

- (51) International Patent Classification:

G01V 1/50 (2006.01) E21B 47/005 (2012.01)
- (21) International Application Number:

PCT/US2024/010133
- (22) International Filing Date:

03 January 2024 (03.01.2024)
- (25) Filing Language:

English
- (26) Publication Language:

English
- (30) Priority Data:

18/403,114 03 January 2024 (03.01.2024) US
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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM,

(54) Title: IDENTIFYING AN ANOMALY IN A CEMENT LAYER OF A WELLBORE USING DIMENSIONALITY REDUCTION

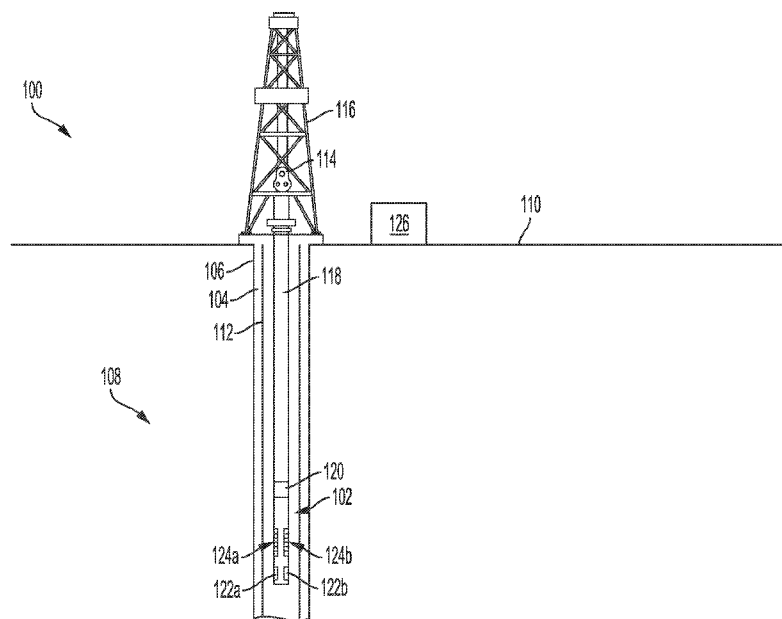


FIG. 1

(57) Abstract: An anomaly in a cement layer of a wellbore can be identified by applying dimensionality reduction to acoustic data of the wellbore. For example, a computing system can receive the acoustic data from a downhole tool deployed downhole in the wellbore using a tool string positioned within a casing string of the wellbore. The computing system can decrease a number of dimensions associated with the acoustic data to generate a dimension-reduced dataset including a predetermined dimensionality. Subsequently, the computing system can analyze the dimension-reduced dataset to determine a likelihood of the anomaly being present in the cement layer of the wellbore. The computing system can output, via a user interface, a cement map based on the dimension-reduced dataset. The cement map can indicate a presence of the anomaly in the cement layer of the wellbore for use in adjusting a wellbore operation.

DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

IDENTIFYING AN ANOMALY IN A CEMENT LAYER OF A WELLBORE USING DIMENSIONALITY REDUCTION

Technical Field

[0001] The present disclosure relates generally to wellbore operations and, more particularly (although not necessarily exclusively), to identifying an anomaly in a cement layer of a wellbore using dimensionality reduction.

Background

[0002] A well system can include a wellbore that can be formed in a subterranean formation to extract produced hydrocarbon or other suitable material. A wellbore operation can be performed to extract the produced carbon material or perform other suitable tasks relating to the wellbore. The wellbore can include an annulus that can be a space between a wall of the wellbore and a casing string that may be run through the wellbore. A cementing material can be used to seal the annulus to prevent undesirable flow paths that may allow fluids in one region of the wellbore to mix with other fluids in another region of the wellbore. The cementing material may be exposed to harsh downhole conditions that can degrade the cementing material over time.

Brief Description of the Drawings

[0003] FIG. 1 is a cross-sectional diagram of a wellsite including a cement monitoring system for identifying an anomaly in a cement layer of a wellbore using dimensionality reduction according to one example of the present disclosure.

[0004] FIG. 2 is a cross-sectional diagram of a wellbore including an anomaly in a cement layer of the wellbore according to one example of the present disclosure.

[0005] FIG. 3 is a block diagram of a computing device for identifying an anomaly in a cement layer of a wellbore using dimensionality reduction according to one example of the present disclosure.

[0006] FIG. 4 is an example of a plot of a proximity dataset including a set of azimuth pairs generated using acoustic data of a wellbore according to one example of the present disclosure.

[0007] FIG. 5 is an example of a plot of pair distance versus azimuth angle for the proximity dataset of FIG. 4 according to one example of the present disclosure.

[0008] FIG. 6 is an example of a user interface including a cement map generated using the proximity dataset of FIG. 4 according to one example of the present disclosure.

[0009] FIG. 7 is a flowchart of a process for identifying an anomaly in a cement layer of a wellbore using dimensionality reduction according to one example of the present disclosure.

Detailed Description

[0010] Certain aspects and examples of the present disclosure relate to identifying an anomaly in a cement layer of a wellbore using dimensionality reduction. The cement layer of the wellbore can be used to couple the casing string to the wellbore, providing structural integrity to the wellbore. Additionally, the cement layer can prevent intermixing of fluids in an annulus of the wellbore between the wellbore and the casing string, enabling zonal isolation. Over time, downhole conditions of the wellbore can degrade or damage the cement layer, which may result in poor zonal isolation. To identify degradation of the cement layer, a cement monitoring system can transmit acoustic signals into the wellbore to gather azimuthal data associated with the cement layer. To facilitate data visualization, the cement monitoring system can compress the azimuthal data by applying dimensionality reduction to decrease a number of dimensions associated with the azimuthal data while minimizing information loss. The cement monitoring system can analyze the compressed azimuthal data to determine whether the cement layer of the wellbore includes one or more anomalies that may correspond to degradation of the cement layer.

[0011] The wellbore can include multiple layers or strings (e.g., in a concentric or nested arrangement) between a center of the wellbore and the cement layer, such as a tool string deployed downhole in the wellbore through the casing string. In some cases, to evaluate the cement layer, a downhole tool positioned downhole using the tool string can transmit the acoustic signals through the layers or strings of the wellbore to reach the cement layer. Through tubing cement evaluation (TTCE) using the acoustic signals can be challenging due to multiple wave modes or interactions, such as reflections, dispersion, refraction through different materials, or wave superposition.

The multiple wave modes and interactions can hinder characterization of the azimuthal data corresponding to the acoustic signals. In some cases, acoustic signals of interest may be minimal compared to baseline variations, resulting in a low signal-to-noise ratio (SNR). Additionally, applying machine learning to data characterization of the azimuthal data can incur a relatively high computational cost while frequently resulting in overfitting of machine-learning models.

[0012] To facilitate data characterization, a number of features in the azimuthal data can be reduced using dimensionality reduction while preserving data of interest. In other words, applying dimensionality reduction to the azimuthal data can convert the azimuthal data from high-dimensional data to a lower-dimensional space while maintaining significant characteristics of the azimuthal data. In particular, dimensionality reduction can improve the data visualization of the azimuthal data such that the azimuthal data is more understandable or accessible for analysis when presented as two-dimensional data or three-dimensional data. In some cases, using dimensionality reduction to facilitate TTCE of the wellbore can avoid removing the tool string from the wellbore, thereby conserving operational time.

[0013] Additionally, in some instances, high-dimensional data can cause the machine-learning models to overfit such that the machine-learning models provide accurate predictions for training data but not for unseen data, resulting in subpar generalization performance. Lowering complexity of the azimuthal data through dimensionality reduction can assist in avoiding overfitting with respect to the machine-learning models. Additionally, simplifying the azimuthal data can reduce storage space or other computing resources (e.g., RAM, threads, power, etc.) used when analyzing the azimuthal data.

