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(54) **Title**: SYSTEM AND METHOD FOR DETECTING STRUCTURAL INTEGRITY OF A WELL CASING

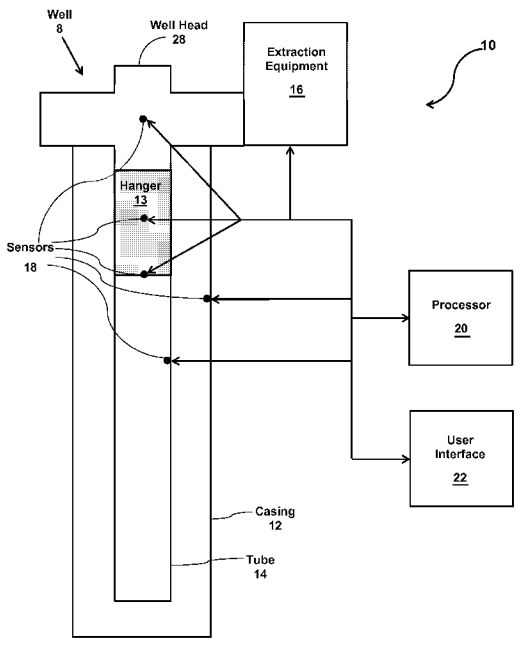


FIG. 1

(57) **Abstract**: This disclosure relates to a system and method for detecting structural integrity of a well casing. The system may detect casing structural integrity events. The casing structural integrity events may include structural failures of the casing and/or potential structural failures of the casing. The well casing may be drilled and/or otherwise embedded into a geologic structure. The well casing may be subject to geologic forces generated by the geologic structure. Unplanned and/or unexpected forces and/or movement may pose a risk to the structural integrity of the casing. Forces and/or movement of sufficient magnitude may result in damage to and/or destruction of the casing. Damage to and/or destruction of the casing may cause a loss of the natural resources being extracted via the well associated with the well casing, contamination of areas surrounding the well, undesirable surface expression, and/or other negative effects.

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SYSTEM AND METHOD FOR DETECTING STRUCTURAL INTEGRITY OF A WELL CASING

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority from U.S. Provisional Patent Application No. 61/777,553 filed March 12, 2013, entitled "System And Method For Detecting Structural Integrity Of A Well Casing," which is incorporated by reference herein.

FIELD OF THE DISCLOSURE

[0002] This disclosure relates to a system and method for detecting structural integrity of a well casing. The system may detect casing structural integrity events. The casing structural integrity events may include structural failures of the casing and/or potential structural failures of the casing related to the well tubing and/or other attached parts of the well structure.

BACKGROUND

[0003] Systems for sensing characteristics inside a well are known. An electrical connection to a well casing and a tubing string may power a down hole gauge and/or actuator. Current systems typically include gauges and/or actuators that monitor characteristics related to the natural resources flowing through the well. The current systems do not detect structural characteristics of the well casing.

SUMMARY

[0004] One aspect of the disclosure relates to a system configured to detect structural integrity of a well casing in a well. The system may comprise a conductive well casing, conductive tubing, one or more sensors, one or more processors, and/or other components.

[0005] The casing may be configured to surround the tubing. The tubing may be configured to communicate liquid and/or gas from an underground reservoir to above ground extraction equipment at or near a wellhead. The casing may be embedded in a geologic structure.

[0006] The one or more sensors may be configured to generate output signals conveying information related to a structural integrity of the casing. The one or more sensors may include fluid level sensors, voltage sensors, acoustic sensors, pressure sensors, motion sensors, strain sensors, and/or other sensors. In some implementations, the one or more sensors may include one or more sensor types. In some implementations, the one or more sensors may include two or more sensor types.

[0007] In some implementations, at least one of the one or more sensors may be electrically coupled with the tubing and the casing separately. At least one of the one or more sensors may be located in the wellhead. The one or more sensors may be located at one or more locations along the tubing within the casing. The one or more sensors may be located within the casing at or near a tubing hanger between the wellhead and the tubing. The tubing hanger may be configured to suspend the tubing in the casing.

[0008] The one or more processors may be configured to detect casing structural integrity events based on the output signals. The one or more processors may be configured to generate casing structural integrity event notifications. The casing structural event notifications may correspond to the detected casing structural integrity events. The notifications may be generated for delivery to a user responsive to the detections. The casing structural integrity events may include structural failures of the casing, potential structural failures of the casing, and/or other events. In some implementations, the one or more processors may be configured such that the casing structural integrity events are detected responsive to one or more forces acting on the casing. The one or more forces may include a shear force, a tensile force, a compressive force, a torsional force, and/or other forces. The one or more forces may be generated by the geologic structure surrounding the casing.

[0009] In some implementations, the one or more processors may be configured to determine extraction parameters and to detect the casing structural integrity events based on the extraction parameters. The extraction parameters may include information indicating whether the well is operating in a production phase or a pre-production phase, and/or other information.

[0010] In some implementations, the one or more processors may be configured to detect the casing structural integrity events based on an algorithm. The one or more processors may determine algorithm inputs based on the output signals. In some implementations, the one or more processors may be configured to cluster the information conveyed by the output signals and

detect the casing structural integrity events based on the clustering. Clustering may comprise arranging the information conveyed by the output signals in a multidimensional space.

[0011] In some implementations, the one or more processors may be configured to generate casing structural integrity scores based on the output signals. The one or more processors may be configured to detect the casing structural integrity events based on the casing structural integrity scores.

[0012] In some implementations, the one or more processors may be configured to determine one or more well parameters based on the output signals. The one or more well parameters may include one or more of a fluid level, a voltage, an acoustic parameter, a pressure, a motion parameter, a strain level, and/or other parameters. The one or more processors may be configured to determine well parameter threshold levels. The one or more processors may be configured to detect the casing structural integrity events responsive to the well parameters breaching the well parameter threshold levels.

[0013] Another aspect of the disclosure relates to method for detecting structural integrity of a well casing in a well. The method may comprise surrounding conductive well tubing with a conductive well casing. The tubing may be configured to communicate liquid and/or gas from an underground reservoir to above ground extraction equipment at a wellhead. The casing may be embedded in a geologic structure.

[0014] The method may comprise generating output signals conveying information related to a structural integrity of the casing. The method may include generating the output signals with one or more sensors. The one or more sensors may include fluid level sensors, voltage sensors, acoustic sensors, pressure sensors, motion sensors, strain sensors, and/or other sensors. The one or more sensors may include one or more sensor types. The one or more sensors may include two or more sensor types.

[0015] In some implementations, the method may include electrically coupling at least one of the one or more sensors with the tubing and the casing separately. At least one of the one or more sensors may be located in the wellhead. The one or more sensors may be located at one or more locations along the tubing within the casing. The one or more sensors may be located within the casing at or near a tubing hanger between the wellhead and the tubing. The tubing hanger may be configured to suspend the tubing in the casing.

[0016] The method may comprise detecting casing structural integrity events based on the output signals. The casing structural integrity events may be detected responsive to one or more forces acting on the casing. The one or more forces may include a shear force, a tensile force, a compressive force, a torsional force, and/or other forces. The one or more forces may be generated by the geologic structure surrounding the casing.

[0017] The method may comprise generating casing structural integrity event notifications that correspond to the detected casing structural integrity events for delivery to a user responsive to the detections. The casing structural integrity events may include structural failures of the casing, potential structural failures of the casing, and/or other events.

