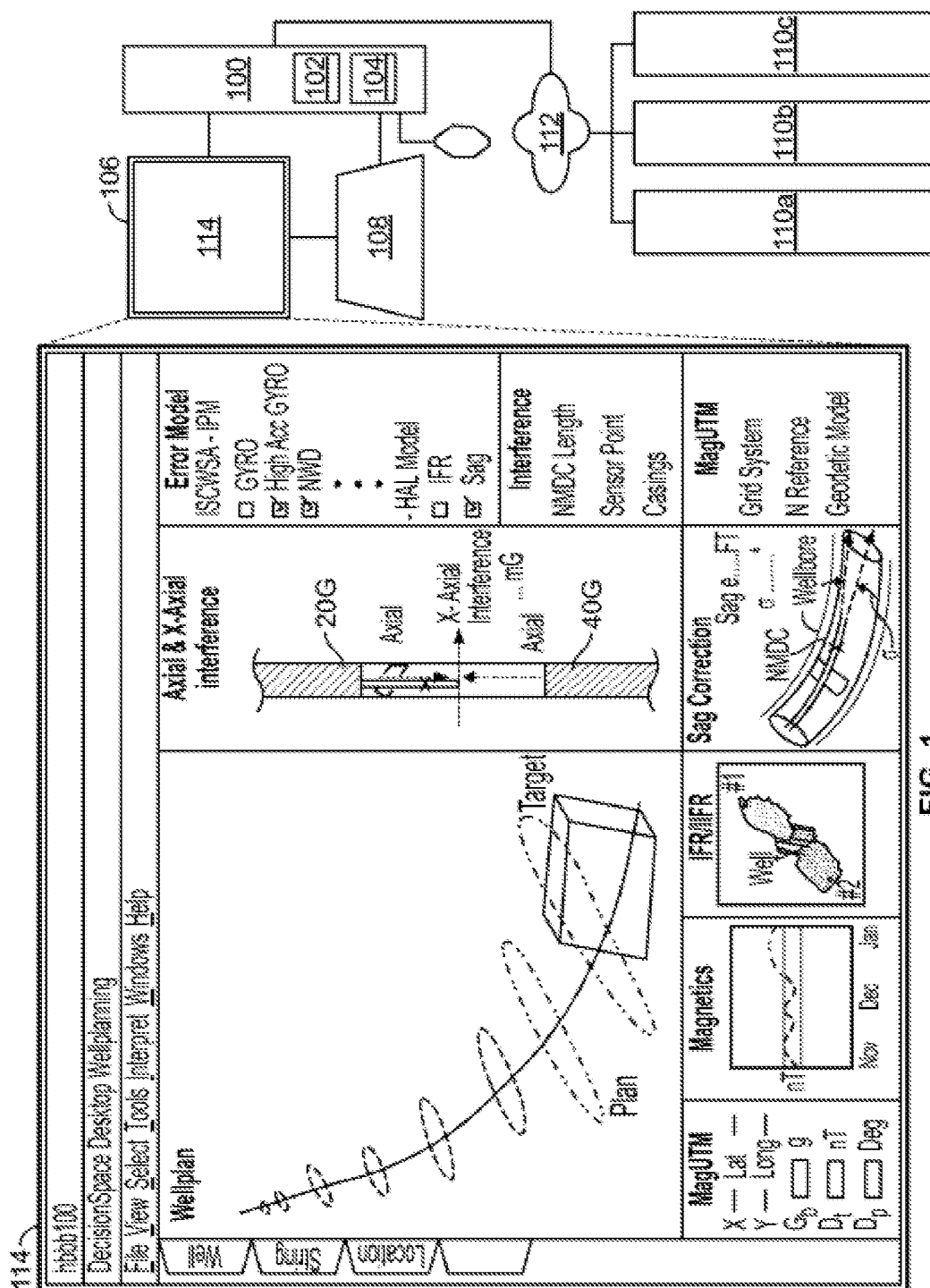
et datamaskinlesbart medium (102), omfattende instruksjoner som, når de utføres av databehandlingsapparatet (104), får databehandlingsapparatet (104) til å utføre fremgangsmåten ifølge krav 7.

19. System, k a r a k t e r i s e r t ved at det omfatter:

et databehandlingsapparat (104); og

et datamaskinlesbart medium (102), omfattende instruksjoner som, når de utføres av databehandlingsapparatet (104), får databehandlingsapparatet (104) til å utføre fremgangsmåten ifølge krav 6.