[0014] Methods to apply dimensionality reduction can include principal component analysis (PCA), singular value decomposition (SVD), or linear discriminant analysis (LDA). In particular, PCA is a statistical method that can lower a dimensionality of the azimuthal data by linearly transforming the azimuthal data into a different coordinate system. PCA can involve applying an orthogonal linear transformation to the azimuthal data. The orthogonal linear transformation can shift the azimuthal data into the different coordinate system such that the largest variance by a scalar projection of the azimuthal data is associated with a first coordinate. Similarly, the second largest variance can be associated with a second coordinate. In

some cases, variances of the azimuthal data can correspond to eigenvalues of the azimuthal data. By introducing the different coordinate system, variance in the dimension-reduced dataset can be express with fewer dimensions than the azimuthal data. Accordingly, PCA can be applied to relatively large datasets to improve data interpretation while retaining significant information.

[0015] To further analyze the dimension-reduced dataset, a proximity search can be applied to the dimension-reduced dataset. For instance, the proximity search may involve implementing a nearest neighbor search (NNS) to find the closest point in the dimension-reduced dataset for a given point. Closeness can be expressed in terms of a dissimilarity function such that a function value is relatively large if the given point and another point in the dimension-reduced dataset are relatively dissimilar. The NNS can be performed for a dataset X in a space S and a query point $x_i \in S$. An objective of the NNS can be to find the closest point in X to x_i . In some cases, S can be a metric space, and dissimilarity can be expressed as a distance metric. The distance metric (e.g., Euclidean distance or Manhattan distance) can be symmetric and can satisfy a triangle inequality.

[0016] Illustrative examples are given to introduce the reader to the general subject matter discussed herein and are not intended to limit the scope of the disclosed concepts. The following sections describe various additional features and examples with reference to the drawings in which like numerals indicate like elements, and directional descriptions are used to describe the illustrative aspects, but, like the illustrative aspects, should not be used to limit the present disclosure.

[0017] FIG. 1 is a cross-sectional diagram of a wellsite 100 including a downhole tool 102 for identifying an anomaly in a cement layer 104 of a wellbore 106 using dimensionality reduction according to one example of the present disclosure. As depicted in FIG. 1, the wellsite 100 includes the wellbore 106 drilled through a subterranean formation 108. The wellbore 106 extends from a well surface 110 into strata of the subterranean formation 108. The strata can include different materials (e.g., rock, soil, oil, water, gas, etc.) and can vary in thickness and shape. In some examples, the wellsite 100 may include more than one wellbore 106. Additionally, the wellbore 106 can be vertical as depicted, deviated, horizontal, or any combination thereof.

[0018] The wellbore 106 can be cased, open-hole, or a combination thereof. For example, a casing string 112 can extend from the well surface 110 through the subterranean formation 108. The casing string 112 can be piping implemented to protect or structurally strengthen the wellbore 106. Examples of material used to produce the casing string 112 can include carbon steel, stainless steel, aluminum, or other suitable material. The casing string 112 may provide a conduit through which wellbore fluid (e.g., production fluid, formation fluid, treatment fluid, etc.), can travel from the wellbore 106 to the well surface 110. In some examples, the casing string 112 can be coupled to walls of the wellbore 106 via annular material, such as cement. For example, the cement layer 104 can be positioned or formed between the casing string 112 and the walls of the wellbore 106 to couple the casing string 112 to the wellbore 106. Due to exposure to downhole conditions (e.g., temperature, pressure, etc.), the cement layer 104 may deteriorate over time, for example causing the casing string 112 to decouple from the wellbore 106.

[0019] The wellbore 106 additionally can include one or more well tools, such as the downhole tool 102. In the example shown in FIG. 1, the downhole tool 102 is positioned in the wellbore 106 by a winch 114 in a derrick 116 positioned above the well surface 110. In other examples, the downhole tool 102 may be positioned in the wellbore 106 in another manner. The downhole tool 102 can be coupled to a tool string 118 to position the downhole tool 102 in the wellbore 106. The downhole tool 102 can be transported into the wellbore 106 by manipulating the tool string 118 using, for example, a guide or the winch 114. In some examples, a wireline or slickline may be used in place of the tool string 118.

[0020] The downhole tool 102 can include at least one subsystem to measure properties of a downhole environment of the wellbore 106. The downhole tool 102 may measure the properties of the downhole environment during or in preparation of a wellbore operation (e.g., production, injection, plug and abandonment planning, etc.). Examples of the subsystem can include a logging-while-drilling (LWD) module, a measuring-while-drilling (MWD) module, a telemetry module 120, a rotary steerable system, a motor, a pump, or any combination thereof.

[0021] In some cases, the downhole tool 102 may include one or more acoustic transmitters 122a-b to transmit acoustic signals into the wellbore 106 to characterize or analyze the cement layer 104 of the wellbore 106. For example, the acoustic

transmitters 122a-b may be unipole acoustic transmitters that can transmit the acoustic signals in all azimuthal directions. The acoustic transmitters 122a-b may be part of the LWD module or the MWD module of the downhole tool 102. Examples of the acoustic signals can include ultrasonic signals or sonic signals. The acoustic transmitters 122a-b may continuously or intermittently transmit the acoustic signals into the wellbore 106 as the downhole tool 102 is transported through the wellbore 106. Due to the downhole tool 102 being positioned by the tool string 118 in the casing string 112, the acoustic signals may travel through multiple layers of the wellbore 106 before reaching the cement layer 104.

[0022] The downhole tool 102 additionally can include one or more acoustic receivers 124a-b to receive a subset of the acoustic signals as backscattered acoustic signals returning after contacting a physical obstruction. In some cases, the acoustic receivers 124a-b may be arranged in an array. Although two acoustic transmitters 122a-b and two acoustic receivers 124a-b are depicted in FIG. 1, it will be appreciated that less than or more than two acoustic transmitters and acoustic receivers may be provided in the downhole tool 102.

[0023] Examples of the physical obstruction can include the cement layer 104, the walls of the wellbore 106, or the subterranean formation 108. The backscattered acoustic signals can be altered from the original acoustic signals based on mechanical properties of the physical obstruction. For instance, a respective strength of the backscattered acoustic signals may differ based on a material of the physical obstruction contacted by the acoustic signals. In some cases, some or all of the backscattered acoustic signals received by the acoustic receivers 124a-b may be stored within the downhole tool 102 (e.g., the telemetry module 120) for later retrieval.

[0024] In some examples, a computing system 126 can receive the backscattered acoustic signals to determine the properties of the downhole environment, for example using dimensionality analysis and a proximity search. In particular, the computing system 126 can analyze the backscattered acoustic signals to identify whether one or more anomalies are present in the cement layer 104 of the wellbore 106. The computing system 126 can be located above the well surface 110 (e.g., at the wellsite 100 or remote from the wellsite 100) or below the well surface 110, such as within the wellbore 106. As an example, the telemetry module 120 of the downhole tool 102 can transfer the backscattered signals collected by the acoustic

receivers 124a-b to the computing system 126. The telemetry module 120 can include a mud pulse telemetry system, an acoustic telemetry system, a wired communications system, a wireless communications system, or any combination thereof. In some cases, the telemetry module 120 may convert the backscattered acoustic signals into electric signals that can be analyzed by the computing system 126.

[0025] The computing system 126 can evaluate an integrity of a cement bond associated with the cement layer 104 of the wellbore 106 using the backscattered acoustic signals. In particular, the computing system 126 can analyze the backscattered acoustic signals to determine a bond quality between the cement layer 104 and the casing string 112 or between the cement layer 104 and the wellbore 106. Deterioration of the cement bond can result in poor zonal isolation in an annulus of the wellbore 106 located between the walls of the wellbore 106 and the casing string 112. A decrease or lack of zonal isolation can result in fluid movement into or from neighboring zones in the annulus of the wellbore 106. As another example, the deterioration of the cement bond can cause gas to build up in the cement layer 104, potentially indicating a depletion of a gas drive mechanism. The depleted gas drive mechanism can enable the gas to percolate into the annulus, causing an increase in pressure that can endanger the wellbore 106.