[0018] In some implementations, the method may include determining extraction parameters and detecting the casing structural integrity events based on the extraction parameters. The extraction parameters may include information indicating whether the well is operating in a production phase or a pre-production phase.

[0019] The method may include detecting casing structural integrity events based on an algorithm. The algorithm inputs may be determined based on the output signals.

[0020] In some implementations, the method may include clustering the information conveyed by the output signals and detecting the casing structural integrity events based on the clustering. Clustering may comprise arranging the information conveyed by the output signals in a multidimensional space.

[0021] In some implementations, the method may include generating casing structural integrity scores based on the output signals, and detecting casing structural integrity events based on the casing structural integrity scores.

[0022] In some implementations, the method may include determining one or more well parameters based on the output signals. The one or more well parameters may include a fluid level, a voltage, an acoustic parameter, a pressure, a motion parameter, a strain level, and/or other parameters. The method may include determining well parameter threshold levels, and detecting the casing structural integrity events responsive to the well parameters breaching the well parameter threshold levels.

[0023] These and other features, and characteristics of the present technology, as well as the methods of operation and functions of the related elements of structure and the combination of parts and economies of manufacture, will become more apparent upon consideration of the

following description and the appended claims with reference to the accompanying drawings, all of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the invention. As used in the specification and in the claims, the singular form of "a", "an", and "the" include plural referents unless the context clearly dictates otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] FIG. 1 illustrates a system configured to detect structural integrity of a well casing.

[0025] FIG. 2 illustrates an example configuration of multiple sensors.

[0026] FIG. 3 illustrates a natural resource field that includes multiple wells.

[0027] FIG. 4 illustrates a method for detecting structural integrity of a well casing.

DETAILED DESCRIPTION

[0028] FIG. 1 illustrates a system 10 configured to detect structural integrity of a well casing 12 in a well 8. Well 8 may be configured to extract minerals from an underground mineral reservoir. During mineral extraction, well 8 may be configured to communicate liquid and/or gas from the underground reservoir to above ground extraction equipment 16 at or near a wellhead 28. Well 8 may be drilled and/or otherwise embedded into a geologic structure. Well 8 may be subject to geologic forces generated by the geologic structure. Unplanned and/or unexpected forces and/or movement may pose a risk to the structural integrity of casing 12. Forces and/or movement of sufficient magnitude may result in damage to and/or destruction of casing 12. Damage to and/or destruction of casing 12 may cause a loss of the natural resources being extracted via well 8, contamination of areas surrounding well 8, undesirable surface expression, and/or other negative effects.

[0029] System 10 may be configured to detect casing structural integrity events and generate casing structural integrity event notifications that correspond to the detected casing structural integrity events. The casing structural integrity events may include structural failures of casing 12, potential structural failures of casing 12, and/or other events. In some implementations,

system 10 may comprise casing 12, tube 14, one or more sensors 18, one or more processors 20, user interface 22, and/or other components.

[0030] Casing 12 may surround tube 14, sensors 18, and/or other components of system 10. Casing 12 may line a borehole and provide structural support for well 8. Casing 12 may separate well 8 from the geologic structure. The geologic structure may include subsurface materials (e.g., rocks, dirt, etc.), water (e.g., in the case of a well in the ocean floor), and/or other environmental materials. Casing 12 may be made from a conductive material such as steel and/or other materials.

[0031] Tube 14 may be configured to communicate liquid and/or gas during mineral extraction. Tube 14 may be configured to communicate liquid and/or gas from the underground reservoir to above ground extraction equipment 16 at or near wellhead 28. Tube 14 may be a tubing string. The tubing string may include a series of coupled tubes. The series of tubes may be coupled via threaded ends of each tube and/or other coupling mechanisms. In some implementations, the series of coupled tubes may be a series of coupled tubing joints. The joints may include, for example, a pup joint. Tube 14 may be made from electrically conductive materials such as steel and/or other electrically conductive materials.

[0032] As described above, tube 14 may be provided within casing 12. Providing tube 14 within casing 12 may create an inner annular space between the outer surface of tube 14 and casing 12. One or more centralizers may be configured to maintain tube 14 in the annular space to maintain a physical separation between tube 14 and casing 12. The centralizers may couple with the outside diameter of tube 14 via one or more coupling devices. The coupling devices may include, for example, a clamp, a collar, a latch, a hook, adhesive, and/or other coupling devices. The centralizers may be configured to engage casing 12 at various locations in well 8 to maintain a physical separation between tube 14 and casing 12. The centralizers may include, for example, bow spring centralizers, floating collars, fixed position devices, mixed dielectric centralizers, and/or other centralizers. In some implementations, the centralizers may be made from one or more conductive materials such as steel and/or other materials. In some implementations, the centralizers may be made from non-conductive materials.

[0033] Tube 14 may cooperate with casing 12 to form a coaxial transmission line. One or more electrical loads (e.g., sensors 18) disposed within well 8 may be powered via the coaxial transmission line formed by casing 12 and tube 14 without the need for electrical wiring. Casing

12 and tube 14 may be configured such that voltage and/or current across casing 12 and tube 14 are sufficient to power the electrical load(s). In some implementations, tube 14 may have a positive polarity and casing 12 may have a negative polarity. In some implementations, an electrical load may be electrically coupled with the electrically positive tube 14 and separately with the electrically negative casing 12 such that the load is powered via the connections.

[0034] Sensors 18 may be configured to generate output signals conveying information related to the structural integrity of casing 12. The output signals may include output signals related to the casing-tubing pair. The information related to the structural integrity of casing 12 may comprise information related to structural failures of casing 12, information related to potential structural failures of casing 12, and/or other information. The information related to structural failures and/or the potential structural failures may include information related to movement of casing 12, tube 14, and/or other components of well 8. The information related to structural failures and/or the potential structural failures may include information related to physical defects and/or a potential for physical defects in casing 12. The physical defects may include, for example, breaks, cracks, holes, deformations, loss of centralization, and/or other defects. Sensors 18 may comprise one or more sensors that measure such information directly (e.g., through direct contact with casing 12). Sensors 18 may comprise one or more sensors that generate output signals related to the structural integrity of casing 12 indirectly. For example, one or more of sensors 18 may generate an output based on a characteristic of tube 14 (e.g., an amount of electrical current running through tube 14) and/or based on a characteristic of the liquid and/or gas in tube 14 (e.g., a fluid level).

[0035] In some implementations, sensors 18 may include a single sensor type. Sensors 18 may include, for example, fluid level sensors, voltage sensors, acoustic sensors, pressure sensors, motion sensors, strain sensors, force sensors, flow sensors, composition sensors, temperature sensors, strain gauges, accelerometers, and/or other sensors. For example, sensors 18 may include one or more strain gauges coupled with the tube 14 and/or casing 12.