1/5



2/5

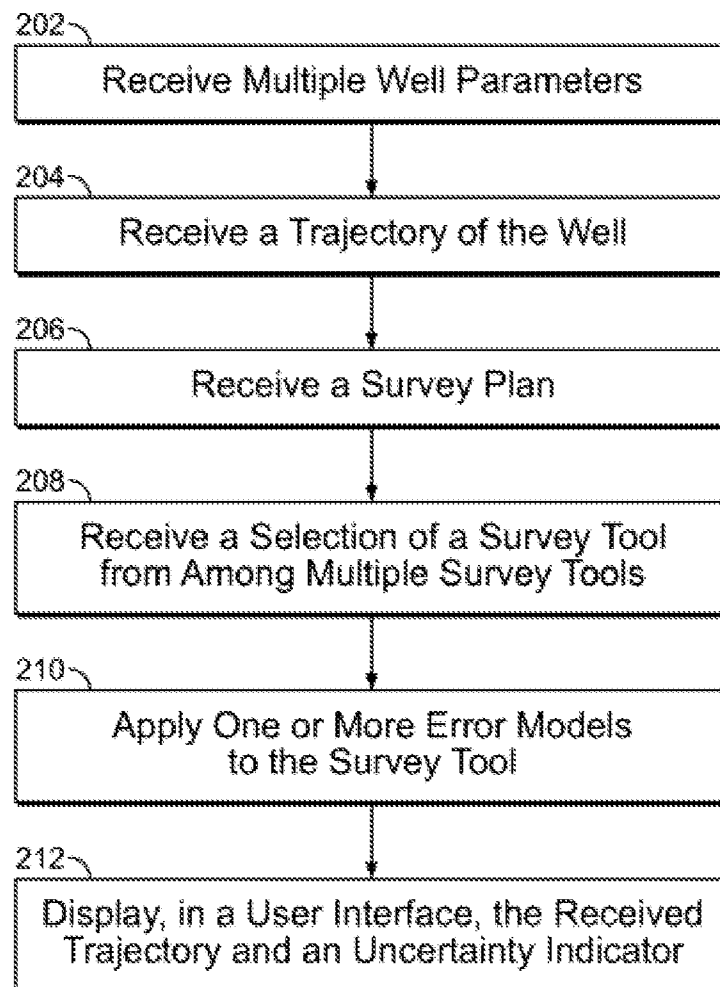


FIG. 2

114

hbb100

DecisionSpace Desktop Wellplanning

File View Select Tools Interpret Windows Help

Well String Location	Wellplan 308	Axial & X-Axial Interference 310	Error Model ISOWSA - IPM ☐ GYRO ☒ High Acc GYRO ☒ NMD ... ☐ HAL Model ☐ IFR ☒ Sag 302 Interference NMD Length Sensor Point Casings 304	MagUTM 312 X — Lat — Y — Long — G₀ ☐ 9 D₁ ☐ nT D₂ ☐ Deg	Magnetics 314	FRUIFR 316	Sag Correction 318 Sag e... FT σ ... NMD Wellbore	MagUTM 306 Grid System N Reference Geodetic Model
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FIG. 3