[0026] If the computing system 126 detects the presence of an anomaly in the cement layer 104, the computing system 126 may determine an adjustment to the wellbore operation based on a location or type of the anomaly. For example, if the computing system 126 detects liquid in the cement layer 104 above a predefined threshold, the computing system 126 may determine a mitigation operation as an adjustment to the wellbore operation to repair the cement layer 104. In some cases, the mitigation operation may involve perforating the casing string 112 and using remedial techniques, such as squeeze cementing, to improve the cement bond of the cement layer 104.

[0027] FIG. 2 is a cross-sectional diagram of a wellbore 200 including an anomaly 202 in a cement layer 104 of the wellbore 106 according to one example of the present disclosure. FIG. 2 is described with reference to components of FIG. 1. In some implementations, the wellbore 200 can correspond to the wellbore 106 of FIG. 1. For example, as described above with respect to FIG. 1, the wellbore 200 can include the cement layer 104 coupled to a casing string 112 of the wellbore 106 that

can provide structural support during a wellbore operation associated with the wellbore 106.

[0028] Additionally, the wellbore 200 can include a downhole tool 102 deployed into the wellbore 106 via a tool string 118. The downhole tool 102 can obtain acoustic measurements of the wellbore 106, for example to monitor the cement layer 104 of the wellbore 106. Based on the acoustic measurements generated by the downhole tool 102, a computing system 126 can determine whether an anomaly 202 is present in the cement layer 104. A presence of gas or liquid (e.g., water or other well fluids) in the cement layer 104 can be indicative of the anomaly 202. As depicted in FIG. 2, the anomaly 202 can be a channel of water or other well fluids located in a region 204 of the cement layer 104 defined by a first azimuth 206a of 45° and a second azimuth 206b of 135°. The anomaly 202 can form in the cement layer 104 due to a deterioration of bonding between the cement layer 104 and the casing string 112. For example, the channel may fill with water or other well fluids from an interior 208 of the wellbore 106 positioned between the casing string 112 and the tool string 118 or between the tool string 118 and the downhole tool 102. Although the anomaly 202 is depicted in FIG. 2 as extending from the first azimuth 206a to the second azimuth 206b, it will be appreciated that the anomaly 202 may reside in part of the region 204 defined by the azimuths 206a-b.

[0029] The computing system 126 can analyze the acoustic measurements after applying a dimensionality reduction to the acoustic measurements to detect the presence of liquid in the cement layer 104 and determine a location of the anomaly 202. Accordingly, if the computing system 126 does not detect liquid in the cement layer 104, the computing system 126 can determine that zonal isolation in the wellbore 106 is sufficient to prevent fluid movement between adjacent zones in an annulus of the wellbore 106. The annulus can correspond to a section of the wellbore 106 between the casing string 112 and walls of the wellbore 106 that can be filled by cement (e.g., the cement layer 104) or other suitable annular material. In some cases, the computing system 126 can be communicatively coupled to the downhole tool 102 to receive the acoustic measurements from the downhole tool 102, for example in real time or in bursts.

[0030] In some examples, a data collection process performed by the downhole tool 102 to generate the acoustic measurements can involve transmitting a respective

acoustic pulse into the wellbore 106 for one or more azimuths 206 or angles of the wellbore 106. Although FIG. 2 depicts the azimuths 206 in increments of 45° counterclockwise around a circumference of the wellbore 106, it will be appreciated that other suitable azimuth increments (e.g., 5°, 10°, etc.) are possible. The downhole tool 102 can repeat the data collection process until a 360-degree revolution is completed. In some cases, the downhole tool 102 can use a 5° angle as a rotation step with respect to the data collection process.

[0031] For each received signal corresponding to the acoustic pulses, the downhole tool 102 can record a respective amplitude of each received signal. The respective amplitude can provide information regarding cement compressive strength, bond index (e.g., a degree of bonding between the wellbore 106 and the cement layer 104), cement-to-formation interface, or a combination thereof. For example, if there is minimal cement bonding between the casing string 112 and the cement layer 104 (e.g., free pipe), a received signal may have a relatively high amplitude and uniform frequency.

[0032] In some implementations, the tool string 118 in the wellbore 200 can be positioned off-center in the wellbore 200. As an example, as depicted in FIG. 2, the tool string 118 can be 25% off-centered or eccentric toward a 0° azimuth of the wellbore 106. Besides identifying the presence of the anomaly 202 in the cement layer 104, the computing system 126 can use the acoustic measurements to determine an eccentricity direction 210 to which the tool string 118 is off-center in the casing string 112 of the wellbore 106. Eccentricity of the tool string 118 can be expressed as a percentage ranging from 0% eccentric (e.g., the tool string 118 being centered in the wellbore 200) to 100% eccentric (e.g., the tool string 118 contacting the casing string 112). In some cases, the eccentricity direction 210 can correspond to an axis 212 or diameter of the wellbore 106, for example such that the tool string 118 is positioned off-center in the casing string 112 while aligned on the axis 212.

[0033] In some examples, the computing system 126 can use the eccentricity direction 210 to estimate or predict damage (e.g., wear) associated with the casing string 112, the downhole tool 102, the tool string 118, or a combination thereof. As an example, the computing system 126 can use the eccentricity direction 210 to reduce a likelihood of packoff occurring in the wellbore 200. The packoff can be caused by an accumulation of downhole debris (cutting debris, settled caving debris, etc.) that blocks

a circulating flow in the wellbore 200. In some cases, if the eccentricity of the tool string 118 is above a certain threshold, gravity can cause cuttings or other downhole debris to accumulate as settled solids (e.g., a cuttings bed) adjacent to the tool string 118 in the wellbore 200. As an example, if the tool string 118 is 80% eccentric toward an azimuth of 270° that is shown in FIG. 2, fluid flow between the tool string 118 and the casing string 112 at the 270° azimuth can have a relatively low velocity. As a result, the settled solids may accumulate around the tool string 118 such that the tool string 118 may become stuck (e.g., unable to rotate or vertically move) in the wellbore 200.

[0034] Circulating wellbore fluids through the tool string 118 or other suitable downhole piping can clean the wellbore 200 by removing the downhole debris from the wellbore 200. The computing system 126 can use the eccentricity direction 210 to determine or adjust parameters (e.g., circulation rate, pipe rotation, etc.) of a wellbore cleaning operation to prevent the downhole debris from accumulating in the wellbore 200 as the settled solids. As an example, based on the eccentricity direction 210, the computing system 126 can adjust a pipe rotational speed at which to rotate the tool string 118 to mechanically agitate the downhole debris, thereby facilitating removal of the downhole debris.

[0035] FIG. 3 is a block diagram of a computing device 300 for identifying an anomaly 202 in a cement layer 104 of a wellbore 106 using dimensionality reduction according to one example of the present disclosure. In some examples, the computing device 300 can be part of the computing system 126 of FIG. 1. The computing device 300 is described below with reference to components discussed in FIGS. 1-5. The computing device 300 can include a processor 302 and a memory 304. Additionally, the computing device 300 can include a user interface 306 to enable a user (e.g., an operator) to interact with the computing device 300. In some cases, the components shown in FIG. 3 can be integrated in a single structure. For example, the components can be positioned within a single housing with a single processing device. In other cases, the components shown in FIG. 3 can be distributed (e.g., in separate housings) and in electrical communication with each other using various processors.

[0036] The processor 302 can include one processing device or multiple processing devices. Non-limiting examples of the processor 302 include a Field-Programmable Gate Array (FPGA), an application-specific integrated circuit (ASIC), a microprocessing device, etc. The processor 302 can execute instructions stored in the

memory 304 to perform operations. In some examples, the instructions can include processing device-specific instructions generated by a compiler or an interpreter from code written in any suitable computer-programming language, such as C, C++, C#, etc.