[0036] In some implementations, sensors 18 may include two or more different sensor types. For example, fluid level sensors may generate output signals conveying information related to a fluid level in well 8. In some implementations, the fluid level information may be indicative of casing 12 collapse, pressure in the casing, sheer forces acting on the casing, an electrical short between tubing 14 and casing 12, an open breach of the wall of casing 12, and/or other

phenomena. A current sensor (e.g., a transformer) on tube 14 may generate output signals conveying information related to voltage and/or current changes in an otherwise closed circuit (e.g., due to movement, damage, etc.). This could be multiplexed in more than one mode (sourced or passive). The passive mode may behave like a voltage and/or current receiver. The voltage and/or current sensors may be located just below a tubing hanger 13. Hanger 13 may be configured to suspend the tube 14 in casing 12. An acoustic sensor (e.g., an accelerometer and/or a microphone) may be mounted to tube 14, hanger 13, in and/or near wellhead 28, and/or at other locations. The spectral character of the monitored sound may include mechanical motion and/or resonance information related to the structural integrity of casing 12. One or more pressure sensors mounted in well 8 (e.g., in the annular space between tube 14 and casing 12, within tube 14, etc.) may convey information related to the pressure in those areas of well 8, and/or the stability of those pressures. For example, an unstable pressure may indicate that a structural integrity event has occurred and/or is about to occur. A motion sensor (e.g., an accelerometer) may generate output signals related to movement of casing 12, tube 14, and/or other components of well 8. Strain gages affixed to tube 14 may generate output signals conveying information related to internal stresses and/or strains.

[0037] Sensors 18 are illustrated in FIG. 1 and described above at various locations within system 10. In some implementations, at least one of sensors 18 may be electrically coupled with tube 14 and casing 12 separately. At least one of sensors 18 may be located in wellhead 28. Sensors 18 may be located at one or more locations along tube 14 within casing 12. In some implementations, one or more of the sensors may communicate via tube 14. Sensors 18 may be located within casing 12 at or near tubing hanger 13 between wellhead 28 and tube 14.

[0038] For example, FIG. 2 illustrates a possible configuration of multiple sensors 18. A sensor assembly 200 may be packaged as a small "launcher" on a four foot sub 204. The sensors shown in FIG. 2 are examples of the sensors that may be included in such an assembly and are not intended to be limiting. Assembly 200 may include other sensors not shown in FIG. 2. The sensors shown in FIG. 2 include a strain sensor 210 (e.g., a strain gauge) and a current sensor 212. The current sensor may include, for example, an RF/AC transformer coupled current monitor including a magnetic core on tube 14. Assembly 200 may be compactly located at or near an underside 206 of tubing hanger 13. In some implementations, assembly 200 may include feed-thru capability in hanger 13 for wire leads 216. In some implementations, an acoustic

transducer (not shown in FIG. 2) may be mounted on the top of hanger 13. In some implementations, the transducer may be thermally isolated. The collective electronics for assembly 200 may be packaged in a small enclosure. In some implementations, sensor assembly 200 may be powered by a battery, solar power, and/or other power sources/supplies. In some implementations, sensor assembly 200 may require a relatively low amount of power. For example, sensor assembly 200 may require about 5 to 10 watts. In some implementations, sensor assembly 200 may include power management and RF source generation circuitry not shown in FIG. 2.

[0039] Returning to FIG. 1, sensors 18 may include sensors disposed in a plurality of alternate locations in addition to and/or instead of those shown in FIG. 1. For example, sensors may be disposed within extraction equipment 16, and/or in other locations. In some implementations, tube 14, casing 12, a conductive centralizer, and/or other components of well 8 may be configured to provide a signal path for the output signals.

[0040] Processor 20 may be configured to provide information processing capabilities in system 10. As such, processor 20 may include one or more of a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information. Although processor 20 is shown in FIG. 1 as a single entity, this is for illustrative purposes only. In some implementations, processor 20 may include a plurality of processing units. These processing units may be physically located within the same device, or processor 20 may represent processing functionality of a plurality of devices operating in coordination. Processor 20 may be configured to execute one or more computer program modules. Individual ones the computer program modules may be configured to provide at least a portion of the functionality attributed herein to processor 20. Processor 20 may be configured to execute the one or more computer program modules by software; hardware; firmware; some combination of software, hardware, and/or firmware; and/or other mechanisms for configuring processing capabilities on processor 20. It should be appreciated that the modules may be co-located within a single processing unit, and/or one or more of the modules may be located remotely from the other modules. In some implementations, processor 20 may be integrated with extraction equipment 16, user interface 22, and/or other components of system 10.

[0041] Processor 20 may be configured to detect casing structural integrity events based on the output signals from sensors 18 and/or other information. In some implementations, the casing structural integrity events may include structural failures of the casing, potential structural failures of the casing, and/or other casing structure failure events. The casing structural integrity events may be detected responsive to one or more forces acting on casing 12. The one or more forces may include a shear force, a tensile force, a compressive force, a torsional force, and/or other forces. The one or more forces may be generated by the geologic structure surrounding casing 12. For example, geologic layers and/or strata may shift on each other creating shear forces that act on casing 12. Processor 20 may be configured to generate casing structural integrity event notifications that correspond to the detected casing structural integrity events. The casing structural integrity event notifications may be generated for delivery to a user responsive to the detections. Processor 20 may be configured to control user interface 22 to display the notifications generated by processor 20.

[0042] In some implementations, processor 20 may be configured to detect casing structural integrity events based on the output signals from a single type of sensors 18 (e.g., strain sensors). In some implementations, processor 20 may be configured to detect casing structural integrity events based on the output signals from at two or more different types of sensors 18. Processor 20 may be configured to process the information conveyed by the output signals of the two or more different types of sensors to detect casing structural integrity events. For example, processor 20 may be configured such that processing the information includes determining baseline well information, detecting casing structural integrity events based on an algorithm, detecting casing structural integrity events by clustering the information conveyed by the output signals in a multidimensional space, determining a casing structural integrity score and/or other metrics related to casing structural integrity, determining well parameters, monitoring change in the determined parameters (e.g., rate of change, standard deviation, and/or other measurements of change), determining well parameter thresholds, and/or other information processing. In some implementations, processing the information may include determining other information based on an integration and/or conglomeration of the information conveyed by the output signals.

[0043] In some implementations, determining baseline well information may include determining information that indicates normal operation of well 8. The information that indicates normal operation of well 8 may be determined by, for example, monitoring and

evaluating multiple wells during various seasons of the year, at various production levels, and/or in various geographic locations. In some implementations, processor 20 may be configured such that determining baseline well information may include determining extraction parameters. The extraction parameters may include information indicating whether the well is operating in a production phase, a pre-production phase, and/or other phases. For example, the extraction parameters may include parameters related to whether or not liquid and/or gas is actively flowing through tube 14. In some implementations, the baseline well information for normal operation of well 8 during the pre-production may be different than during the production phase. Processor 20 may be configured to detect the casing structural integrity events based on the extraction parameters. For example, processor 20 may be configured to determine that well 8 is in a pre-production phase based on the extraction parameters. Processor 20 may detect a casing structural integrity event responsive to the information conveyed by the output signals of sensors 18 being outside the normal well information range for the pre-production phase.

[0044] In some implementations, processor 20 may be configured to detect the casing structural integrity events based on an algorithm. Processor 20 may determine algorithm inputs based on the output signals. In some implementations, processor 20 may be configured such that the algorithm may be configured to indicate whether a casing structural integrity event has occurred and/or will occur. The algorithm may be configured to indicate one or more structural integrity events occurring at one or more locations in casing 12. Algorithm inputs may include information conveyed by the output signals of sensors 18, baseline well information determined by processor 20, one or more extraction parameters determined by processor 20, one or more well parameters determined by processor 20, and/or other inputs. The one or more well parameters may include, for example, a fluid level, a voltage, an acoustic parameter, a pressure, a motion parameter, a strain level, and/or other parameters. Algorithm inputs may include currently determined information (e.g., the spectral character of current well noise) and/or previously determined information (e.g., the normal spectral character of well noise). In some implementations, the algorithm may include and/or represent an electronic model of well 8. In some implementations, the electronic model may be a mathematical model. The mathematical model may include multi-dimensional model-based algorithms and/or other algorithms configured to interpret the output signals generated by sensors 18.