4/5

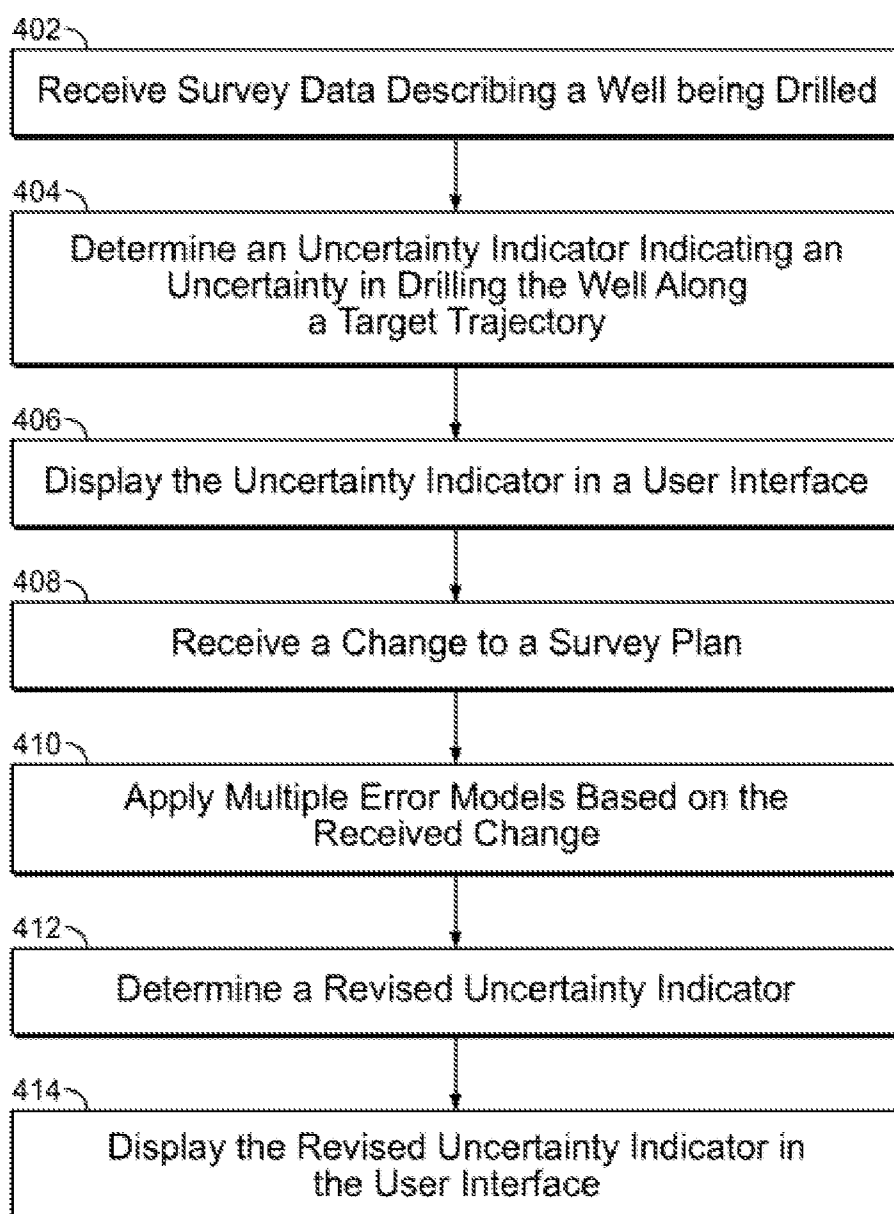


FIG. 4

5/5

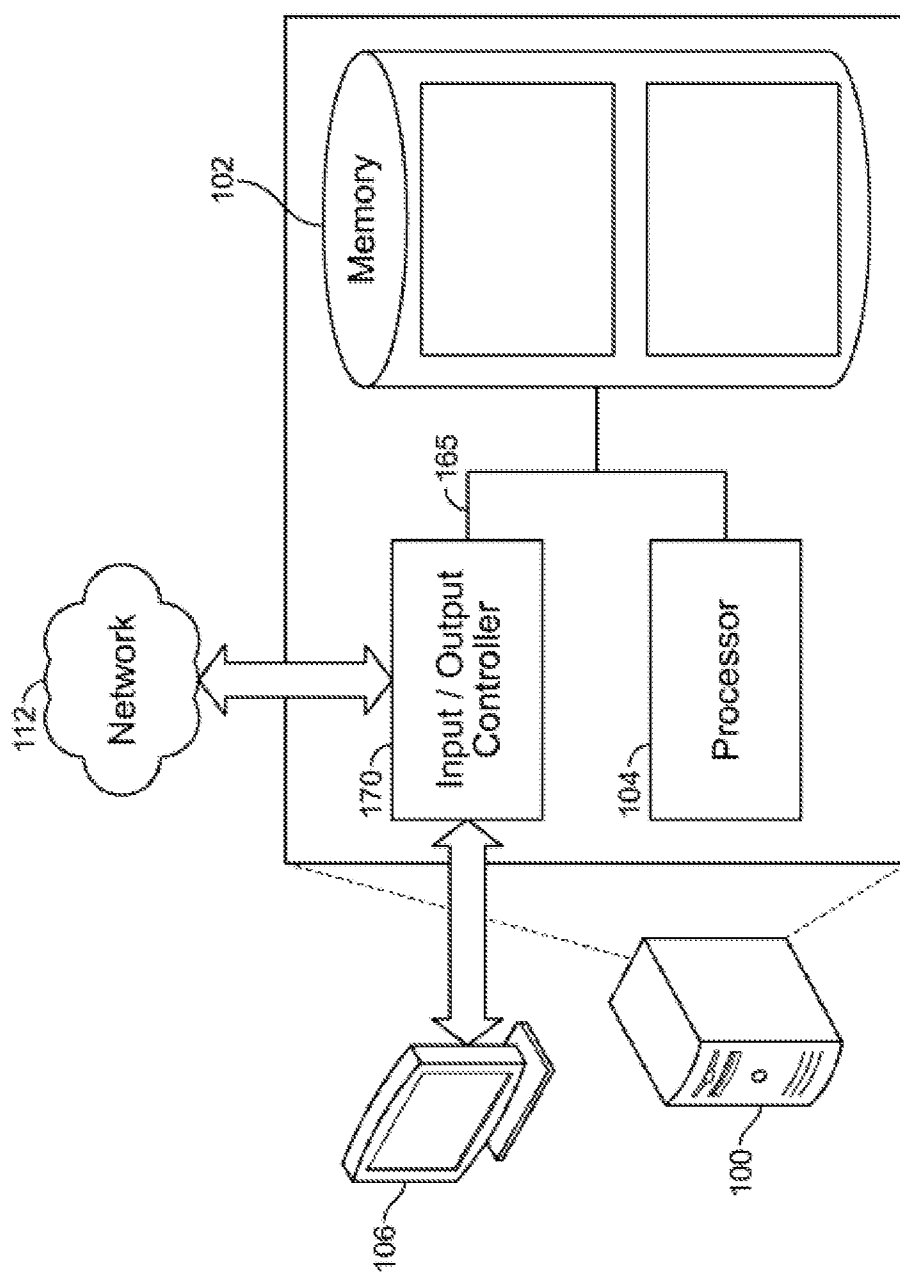


FIG. 5