[0037] The processor 302 can be communicatively coupled to the memory 304 via a bus. The memory 304 can include one memory or multiple memories and can include a memory device. The memory 304 can be non-volatile and may include any type of memory that retains stored information when powered off. Non-limiting examples of the memory 304 include electrically erasable and programmable read-only memory (EEPROM), flash memory, or any other type of non-volatile memory. At least some of the memory can include a non-transitory computer-readable medium from which the processor 302 can read instructions. The non-transitory computer-readable medium can include electronic, optical, magnetic, or other storage devices capable of providing the processor 302 with computer-readable instructions or other program code. Examples of the non-transitory computer-readable medium include magnetic disk(s), memory chip(s), ROM, random-access memory (RAM), an ASIC, a configured processing device, optical storage, or any other medium from which a computer processing device can read the instructions.

[0038] In some examples, the memory 304 can include instructions for causing the processor 302 of the computing device 300 to evaluate an integrity of a cement bond associated with the cement layer 104 of the wellbore 106 using acoustic data 308. The computing device 300 can receive the acoustic data 308 from a downhole tool 102 positioned in the wellbore 106. The acoustic data 308 can correspond to azimuthal data for a complete (e.g., 360-degree) rotation of the wellbore 106. In some cases, once the computing device 300 receives the acoustic data 308, the computing device 300 can store the acoustic data 308 in the memory 304, for example to monitor the cement layer 104 over time.

[0039] The computing device 300 can analyze the acoustic data 308 to determine whether the anomaly 202 is present in the cement layer 104. In some examples, to prepare the acoustic data 308 for analysis, the computing device 300 can implement pre-processing filtering, for example to remove or minimize noise in the acoustic data 308. Additionally or alternatively, the computing device 300 can decrease a number of dimensions 310 associated with the acoustic data 308 to

generate a dimension-reduced dataset 312 with a predetermined dimensionality 314. In some cases, the dimension-reduced dataset 312 can be referred to as a reduced dataset. The number of the dimensions 310 associated with acoustic data 308 provided by the downhole tool 102 may complicate the analysis of the acoustic data 308. Accordingly, the computing device 300 can reduce the number of the dimensions 310 to match the predetermined dimensionality 314, thereby simplifying the acoustic data 308 to facilitate computation and visualization of the acoustic data 308.

[0040] As an example, the computing device 300 can apply principal component analysis (PCA) to the acoustic data 308 to reduce the number of dimensions 310 associated with the acoustic data 308. The computing device 300 then can generate the dimension-reduced dataset 312 that has the predetermined dimensionality 314 while preserving a majority of information of the acoustic data 308. Using PCA to reduce the number of the dimensions 310 can involve determining a respective variance for each dimension of the dimensions 310 associated with the acoustic data 308. The respective variance can indicate an amount of variation in the acoustic data 308 that can be attributed to a corresponding dimension. In some cases, each variance 316 can be represented by a respective eigenvalue of each dimension of the dimensions 310 of the acoustic data 308.

[0041] Determining the predetermined dimensionality 314 can involve selecting a subset of the dimensions 310 based on a variance threshold 318 to preserve a suitable amount of information from the acoustic data 308. A collective variance 320 of the dimension-reduced dataset 312 can equal a summation of the variances 316a-b corresponding to the selected subset. Accordingly, the dimensions 310a-b of the selected subset can be selected to generate the collective variance 320 that meets the variance threshold 318.

[0042] In some cases, a scree plot can be used to determine the predetermined dimensionality 314 that corresponds to how many dimensions of the dimensions 310 to retain in the PCA. The scree plot can provide a line plot of each variance 316 (e.g., eigenvalue) of the dimensions in the acoustic data 308. As an example, the variance threshold 318 can be 80% such that 80% of information associated with the acoustic data 308 is kept in the dimension-reduced dataset 312 after PCA. Using a scree plot or another suitable calculation, the computing device 300 can determine that a first dimension 310a and a second dimension 310b can provide the collective variance 320

sufficient to meet the variance threshold 318. Accordingly, the computing device 300 can reduce the number of the dimensions 310 to generate the dimension-reduced dataset 312 with the predetermined dimensionality 314 of two dimensions.

[0043] After generating the dimension-reduced dataset 312, the computing device 300 can analyze the dimension-reduced dataset 312 to determine a likelihood of the anomaly 202 being present in the cement layer 104 of the wellbore 106. In some cases, the computing device 300 can analyze the dimension-reduced dataset 312 by applying a proximity search 322 to the dimension-reduced dataset 312 to generate a proximity dataset 324 including one or more azimuth pairs. For example, the computing device 300 may apply a nearest neighbor search (NNS) as the proximity search 322. In some cases, the computing device 300 may execute a machine-learning model trained to generate the proximity dataset 324 by applying the proximity search 322 to the dimension-reduced dataset 312. The proximity dataset 324 can be visualized based on the predetermined dimensionality 314 of the dimension-reduced dataset 312 that can be retained in the proximity dataset 324.

[0044] For example, referring to FIG. 4, a plot 400 visualizing the proximity dataset 324 can include a first axis 402a and a second axis 402b due to the predetermined dimensionality 314 being two. The first axis 402a can correspond to the first dimension 310a of the dimension-reduced dataset 312, while the second axis 402b can correspond to the second dimension 310b of the dimension-reduced dataset 312. In some instances, the dimensions 310a-b can be referred to as principal components. The collective variance 320 of the first dimension 310a and the second dimension 310b can meet the variance threshold 318 of the predetermined dimensionality 314.

[0045] As depicted in FIG. 4, the proximity dataset 324 can include one or more azimuth pairs 404 that can each include two azimuths paired together using the NNS to form the azimuth pairs 404. For example, a first azimuth pair 404a of the azimuth pairs 404 can include a first azimuth 406a and a second azimuth 406b. In particular, the first azimuth 406a can correspond to 105°, while the second azimuth 406b can correspond to 255°. Each azimuth pair of the azimuth pairs 404 can be symmetric about the same axis or diameter of the wellbore 106. For example, the azimuths 406a-b of the first azimuth pair 404a can be symmetric with respect to the axis 180 of FIG. 2, thereby indicating the eccentricity direction 210 of the tool string 118.

[0046] To form the first azimuth pair 404a, the computing device 300 can identify the first azimuth 406a and apply the NNS with respect to the first azimuth 406a to determine that the second azimuth 406b is closest in the proximity dataset 324 to the first azimuth 406a.

[0047] In some examples, proximity between the first azimuth 406a and the second azimuth 406b can be determined using a dissimilarity function. Accordingly, a closest point (e.g., the second azimuth 406b) with respect to the first azimuth 406a can be determined by minimizing the dissimilarity function. Dissimilarity between the first azimuth 406a and the second azimuth 406b can be caused by a difference in material, phase, or other suitable physical characteristics of physical obstructions in the wellbore 106. As an example, returning to FIG. 3, the computing device 300 can determine a set of dissimilarity values 326 including a respective dissimilarity value of each remaining azimuth in the dimension-reduced dataset 312 with respect to the first azimuth 406a of FIG. 4. A minimum dissimilarity value 328 of the set of dissimilarity values 326 can correspond to the second azimuth 406b of FIG. 4. Based on the minimum dissimilarity value 328, the second azimuth 406b can be paired with the first azimuth 406a to form the first azimuth pair 404a of FIG. 4.

[0048] In some cases, the dissimilarity within the proximity dataset 324 can be expressed using distance (e.g., Euclidean distance or Manhattan distance). As depicted in FIG. 4, a first pair distance 408a of the first azimuth pair 404a is greater than a second pair distance 408b of the second azimuth pair 404b. Accordingly, the pair distances 408a-b can indicate that the first azimuth 406a and the second azimuth 406b of the first azimuth pair 404a are more dissimilar compared to individual azimuths of the second azimuth pair 404b. In some examples, the pair distances 408a-b can indicate whether a material change is detected or present in a section of the cement layer 104 delineated by individual azimuths corresponding to the pair distances 408a-b.