[0045] By way of a non-limiting example, processor 20 may be configured to determine a fluid level in well 8, a strain level in tube 14, and the spectral character of current noise in well 8 based on the output signals generated by three different types of sensors 18. The fluid level, the strain level, and the spectral character of the noise may be algorithm inputs. Processor 20 may be configured such that the algorithm indicates that a structural integrity event is about to occur based on the fluid level, the strain level, and the spectral character inputs. In this example, processor 20 may not have detected the structural integrity event based on the fluid level, the strain level, and or the spectral character of the noise alone. But as inputs to the algorithm, the fluid level, the strain level, and the spectral character of the noise together indicated the structural integrity event. The three types of information used in this example are not intended to be limiting. The algorithm may be configured to indicate structural integrity events based on any amount and/or type of input.

[0046] In some implementations, the algorithm may include one or more algorithms. The one or more algorithms may be determined at manufacture, programmed, adjusted, uploaded, and/or updated by a user via user interface 22, and/or determined by other methods.

[0047] In some implementations, processor 20 may be configured to cluster the information conveyed by the output signals. Processor 20 may be configured to detect the casing structural integrity events based on the clustering. Clustering may comprise arranging the information conveyed by the output signals in a multidimensional space. Arranging the information in the multidimensional space may comprise grouping the information conveyed by the output signals of sensors 18 into separate data clusters based on similarities in the information conveyed by the output signals. Similarities in the data may indicate, for example, that well 8 is operating normally. In some implementations, processor 20 may be configured to cluster information conveyed by the output signals of sensors 18 that indicates well 8 is operating normally into a first data cluster and information that indicates a casing structural integrity event into one or more additional data clusters. The information conveyed by the output signals of sensors 18 may be clustered by processor 20 based on statistical similarities in the information, magnitudes and/or directions of vectors that represent the information in the multidimensional space, and/or other information. Clustering may be known as networking in some implementations.

[0048] In some implementations, processor 20 may be configured to generate casing structural integrity scores based on the output signals. Processor 20 may be configured to detect

the casing structural integrity events based on the casing structural integrity scores. In some implementations, the casing structural integrity scores may be individual values related to individual structural integrity events. In some implementations, the casing structural integrity scores may be individual values that indicate a likelihood that a structural integrity event has occurred and/or will occur. In some implementations, processor 20 may be configured such that the casing structural integrity scores comprise weighted structural integrity scores. A weighted structural integrity score may comprise a collection of individually weighted scores based on information conveyed by the output signals from individual ones of the different types of sensors 18 (e.g., fluid level, strain, etc.) The individually weighted scores may be weighted based on individual relationships between the information conveyed by the output signals from specific sensors 18 and whether that information has more or less importance relative to a specific casing structural integrity event. Processor 20 may be configured to determine the importance of the information conveyed by the output signals from specific sensors 18 based on input from user interface 22, information determined at manufacture, and/or other information.

[0049] In some implementations, processor 20 may be configured to determine one or more well parameters based on the output signals. As described above, the one or more well parameters may include a fluid level, a voltage, an acoustic parameter, a pressure, a motion parameter, a strain level, and/or other parameters.

[0050] In some implementations, processor 20 may be configured to monitor change in the determined parameters. Monitoring change may include, analyzing the determined parameters, comparing currently determined parameters to previously determined parameters, generating one or more graphics showing change in a given parameter over time, and/or other monitoring. For example, processor 20 may be configured to analyze the determined parameters by determining a rate of change, a standard deviation, a moving average, and/or other determinations representative of change for a given parameter. Processor 20 may be configured to generate a two dimensional graph showing a level of a given parameter over time. Change may be monitored based on various increments of time. Change may be monitored on a yearly basis, a monthly basis, a weekly basis, a daily basis, an hourly basis, a minute by minute basis, a second by second basis, and/or based on other increments of time. For example, a current pressure may be compared to a previous pressure that was determined one second prior to the current pressure.

A current amount of strain may be represented on a two dimensional graph with prior strain levels determined one day, one week, one month, and one year prior to the current strain level.

[0051] In some implementations, processor 20 may be configured to determine well parameter threshold levels, and to detect the casing structural integrity events responsive to the well parameters breaching the well parameter threshold levels. For example, a first casing structural integrity event may be detected responsive to a first well parameter breaching a first well parameter threshold level. As a second example, a second casing structural integrity event may be detected responsive to the first well parameter breaching the first well parameter threshold level and a second well parameter breaching a second well parameter threshold level. Processor 20 may be configured to detect casing structural integrity events based on any number well parameters breaching any number of well parameter threshold levels. For example, processor 20 may detect a casing structural integrity event responsive to six different well parameters breaching six corresponding well parameter threshold levels. In some implementations, the well parameter threshold levels may be determined at manufacture, programmed, adjusted, uploaded, and/or updated by a user via user interface 22, and/or determined by other methods.

[0052] User interface 22 may be configured to facilitate delivery of casing structural integrity event notifications generated by processor 20 and/or other information to users. User interface 22 may be configured to receive entry and/or selection of information from users. User interface 22 may be configured to receive entry and/or selection of control inputs from users that facilitate operation of well 8 such that the users may adjust and/or cease the operation of well 8 if necessary, responsive to receiving casing structural integrity event notifications. Users may include well site managers, remote operators, petroleum engineers, and/or other users. This enables data, cues, results, notifications, instructions, and/or any other communicable items, collectively referred to as "information," to be communicated between users and processor 20, extraction equipment 16, and/or other components of system 10. Examples of interface devices suitable for inclusion in user interface 22 comprise a keypad, buttons, switches, a keyboard, knobs, levers, a display screen, a touch screen, speakers, a microphone, an indicator light, an audible alarm, a printer, a tactile feedback device, and/or other interface devices. In some implementations, user interface 22 comprises a plurality of separate interfaces. In some

implementations, user interface 22 comprises at least one interface that is provided integrally with processor 20 and/or extraction equipment 16.

[0053] It is to be understood that other communication techniques, either hard-wired or wireless, are also contemplated by the present disclosure as user interface 22. For example, the present disclosure contemplates that user interface 22 may be integrated with a removable electronic storage interface disposed in extraction equipment 16. In this example, information may be loaded into system 10 from removable storage (e.g., a smart card, a flash drive, a removable disk, etc.) that enables the user(s) to customize the implementation of system 10. Other exemplary input devices and techniques adapted for use with system 10 as user interface 22 comprise, but are not limited to, an RS-232 port, RF link, an IR link, modem (telephone, cable or other). In short, any technique for communicating information with system 10 is contemplated by the present disclosure as user interface 22.

[0054] In some implementations, extraction equipment 16 may include equipment configured to manage operation of well 8. Managing the operation of well 8 may include drawing liquid and/or gas through well 8, storing the liquid and/or gas, monitoring well 8, powering well 8, preparing well 8 for production, analyzing data related to the operation of well 8, and/or other activities. Such equipment may include pumps, piping, wiring, liquid and/or gas storage devices, power supplies, data processing equipment (e.g., one or more computers and/or processors), communication equipment, cameras, safety systems, well control devices, and/or other extraction equipment. For example, a well power supply may be configured to supply a positive polarity to tube 14 and a negative polarity to casing 12. As another example, user interface 22 may be provided by extraction equipment 16.

[0055] Wellhead 28 may be located at the surface of well 8. Wellhead 28 may be configured to suspend tube 14 and/or casing 12 in well 8. Wellhead 28 may be a structural interface between tube 14 and extraction equipment 16 configured to couple tube 14 with extraction equipment 16. Wellhead 28 may be configured to contain pressure present in well 8. Wellhead 28 may be configured to provide physical access to well 8 including access to annular space(s) between casing 12 and/or tube 14. Wellhead 28 may be configured to provide electrical ports that are electrically coupled with tube 14, casing 12, sensors 18, and/or other components of system 10.

[0056] Extraction equipment 16, sensors 18, processor 20, user interface 22, and/or other components of system 10 may be operatively linked via one or more electronic communication links. Such electronic communication links may be wired and/or wireless. For example, such electronic communication links may be established, at least in part, via a network and/or other links. In some implementations, extraction equipment 16, sensors 18, processor 20, and/or user interface 22, may be configured to communicate directly. It will be appreciated that this is not intended to be limiting, and that the scope of this disclosure includes implementations in which extraction equipment 16, sensors 18, processor 20, user interface 22, and/or other components of system 10 may be operatively linked via some other communication media, or with linkages not shown in FIG. 1.

[0057] FIG. 3 illustrates a natural resource field 300 that includes multiple wells 8. Sensors 18 and/or the other components of system 10 may be located at the individual wells 8 and generate output signals conveying information related to the structural integrity of the casings of the individual wells 8 to processor 20. Such an arrangement of sensors 18 and/or wells 8 in natural resource field 300 may facilitate mapping geologic behavior of field 300. Geologic behavior may include, for example, geologic movement, temperature changes, pressure changes, satellite provided geologic data, GPS data, and/or other geologic behavior. In some implementations, the information generated for each well 8 may be time synchronized by processor 20 such that geologic events may be detected and/or predicted in the areas of natural resource field 300 that are not directly instrumented. Notifications related to the geologic behavior of natural resource field 300 may be generated by processor 20 for delivery to a user via user interface 22, for example.

[0058] FIG. 4 illustrates a method 400 for detecting structural integrity of a well casing in a well. The operations of method 400 presented below are intended to be illustrative. In some implementations, method 400 may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. Additionally, the order in which the operations of method 400 are illustrated in FIG. 4 and described herein is not intended to be limiting.

[0059] In some implementations, method 400 may be implemented in one or more processing devices (e.g., a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or

other mechanisms for electronically processing information). The one or more processing devices may include one or more devices executing some or all of the operations of method 400 in response to instructions stored electronically on one or more electronic storage mediums. The one or more processing devices may include one or more devices configured through hardware, firmware, and/or software to be specifically designed for execution of one or more of the operations of method 400.

[0060] At an operation 402, conductive well tubing may be surrounded with a conductive well casing. The tubing may be configured to communicate liquid and/or gas from an underground reservoir to above ground extraction equipment at a wellhead. In some implementations, the tubing may be a tubing string. The casing may be embedded in a geologic structure. In some implementations, operation 402 may be performed by a well casing the same as or similar to casing 12 (shown in FIG. 1 and described herein).

[0061] At an operation 404, output signals conveying information related to a structural integrity of the casing may be generated. The output signals may be generated with one or more sensors. In some implementations, the one or more sensors may include one or more sensor types. In some implementations, the one or more sensors may include two or more sensor types. The sensor types may include fluid level sensors, voltage sensors, acoustic sensors, pressure sensors, motion sensors, strain sensors, and/or other sensors. The sensors may be located at various locations in and/or near the well. At least one of the sensors may be electrically coupled with the well tubing and the well casing separately. At least one of the sensors may be located in the wellhead. The one or more sensors may be located at one or more locations along the tubing within the casing. The one or more sensors may be located within the well casing at or near a tubing hanger between the wellhead and the well tubing. The tubing hanger may be configured to suspend the tubing in the casing. In some implementations, operation 404 may be performed by sensors the same as or similar to sensors 18 (shown in FIG. 1 and described herein).

[0062] At an operation 406, casing structural integrity events may be detected. The casing structural integrity events may be detected based on the output signals. The casing structural integrity events may be detected responsive to one or more forces acting on the well casing. The one or more forces may include a shear force, a tensile force, and a compressive force, a torsional force, and/or other forces. The one or more forces may be generated by the geologic structure surrounding the casing.

[0063] In some implementations, extraction parameters may be determined at operation 406. The extraction parameters may be determined based on the output signals and/or other information. Detecting the well casing structural integrity events may be based on the extraction parameters. The extraction parameters may include information indicating whether the well is operating in a production phase or a pre-production phase. In some implementations, the casing structural integrity events may be detected based on an algorithm. The algorithm inputs may be determined based on the output signals. In some implementations, at operation 406, the information conveyed by the output signals may be clustered and/or networked. Detecting the casing structural integrity events may be based on the clustering. Clustering may comprise arranging the information conveyed by the output signals in a multidimensional space. In some implementations, at operation 406, casing structural integrity scores may be generated based on the output signals. Detecting the casing structural integrity events may be based on the casing structural integrity scores. In some implementations, at operation 406, one or more well parameters may be determined based on the output signals. The one or more well parameters may include one or more of a fluid level, a voltage, an acoustic parameter, a pressure, a motion parameter, a strain level, and/or other parameters. Well parameter threshold levels may be determined and the casing structural integrity events may be detected responsive to the well parameters breaching the well parameter threshold levels. For example, a first casing structural integrity event may be detected responsive to a first well parameter breaching a first well parameter threshold level.

[0064] In some implementations, operation 406 may be performed by a processor the same as or similar to processor 20 (shown in FIG. 1 and described herein).

[0065] At an operation 408, casing structural integrity event notifications that correspond to the detected casing structural integrity events may be generated. The notifications may be generated for delivery to a user responsive to the detections. The well casing structural integrity events may include one or both of structural failures of the casing and/or potential structural failures of the casing. In some implementations, operation 408 may be performed by a processor the same as or similar to processor 20 (shown in FIG. 1 and described herein).

[0066] Although the present technology has been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred implementations, it is to be understood that such detail is solely for that purpose and that the

technology is not limited to the disclosed implementations, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. For example, it is to be understood that the present technology contemplates that, to the extent possible, one or more features of any implementation can be combined with one or more features of any other implementation.

CLAIMS

What is claimed is:

1. A system configured to detect structural integrity of a well casing in a well, the system comprising:

a conductive well casing configured to surround conductive well tubing, the tubing being configured to communicate liquid and/or gas from an underground reservoir to above ground extraction equipment at or near a wellhead, the casing being embedded in a geologic structure;

one or more sensors configured to generate output signals conveying information related to a structural integrity of the casing and/or a casing-tubing pair, and

one or more processors configured to detect casing structural integrity events based on the output signals, and to generate casing structural integrity event notifications that correspond to the detected casing structural integrity events for delivery to a user responsive to the detections, the casing structural integrity events including one or both of structural failures of the casing or potential structural failures of the casing.

2. The system of claim 1, wherein the one or more processors are further configured to determine extraction parameters and to detect the casing structural integrity events based on the extraction parameters, the extraction parameters including information indicating whether the well is operating in a production phase or a pre-production phase.

3. The system of claim 1, wherein the one or more processors are configured to detect the casing structural integrity events based on an algorithm, wherein the one or more processors determine algorithm inputs based on the output signals.