[0049] Based on a respective pair distance corresponding to each azimuth pair of the azimuth pairs 404a-b, the computing device 300 can determine the region 204 of the cement layer 104 that can include the anomaly 202. As an example, referring to FIG. 5, a plot 500 including a first axis 502a corresponding to pair distance and a second axis 502b corresponding to azimuth angle can include a maximum point 504 associated with a location of the anomaly 202. In particular, the maximum point 504

can correspond to a maximum pair distance of the first axis 502a and an individual azimuth 506 of the second axis 502b. The individual azimuth 506 can indicate an azimuthal direction or location of the anomaly 202. For example, the individual azimuth 506 depicted in FIG. 5 is 90°. As depicted in FIG. 2, the 90° azimuth corresponds to a midpoint between the first azimuth 206a and the second azimuth 206b that define the region 204 of the cement layer 104 including the anomaly 202.

[0050] In some cases, the computing device 300 can use a distance threshold 330 to determine a subset of azimuths 508 that can be associated with the anomaly 202. In particular, the distance threshold 330 can indicate a minimum value with respect to the pair distances of the first axis 502a that is associated with a relatively high likelihood of the anomaly 202 being present in the cement layer 104. Accordingly, the subset of azimuths 508 can correspond to a subset of pair distances 510 greater than or equal to the distance threshold 330. For example, with a distance threshold 330 of about 0.0018, a minimum azimuth 512a and a maximum azimuth 512b of the subset of azimuths 508 can delineate the region 204 including the anomaly 202. As depicted in FIG. 5, the minimum azimuth 512a is the first azimuth 406a of the first azimuth pair 404a described above with respect to FIG. 4. The maximum azimuth 512b of the subset of azimuths 508 can be the second azimuth 406b of the first azimuth pair 404a. Accordingly, the first azimuth pair 404a can define the region 204 of the cement layer 104 that may include the anomaly 202. The computing device 300 can flag a particular region of the cement layer 104 defined by the first azimuth pair 404a to indicate a material change in the particular region. For example, the computing device 300 can flag the azimuths 406a-b of the first azimuth pair 404a, the particular region defined by the azimuths 406a-b, or a combination thereof to indicate an association with the anomaly 202.

[0051] Based on the proximity dataset 324, the computing device 300 can generate a cement map 332 to indicate a presence of the anomaly 202 in the cement layer 104 of the wellbore 106. In some examples, the computing device 300 may output the cement map 332 in response to detecting the anomaly 202 after analyzing the azimuth pairs 404. In other examples, the computing device 300 can detect the anomaly 202 based on the cement map 332.

[0052] Additionally, the cement map 332 can be used to adjust a wellbore operation 334 associated with the wellbore 106, for example to repair the cement layer

104 using plug cementing techniques. Referring to FIG. 6, a user interface 306 including a cement map 332 can be generated after applying dimensionality reduction to acoustic data 308 of a wellbore (e.g., the wellbore 106 of FIG. 1). The cement map 332 can include a first axis 602a corresponding to depth (e.g., true vertical depth (TVD)) of the wellbore. Additionally, the cement map 332 can include a second axis 602b associated with azimuthal directionality (e.g., with respect to azimuths 606) of the wellbore. In some cases, the azimuths 606 can range from 0° to 360°.

[0053] To indicate a presence of an anomaly (e.g., the anomaly 202 of FIG. 2) in the wellbore, the user interface 306 can include at least one visual indicator outputted on the cement map 332. The visual indicator can indicate a size or a location of the anomaly in a cement layer (e.g., the cement layer 104) of the wellbore. In some examples, the visual indicator can be provided as color indicators 604a-c that can provide an adjustment in a color property (e.g., hue, saturation, opacity, etc.) of the user interface 306. The color indicators 604a-c can provide a relative indication of a likelihood of the anomaly being present at a location of the wellbore with respect to the first axis 602a and the second axis 602b. Although the visual indicator is described herein with respect to the color indicators 604a-c, other suitable visual indications (e.g., adjustments of transparency, contrast, pattern, etc.) outputted via the user interface 306 are possible.

[0054] In some cases, the color indicators 604a-c can correspond to a respective pair distance of individual azimuth pairs in the proximity dataset 324 to provide the relative indication of the likelihood of the anomaly being present. For example, the pair distances of the individual azimuth pairs can be divided into one or more ranges such that a respective range of pair distances can be assigned to each color indicator 604. As an example, with three color indicators 604a-c provided in FIG. 6, the pair distances of the individual azimuth pairs can be separated into three ranges. Referring to FIG. 5, a first range of the three ranges can have a relative maximum value of 0.0010 with respect to pair distance, and a second range can include a subset of the pair distances that are equal to or greater than the distance threshold 330 of 0.0018. A third range can include another subset of the pair distances that are greater than 0.0010 and lower than the distance threshold 330 of 0.0018.

[0055] Returning to FIG. 6, of the three color indicators 604a-c, a first color indicator 604a can correspond to the first range such that a portion of the cement map

332 displaying the first color indicator 604a is relatively unlikely to include the anomaly. Additionally, the first color indicator 604a can have the lowest saturation of the three color indicators 604a-c to visually indicate the relatively low likelihood of the anomaly being present. A second color indicator 604b can exhibit the highest saturation of the three color indicators 604a-c to indicate a relatively high likelihood of the anomaly being present. Accordingly, the second color indicator 604b can correspond to the second range. The third color indicator 604c can correspond to the third range and can have a saturation value between the first color indicator 604a and the second color indicator 604b. Accordingly, the third color indicator 604c can indicate a relative likelihood of the anomaly being present that is between the relatively low likelihood of the first color indicator 604a and the relatively high likelihood of the second color indicator 604b.

[0056] A location of the anomaly can correspond to a positioning of the second color indicator 604b with respect to the first axis 602a and the second axis 602b. In some examples, a user or operator associated with the wellbore operation can locate the anomaly in the cement layer of the wellbore based on the second color indicator 606b. Additionally, the positioning of the second color indicator 606b can provide an indication with respect to a size of the anomaly in the cement layer of the wellbore. In additional or alternative examples, a computing device (e.g., the computing device 300 of FIG. 3) can detect the anomaly based on the visual indicator outputted with the cement map 332 via the user interface 306.

[0057] Returning to FIG. 3, once the anomaly is detected, the computing device 300 can determine an adjustment 336 to a wellbore operation 334 to address the anomaly 202. In some cases, the adjustment 336 determined by the computing device 300 can depend on parameters of the anomaly 202, such as the size of the anomaly 202. For example, if the anomaly 202 is relatively large, the computing device 300 may select a hesitation squeeze technique to apply remedial cementing as the adjustment 336 to the wellbore operation 334. In some instances, the computing device 300 may perform the adjustment 336 to the wellbore operation 334 at least in part based on input from the user or operator associated with the wellbore operation 334. Additionally or alternatively, the computing device 300 may automatically perform the adjustment 336 in response to detecting the anomaly 202, for example based on the cement map 332.

[0058] FIG. 7 is a flowchart of a process 700 for identifying an anomaly 202 in a cement layer 104 of a wellbore 106 using dimensionality reduction according to one example of the present disclosure. Other examples can involve more steps, fewer steps, different steps, or a different order of the steps depicted in FIG. 7. The steps of FIG. 7 are described below with reference to components discussed above in FIGS. 1-4. In some examples, the computing device 300 can perform one or more of the steps shown in FIG. 7.

[0059] In block 702, the computing device 300 receives acoustic data 308 from a downhole tool 102 deployed downhole in the wellbore 106 using a tool string 118 positioned within a casing string 112 of the wellbore 106. The acoustic data 308 can be associated with a cement layer 104 of the wellbore 106 that couples the casing string 112 to the wellbore 106. For example, the downhole tool 102 can be an acoustic logging tool including one or more acoustic transmitters 122a-b to transmit a set of acoustic signals into the wellbore 106. The acoustic data 308 can be generated by one or more acoustic receivers 124a-b of the downhole tool 102 after the acoustic receivers 124a-b receive at least part of the set of acoustic signals after backscattering. Once the acoustic data 308 is generated by the downhole tool 102, the acoustic data 308 can be transmitted by the downhole tool 102 to the computing device 300, for example via a telemetry module 120 of the downhole tool 102.