4. The system of claim 1, wherein the one or more sensors include one or more sensor types, the one or more sensors including fluid level sensors, voltage sensors, acoustic sensors, pressure sensors, motion sensors, current sensors, and strain sensors.

5. The system of claim 1, wherein the one or more sensors include two or more sensor types, the one or more sensors including fluid level sensors, voltage sensors, current sensors, acoustic sensors, pressure sensors, motion sensors, and strain sensors.

6. The system of claim 1, wherein the one or more processors are configured such that the casing structural integrity events are detected responsive to one or more forces acting on the casing, the one or more forces including a shear force, a tensile force, a compressive force, and a torsional force, the one or more forces generated by the geologic structure surrounding the casing.

7. The system of claim 1, wherein the one or more processors are configured to cluster the information conveyed by the output signals and detect the casing structural integrity events based on the clustering, wherein clustering includes networking and/or arranging the information conveyed by the output signals in a multidimensional space.

8. The system of claim 1, where the one or more processors are configured to generate casing structural integrity scores based on the output signals, and detect the casing structural integrity events based on the casing structural integrity scores.

9. The system of claim 1, wherein the one or more processors are further configured to determine one or more well parameters based on the output signals, the one or more well parameters including one or more of a fluid level, a voltage, a current, an acoustic parameter, a pressure, a motion parameter, or a strain level,

wherein the one or more processors are configured to determine well parameter threshold levels, and

wherein the one or more processors are configured to detect the casing structural integrity events responsive to the well parameters breaching the well parameter threshold levels such that a first casing structural integrity event is detected responsive to a first well parameter breaching a first well parameter threshold level.

10. The system of claim 1, wherein at least one of the one or more sensors is electrically coupled with the tubing and the casing separately.

11. The system of claim 1, wherein at least one of the one or more sensors is located in the wellhead.

12. The system of claim 1, wherein the one or more sensors are located at one or more locations along the tubing within the casing.

13. The system of claim 1, wherein the one or more sensors are located within the casing at or near a tubing hanger between the wellhead and the tubing, the tubing hanger being configured to suspend the tubing in the casing.

14. A method for detecting structural integrity of a well casing in a well, the method comprising:

surrounding conductive well tubing with a conductive well casing, the tubing being configured to communicate liquid and/or gas from an underground reservoir to above ground extraction equipment at a wellhead, the casing being embedded in a geologic structure;

generating output signals conveying information related to a structural integrity of the casing;

detecting casing structural integrity events based on the output signals, and

generating casing structural integrity event notifications that correspond to the detected casing structural integrity events for delivery to a user responsive to the detections, the casing structural integrity events including one or both of structural failures of the casing or potential structural failures of the casing.

15. The method of claim 14, further comprising determining extraction parameters and detecting the casing structural integrity events based on the extraction parameters, the extraction parameters including information indicating whether the well is operating in a production phase or a pre-production phase.

16. The method of claim 14, further comprising detecting the casing structural integrity events based on an algorithm, wherein the algorithm inputs are determined based on the output signals.

17. The method of claim 14, further comprising generating the output signals with one or more sensors, the one or more sensors including one or more sensor types, the one or more sensors including fluid level sensors, voltage sensors, current sensors, acoustic sensors, pressure sensors, motion sensors, and strain sensors.

18. The method of claim 14, further comprising generating the output signals with one or more sensors, wherein the one or more sensors include two or more sensor types, the one or more sensors including fluid level sensors, voltage sensors, acoustic sensors, pressure sensors, motion sensors, and strain sensors.

19. The method of claim 14, wherein the casing structural integrity events are detected responsive to one or more forces acting on the casing, the one or more forces including a shear force, a torsional force, a tensile force, and a compressive force, the one or more forces generated by the geologic structure surrounding the casing.

20. The method of claim 14, further comprising clustering the information conveyed by the output signals and detecting the casing structural integrity events based on the clustering, wherein clustering comprises arranging the information conveyed by the output signals in a multidimensional space.

21. The method of claim 14, further comprising generating casing structural integrity scores based on the output signals, and detecting the casing structural integrity events based on the casing structural integrity scores.

22. The method of claim 14, further comprising determining one or more well parameters based on the output signals, the one or more well parameters including one or more of a fluid level, a voltage, an acoustic parameter, a pressure, a motion parameter, or a strain level,

determining well parameter threshold levels, and

detecting the casing structural integrity events responsive to the well parameters breaching the well parameter threshold levels such that a first casing structural integrity event is detected responsive to a first well parameter breaching a first well parameter threshold level.

23. The method of claim 14, further comprising generating the output signals with one or more sensors, and electrically coupling at least one of the one or more sensors with the tubing and the casing separately.

24. The method of claim 14, further comprising generating the output signals with one or more sensors, wherein at least one of the one or more sensors is located in the wellhead.

25. The method of claim 14, further comprising generating the output signals with one or more sensors, wherein the one or more sensors are located at one or more locations along the tubing within the casing.

26. The method of claim 14, further comprising generating the output signals with one or more sensors, wherein the one or more sensors are located within the casing at or near a tubing hanger between the wellhead and the tubing, the tubing hanger being configured to suspend the tubing in the casing.

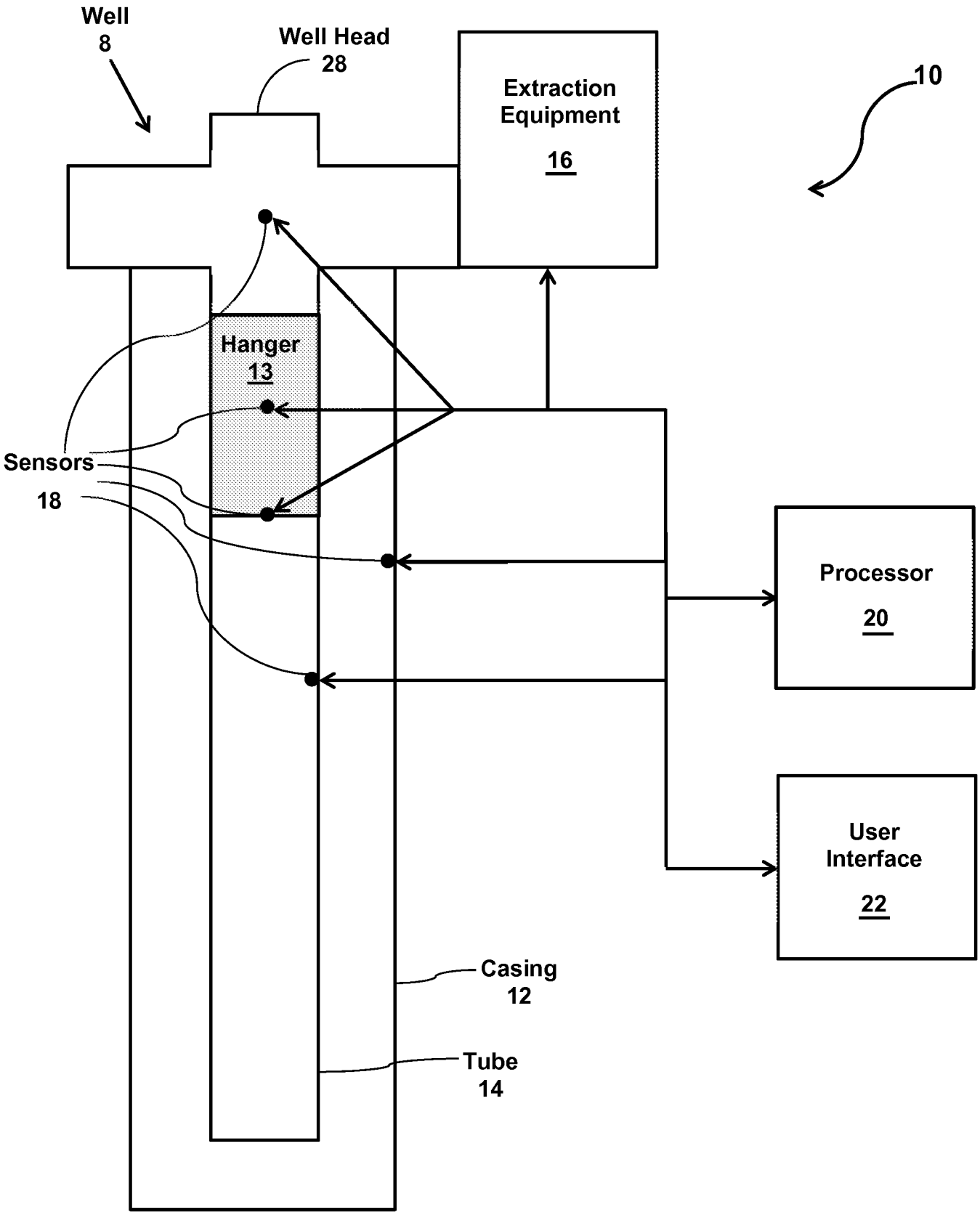

Well
8
Well Head
28
Extraction
Equipment
16
10
Hanger
13
Sensors
18
Processor
20
User
Interface
22
Casing
12
Tube
14