[0060] In block 704, the computing device 300 decreases a number of dimensions 310 associated with the acoustic data 308 to generate a dimension-reduced dataset 312 with a predetermined dimensionality 314. The computing device 300 can decrease the number of the dimensions 310 by applying dimensionality reduction to the acoustic data 308. In some examples, the computing device 300 may implement principal component analysis (PCA) to reduce the dimensions 310 of the acoustic data 308.

[0061] In block 706, subsequent to generating the dimension-reduced dataset 312, the computing device 300 analyzes the dimension-reduced dataset 312 to determine a likelihood of the anomaly 202 being present in the cement layer 104 of the wellbore 106. In some examples, the computing device 300 can apply a proximity search 322 to the dimension-reduced dataset 312 to generate a proximity dataset 324 including a set of azimuth pairs 404. As an example, the computing device 300 can implement a nearest neighbor search (NNS) as the proximity search to pair each

individual azimuth 406 of the dimension-reduced dataset 312 to form the set of azimuth pairs 404. A respective pair distance between each azimuth 406 in an individual azimuth pair of the set of azimuth pairs 404 can correspond to a likelihood of the anomaly 202 being present in the cement layer 104 of the wellbore 106.

[0062] In some cases, the computing device 300 can execute a machine-learning model to perform the step of block 706. For example, the machine-learning model can be trained to process or analyze the dimension-reduced dataset 312 using the proximity search 322 to generate the proximity dataset 324. Reducing the dimensions 310 of the acoustic data 308 to the predetermined dimensionality 314 can minimize overfitting of the machine-learning model to improve generalization performance of the machine-learning model. Additionally, dimensionality reduction can simplify the acoustic data 308, thereby speeding up computation performed by the machine-learning model. In some examples, the machine-learning model can be updated or further trained over time to improve its accuracy and abilities.

[0063] In block 708, the computing device 300 outputs, via a user interface 306, a cement map 332 based on the proximity dataset 324. The cement map 332 can be used to indicate a presence of the anomaly 202 in the cement layer 104 of the wellbore 106 for use in adjusting a wellbore operation 334. For example, the cement map 332 can include a visual indicator to indicate a location or a size of the anomaly in the cement layer 104. In some cases, as described above with respect to FIG. 6, the visual indicator can include one or more color indicators 604a-c that can correspond to a respective confidence level of the anomaly 202 being present in the cement layer 104.

[0064] In some aspects, a system, a method, and a non-transitory computer-readable medium for identifying an anomaly in a cement layer of a wellbore using dimensionality reduction are provided according to one or more of the following examples:

[0065] As used below, any reference to a series of examples is to be understood as a reference to each of those examples disjunctively (e.g., "Examples 1-4" is to be understood as "Examples 1, 2, 3, or 4").

[0066] Example 1 is a system comprising: a downhole tool deployable downhole in a wellbore using a tool string positionable within a casing string of the wellbore; a processing device; and a memory device that includes instructions

executable by the processing device for causing the processing device to perform operations comprising: receiving a plurality of acoustic data from the downhole tool, the plurality of acoustic data used to analyze a cement layer of the wellbore, the cement layer positioned to couple the casing string to the wellbore; decreasing a number of dimensions associated with the plurality of acoustic data to generate a dimension-reduced dataset comprising a predetermined dimensionality; subsequent to generating the dimension-reduced dataset, analyzing the dimension-reduced dataset to determine a likelihood of an anomaly being present in the cement layer of the wellbore; and outputting, via a user interface, a cement map based on the dimension-reduced dataset, the cement map indicating a presence of the anomaly in the cement layer of the wellbore for use in adjusting a wellbore operation.

[0067] Example 2 is the system of example(s) 1, wherein analyzing the dimension-reduced dataset further comprises: applying a proximity search to the dimension-reduced dataset to generate a proximity dataset comprising a plurality of azimuth pairs, a respective distance between each azimuth in an individual azimuth pair of the plurality of azimuth pairs corresponding to the likelihood of the anomaly being present in the cement layer of the wellbore.

[0068] Example 3 is the system of example(s) 1-2, wherein the operations further comprise, subsequent to applying the proximity search to the dimension-reduced dataset: determining the respective distance between each azimuth of the individual azimuth pair of the plurality of azimuth pairs; identifying that a pair distance between a first azimuth and a second azimuth of an azimuth pair is above a predefined threshold; and flagging a region of the cement layer defined by the first azimuth and the second azimuth to indicate a material change in the region of the cement layer, wherein the material change corresponds to at least part of the anomaly in the wellbore.

[0069] Example 4 is the system of example(s) 1-3, wherein applying the proximity search further comprises, for each azimuth pair of the plurality of azimuth pairs: identifying a first azimuth of the dimension-reduced dataset to create an azimuth pair; determining a set of dissimilarity values including a respective dissimilarity value of each remaining azimuth in the dimension-reduced dataset, wherein each dissimilarity value is determined with respect to the first azimuth; identifying a minimum dissimilarity value of the set of dissimilarity values, wherein the minimum dissimilarity

value corresponds to a second azimuth of the dimension-reduced dataset; and creating the azimuth pair by pairing the first azimuth and the second azimuth of the dimension-reduced dataset.

[0070] Example 5 is the system of example(s) 1-4, wherein the operations further comprise, subsequent to applying the proximity search to the plurality of acoustic data: determining that each azimuth pair of the plurality of azimuth pairs is symmetric with respect to an axis of the wellbore, wherein the axis corresponds to an eccentricity direction to which the tool string is off-center in the casing string of the wellbore.

[0071] Example 6 is the system of example(s) 1-5, wherein the operations further comprise, subsequent to outputting the cement map: outputting, via the user interface, a visual indicator on the cement map, wherein the visual indicator indicates a size of the anomaly and a location of the anomaly in the cement layer of the wellbore; detecting, based on the visual indicator of the cement map, the anomaly in the cement layer, wherein the anomaly corresponds to deterioration of the cement layer; in response to detecting the anomaly, determining, based on the anomaly in the cement layer, an adjustment to the wellbore operation associated with the wellbore; and subsequent to determining the adjustment, automatically controlling the wellbore operation to perform the adjustment to address the anomaly in the cement layer.

[0072] Example 7 is the system of example(s) 1-6, wherein the cement map comprises: a first axis associated with a depth of the wellbore; a second axis associated with azimuthal directionality of the wellbore; and a plurality of color indicators as the visual indicator, wherein the plurality of color indicators indicates the size of the anomaly and the location of the anomaly with respect to the first axis and the second axis of the cement map.

[0073] Example 8 is the system of example(s) 1-7, wherein the predetermined dimensionality of the dimension-reduced dataset is determined by: determining a respective variance corresponding to each dimension of the number of dimensions associated with the plurality of acoustic data, wherein each variance indicates an amount of variation in the plurality of acoustic data that is attributed to a corresponding dimension; and selecting, based on a variance threshold, a subset of the number of dimensions to determine the predetermined dimensionality of the dimension-reduced dataset, wherein a collective variance of the subset meets the variance threshold.

[0074] Example 9 is a method comprising: receiving a plurality of acoustic data from a downhole tool deployed downhole in a wellbore using a tool string positioned within a casing string of the wellbore, the plurality of acoustic data associated with a cement layer of the wellbore coupling the casing string to the wellbore; decreasing a number of dimensions associated with the plurality of acoustic data to generate a dimension-reduced dataset comprising a predetermined dimensionality; subsequent to generating the dimension-reduced dataset, analyzing the dimension-reduced dataset to determine a likelihood of an anomaly being present in the cement layer of the wellbore; and outputting, via a user interface, a cement map based on the dimension-reduced dataset, the cement map indicating a presence of the anomaly in the cement layer of the wellbore for use in adjusting a wellbore operation.

[0075] Example 10 is the method of example(s) 9, wherein analyzing the dimension-reduced dataset further comprises: applying a proximity search to the dimension-reduced dataset to generate a proximity dataset comprising a plurality of azimuth pairs, a respective distance between each azimuth in an individual azimuth pair of the plurality of azimuth pairs corresponding to the likelihood of the anomaly being present in the cement layer of the wellbore.

[0076] Example 11 is the method of example(s) 9-10, further comprising, subsequent to applying the proximity search to the dimension-reduced dataset: determining the respective distance between each azimuth of the individual azimuth pair of the plurality of azimuth pairs; identifying that a distance between a first azimuth and a second azimuth of an azimuth pair is above a predefined threshold; and flagging a region of the cement layer defined by the first azimuth and the second azimuth to indicate a material change in the region of the cement layer, wherein the material change corresponds to at least part of the anomaly in the wellbore.

[0077] Example 12 is the method of example(s) 9-11, wherein applying the proximity search further comprises, for each azimuth pair of the plurality of azimuth pairs: identifying a first azimuth of the dimension-reduced dataset to create an azimuth pair; determining a set of dissimilarity values including a respective dissimilarity value of each remaining azimuth in the dimension-reduced dataset, wherein each dissimilarity value is determined with respect to the first azimuth; identifying a minimum dissimilarity value of the set of dissimilarity values, wherein the minimum dissimilarity value corresponds to a second azimuth of the dimension-reduced dataset; and

creating the azimuth pair by pairing the first azimuth and the second azimuth of the dimension-reduced dataset.

[0078] Example 13 is the method of example(s) 9-12, further comprising, subsequent to applying the proximity search to the plurality of acoustic data: determining that each azimuth pair of the plurality of azimuth pairs is symmetric with respect to an axis of the wellbore, wherein the axis corresponds to an eccentricity direction to which the tool string is off-center in the casing string of the wellbore.

[0079] Example 14 is the method of example(s) 9-13, further comprising, subsequent to outputting the cement map: outputting, via the user interface, a visual indicator on the cement map, wherein the visual indicator indicates a size of the anomaly and a location of the anomaly in the cement layer of the wellbore; detecting, based on the visual indicator of the cement map, the anomaly in the cement layer, wherein the anomaly corresponds to deterioration of the cement layer; in response to detecting the anomaly, determining, based on the anomaly in the cement layer, an adjustment to the wellbore operation associated with the wellbore; and subsequent to determining the adjustment, automatically controlling the wellbore operation to perform the adjustment to address the anomaly in the cement layer.

[0080] Example 15 is the method of example(s) 9-14, wherein the predetermined dimensionality of the dimension-reduced dataset is determined by: determining a respective variance corresponding to each dimension of the number of dimensions associated with the plurality of acoustic data, wherein each variance indicates an amount of variation in the plurality of acoustic data that is attributed to a corresponding dimension; and selecting, based on a variance threshold, a subset of the number of dimensions to determine the predetermined dimensionality of the dimension-reduced dataset, wherein a collective variance of the subset meets the variance threshold.

[0081] Example 16 is a non-transitory computer-readable medium comprising instructions that are executable by a processing device for causing the processing device to perform operations comprising: receiving a plurality of acoustic data from a downhole tool deployed downhole in a wellbore using a tool string positioned within a casing string of the wellbore, the plurality of acoustic data associated with a cement layer of the wellbore coupling the casing string to the wellbore; decreasing a number of dimensions associated with the plurality of acoustic data to generate a dimension-

reduced dataset comprising a predetermined dimensionality; subsequent to generating the dimension-reduced dataset, analyzing the dimension-reduced dataset to determine a likelihood of an anomaly being present in the cement layer of the wellbore; and outputting, via a user interface, a cement map based on the dimension-reduced dataset, the cement map indicating a presence of the anomaly in the cement layer of the wellbore for use in adjusting a wellbore operation.

[0082] Example 17 is the non-transitory computer-readable medium of example(s) 16, wherein analyzing the dimension-reduced dataset further comprises: applying a proximity search to the dimension-reduced dataset to generate a proximity dataset comprising a plurality of azimuth pairs, a respective distance between each azimuth in an individual azimuth pair of the plurality of azimuth pairs corresponding to the likelihood of the anomaly being present in the cement layer of the wellbore.

[0083] Example 18 is the non-transitory computer-readable medium of example(s) 16-17, wherein the operations further comprise, subsequent to applying the proximity search to the dimension-reduced dataset: determining the respective distance between each azimuth of the individual azimuth pair of the plurality of azimuth pairs; identifying that a distance between a first azimuth and a second azimuth of an azimuth pair is above a predefined threshold; and flagging a region of the cement layer defined by the first azimuth and the second azimuth to indicate a material change in the region of the cement layer, wherein the material change corresponds to at least part of the anomaly in the wellbore.

[0084] Example 19 is the non-transitory computer-readable medium of example(s) 16-18, wherein the operations further comprise, subsequent to outputting the cement map: outputting, via the user interface, a visual indicator on the cement map, wherein the visual indicator indicates a size of the anomaly and a location of the anomaly in the cement layer of the wellbore; detecting, based on the visual indicator of the cement map, the anomaly in the cement layer, wherein the anomaly corresponds to deterioration of the cement layer; in response to detecting the anomaly, determining, based on the anomaly in the cement layer, an adjustment to the wellbore operation associated with the wellbore; and subsequent to determining the adjustment, automatically controlling the wellbore operation to perform the adjustment to address the anomaly in the cement layer.

[0085] Example 20 is the non-transitory computer-readable medium of example(s) 16-19, wherein the predetermined dimensionality of the dimension-reduced dataset is determined by: determining a respective variance corresponding to each dimension of the number of dimensions associated with the plurality of acoustic data, wherein each variance indicates an amount of variation in the plurality of acoustic data that is attributed to a corresponding dimension; and selecting, based on a variance threshold, a subset of the number of dimensions to determine the predetermined dimensionality of the dimension-reduced dataset, wherein a collective variance of the subset meets the variance threshold.

[0086] The foregoing description of certain examples, including illustrated examples, has been presented only for the purpose of illustration and description and is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Numerous modifications, adaptations, and uses thereof will be apparent to those skilled in the art without departing from the scope of the disclosure.

Claims

What is claimed is:

1. A system comprising:
 - a downhole tool deployable downhole in a wellbore using a tool string positionable within a casing string of the wellbore;
 - a processing device; and
 - a memory device that includes instructions executable by the processing device for causing the processing device to perform operations comprising:
 - receiving a plurality of acoustic data from the downhole tool, the plurality of acoustic data used to analyze a cement layer of the wellbore, the cement layer positioned to couple the casing string to the wellbore;
 - decreasing a number of dimensions associated with the plurality of acoustic data to generate a dimension-reduced dataset comprising a predetermined dimensionality;
 - subsequent to generating the dimension-reduced dataset, analyzing the dimension-reduced dataset to determine a likelihood of an anomaly being present in the cement layer of the wellbore; and
 - outputting, via a user interface, a cement map based on the dimension-reduced dataset, the cement map indicating a presence of the anomaly in the cement layer of the wellbore for use in adjusting a wellbore operation.
2. The system of claim 1, wherein analyzing the dimension-reduced dataset further comprises:
 - applying a proximity search to the dimension-reduced dataset to generate a proximity dataset comprising a plurality of azimuth pairs, a respective distance between each azimuth in an individual azimuth pair of the plurality of azimuth pairs corresponding to the likelihood of the anomaly being present in the cement layer of the wellbore.
3. The system of claim 2, wherein the operations further comprise, subsequent to applying the proximity search to the dimension-reduced dataset:

determining the respective distance between each azimuth of the individual azimuth pair of the plurality of azimuth pairs;

identifying that a pair distance between a first azimuth and a second azimuth of an azimuth pair is above a predefined threshold; and

flagging a region of the cement layer defined by the first azimuth and the second azimuth to indicate a material change in the region of the cement layer, wherein the material change corresponds to at least part of the anomaly in the wellbore.