FIG. 1

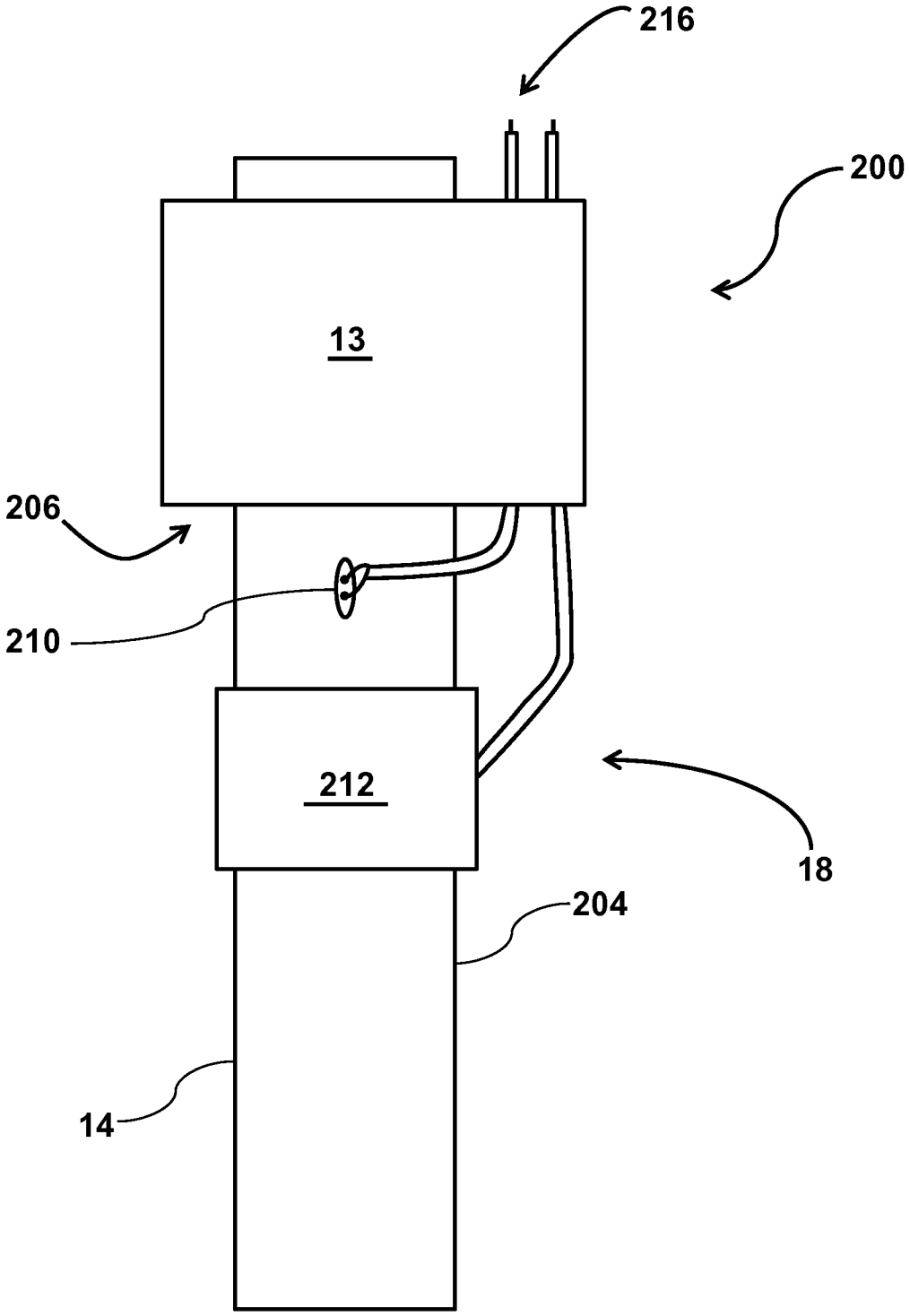


FIG. 2

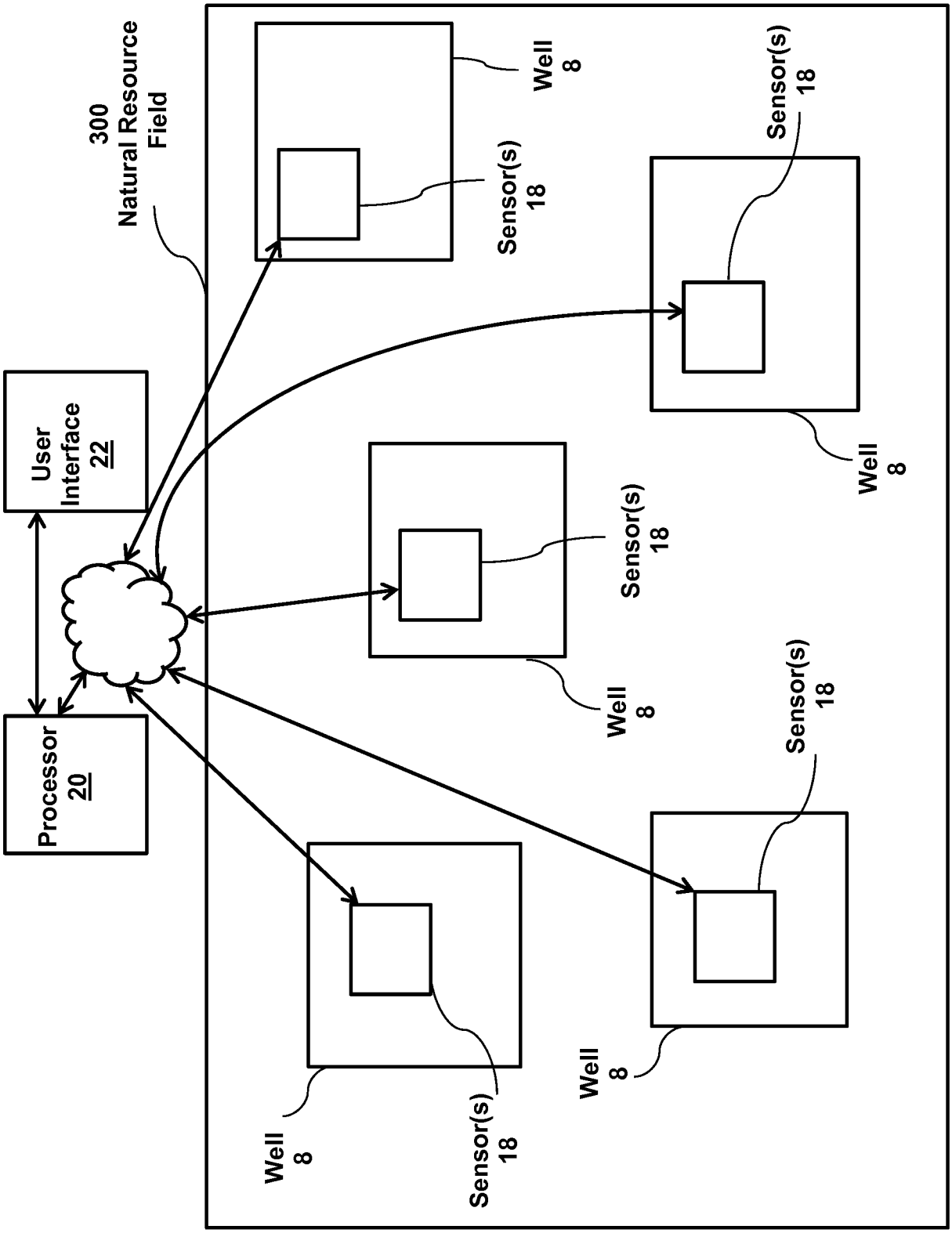

300
Natural Resource
Field
Well
8
Sensor(s)
18
User
Interface
22
Processor
20

FIG. 3

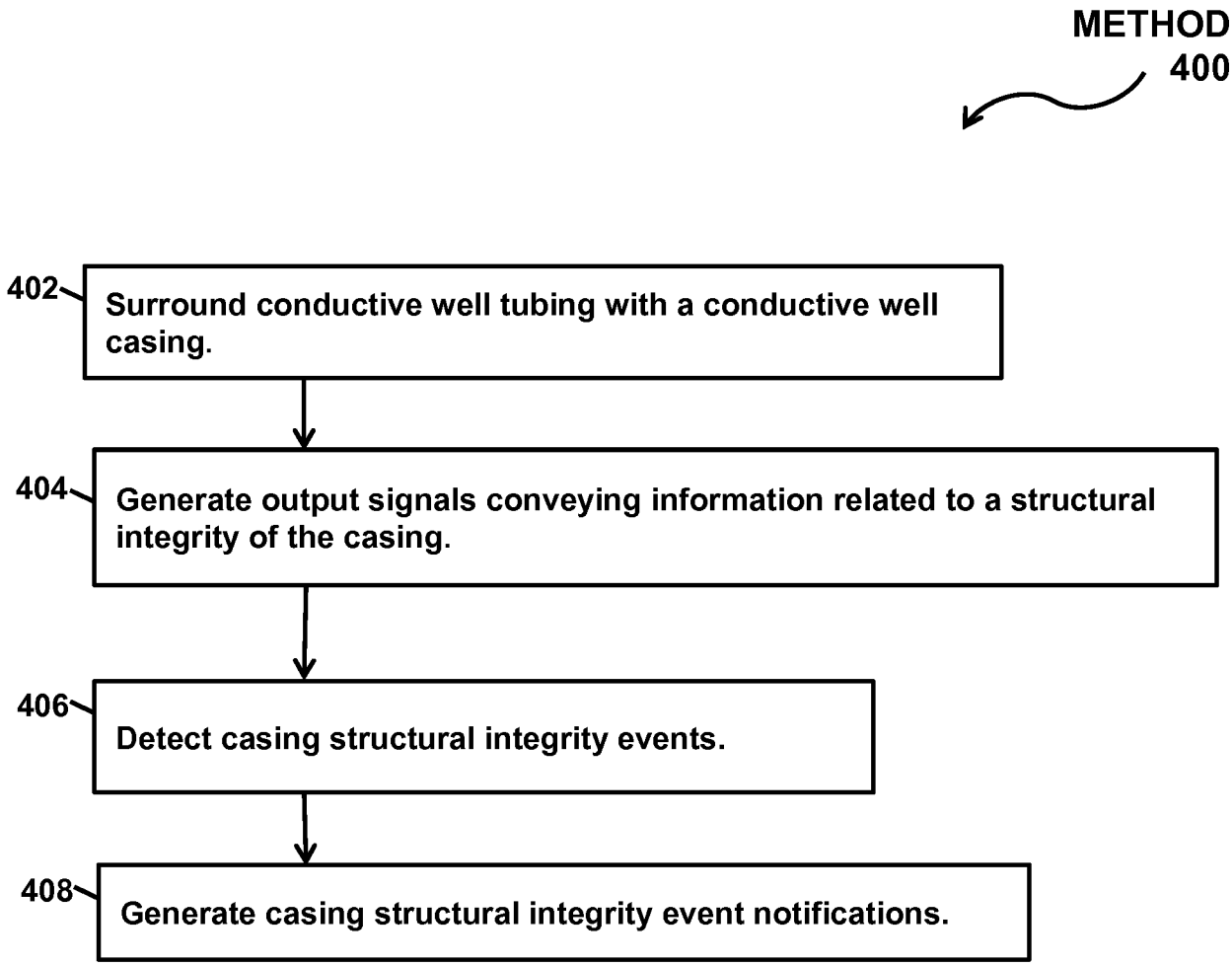

METHOD
400
402
Surround conductive well tubing with a conductive well casing.
404
Generate output signals conveying information related to a structural integrity of the casing.
406
Detect casing structural integrity events.
408
Generate casing structural integrity event notifications.

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US14/23863

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - E21B 47/00; G01V 1/40, 1/48 (2014.01)
USPC - 166/250.05; 204/404; 702/6
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): E21B 47/00; G01V 1/40, 1/48 (2014.01)
USPC: 166/250.05; 204/404; 702/6

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
MicroPatent (US Granted, US Applications, EP-A, EP-B, WO, JP, DE-G, DE-A, DE-T, DE-U, GB-A, FR-A); Google; Google Scholar; ProQuest KEYWORDS: conductive, well, casing, tubing, sensor, processor, detector, computer, notif*, alert*, light, message, tubular, parameter, threshold, maximum, minimum, limit, signal, hanger

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7,805,248 B2 (THIGPEN B et al.) 28 September 2010; figure 1A, 1B; column 1, lines 10-35, 55-60, column 3, lines 5-10, 15-25, column 4, lines 5-20, 45-55, column 5, lines 10-40, column 7, lines 5-40, column 8, lines 1-40	1-8, 10-12, 14-21, 23-25 --- 9, 13, 22, 26
Y	US 8,176,979 B2 (OLLRE A) 15 May 2012; figure 8; column 4, lines 40-50, 60-65, column 7, lines 1-15	9, 22
Y	US 2002/0074127 A1 (BIRCKHEAD J et al.) 20 June 2002; figures 1, 12; paragraphs [0012], [0016]	13, 26

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 June 2014 (30.06.2014)	21 JUL 2014
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)