4. The system of claim 2, wherein applying the proximity search further comprises, for each azimuth pair of the plurality of azimuth pairs:

identifying a first azimuth of the dimension-reduced dataset to create an azimuth pair;

determining a set of dissimilarity values including a respective dissimilarity value of each remaining azimuth in the dimension-reduced dataset, wherein each dissimilarity value is determined with respect to the first azimuth;

identifying a minimum dissimilarity value of the set of dissimilarity values, wherein the minimum dissimilarity value corresponds to a second azimuth of the dimension-reduced dataset; and

creating the azimuth pair by pairing the first azimuth and the second azimuth of the dimension-reduced dataset.

5. The system of claim 2, wherein the operations further comprise, subsequent to applying the proximity search to the plurality of acoustic data:

determining that each azimuth pair of the plurality of azimuth pairs is symmetric with respect to an axis of the wellbore, wherein the axis corresponds to an eccentricity direction to which the tool string is off-center in the casing string of the wellbore.

6. The system of claim 1, wherein the operations further comprise, subsequent to outputting the cement map:

outputting, via the user interface, a visual indicator on the cement map, wherein the visual indicator indicates a size of the anomaly and a location of the anomaly in the cement layer of the wellbore;

detecting, based on the visual indicator of the cement map, the anomaly in the cement layer, wherein the anomaly corresponds to deterioration of the cement layer;

in response to detecting the anomaly, determining, based on the anomaly in the cement layer, an adjustment to the wellbore operation associated with the wellbore; and

subsequent to determining the adjustment, automatically controlling the wellbore operation to perform the adjustment to address the anomaly in the cement layer.

7. The system of claim 6, wherein the cement map comprises:

a first axis associated with a depth of the wellbore;

a second axis associated with azimuthal directionality of the wellbore; and

a plurality of color indicators as the visual indicator, wherein the plurality of color indicators indicates the size of the anomaly and the location of the anomaly with respect to the first axis and the second axis of the cement map.

8. The system of claim 1, wherein the predetermined dimensionality of the dimension-reduced dataset is determined by:

determining a respective variance corresponding to each dimension of the number of dimensions associated with the plurality of acoustic data, wherein each variance indicates an amount of variation in the plurality of acoustic data that is attributed to a corresponding dimension; and

selecting, based on a variance threshold, a subset of the number of dimensions to determine the predetermined dimensionality of the dimension-reduced dataset, wherein a collective variance of the subset meets the variance threshold.

9. A method comprising:

receiving a plurality of acoustic data from a downhole tool deployed downhole in a wellbore using a tool string positioned within a casing string of the wellbore, the plurality of acoustic data associated with a cement layer of the wellbore coupling the casing string to the wellbore;

decreasing a number of dimensions associated with the plurality of acoustic data to generate a dimension-reduced dataset comprising a predetermined dimensionality;

subsequent to generating the dimension-reduced dataset, analyzing the dimension-reduced dataset to determine a likelihood of an anomaly being present in the cement layer of the wellbore; and

outputting, via a user interface, a cement map based on the dimension-reduced dataset, the cement map indicating a presence of the anomaly in the cement layer of the wellbore for use in adjusting a wellbore operation.

10. The method of claim 9, wherein analyzing the dimension-reduced dataset further comprises:

applying a proximity search to the dimension-reduced dataset to generate a proximity dataset comprising a plurality of azimuth pairs, a respective distance between each azimuth in an individual azimuth pair of the plurality of azimuth pairs corresponding to the likelihood of the anomaly being present in the cement layer of the wellbore.

11. The method of claim 10, further comprising, subsequent to applying the proximity search to the dimension-reduced dataset:

determining the respective distance between each azimuth of the individual azimuth pair of the plurality of azimuth pairs;

identifying that a distance between a first azimuth and a second azimuth of an azimuth pair is above a predefined threshold; and

flagging a region of the cement layer defined by the first azimuth and the second azimuth to indicate a material change in the region of the cement layer, wherein the material change corresponds to at least part of the anomaly in the wellbore.

12. The method of claim 10, wherein applying the proximity search further comprises, for each azimuth pair of the plurality of azimuth pairs:

identifying a first azimuth of the dimension-reduced dataset to create an azimuth pair;

determining a set of dissimilarity values including a respective dissimilarity value of each remaining azimuth in the dimension-reduced dataset, wherein each dissimilarity value is determined with respect to the first azimuth;

identifying a minimum dissimilarity value of the set of dissimilarity values, wherein the minimum dissimilarity value corresponds to a second azimuth of the dimension-reduced dataset; and

creating the azimuth pair by pairing the first azimuth and the second azimuth of the dimension-reduced dataset.

13. The method of claim 10, further comprising, subsequent to applying the proximity search to the plurality of acoustic data:

determining that each azimuth pair of the plurality of azimuth pairs is symmetric with respect to an axis of the wellbore, wherein the axis corresponds to an eccentricity direction to which the tool string is off-center in the casing string of the wellbore.

14. The method of claim 9, further comprising, subsequent to outputting the cement map:

outputting, via the user interface, a visual indicator on the cement map, wherein the visual indicator indicates a size of the anomaly and a location of the anomaly in the cement layer of the wellbore;

detecting, based on the visual indicator of the cement map, the anomaly in the cement layer, wherein the anomaly corresponds to deterioration of the cement layer;

in response to detecting the anomaly, determining, based on the anomaly in the cement layer, an adjustment to the wellbore operation associated with the wellbore; and

subsequent to determining the adjustment, automatically controlling the wellbore operation to perform the adjustment to address the anomaly in the cement layer.

15. The method of claim 9, wherein the predetermined dimensionality of the dimension-reduced dataset is determined by:

determining a respective variance corresponding to each dimension of the number of dimensions associated with the plurality of acoustic data, wherein each

variance indicates an amount of variation in the plurality of acoustic data that is attributed to a corresponding dimension; and

selecting, based on a variance threshold, a subset of the number of dimensions to determine the predetermined dimensionality of the dimension-reduced dataset, wherein a collective variance of the subset meets the variance threshold.

16. A non-transitory computer-readable medium comprising instructions that are executable by a processing device for causing the processing device to perform operations comprising:

receiving a plurality of acoustic data from a downhole tool deployed downhole in a wellbore using a tool string positioned within a casing string of the wellbore, the plurality of acoustic data associated with a cement layer of the wellbore coupling the casing string to the wellbore;

decreasing a number of dimensions associated with the plurality of acoustic data to generate a dimension-reduced dataset comprising a predetermined dimensionality;

subsequent to generating the dimension-reduced dataset, analyzing the dimension-reduced dataset to determine a likelihood of an anomaly being present in the cement layer of the wellbore; and

outputting, via a user interface, a cement map based on the dimension-reduced dataset, the cement map indicating a presence of the anomaly in the cement layer of the wellbore for use in adjusting a wellbore operation.

17. The non-transitory computer-readable medium of claim 16, wherein analyzing the dimension-reduced dataset further comprises:

applying a proximity search to the dimension-reduced dataset to generate a proximity dataset comprising a plurality of azimuth pairs, a respective distance between each azimuth in an individual azimuth pair of the plurality of azimuth pairs corresponding to the likelihood of the anomaly being present in the cement layer of the wellbore.

18. The non-transitory computer-readable medium of claim 17, wherein the operations further comprise, subsequent to applying the proximity search to the dimension-reduced dataset:

determining the respective distance between each azimuth of the individual azimuth pair of the plurality of azimuth pairs;

identifying that a distance between a first azimuth and a second azimuth of an azimuth pair is above a predefined threshold; and

flagging a region of the cement layer defined by the first azimuth and the second azimuth to indicate a material change in the region of the cement layer, wherein the material change corresponds to at least part of the anomaly in the wellbore.

19. The non-transitory computer-readable medium of claim 16, wherein the operations further comprise, subsequent to outputting the cement map:

outputting, via the user interface, a visual indicator on the cement map, wherein the visual indicator indicates a size of the anomaly and a location of the anomaly in the cement layer of the wellbore;

detecting, based on the visual indicator of the cement map, the anomaly in the cement layer, wherein the anomaly corresponds to deterioration of the cement layer;

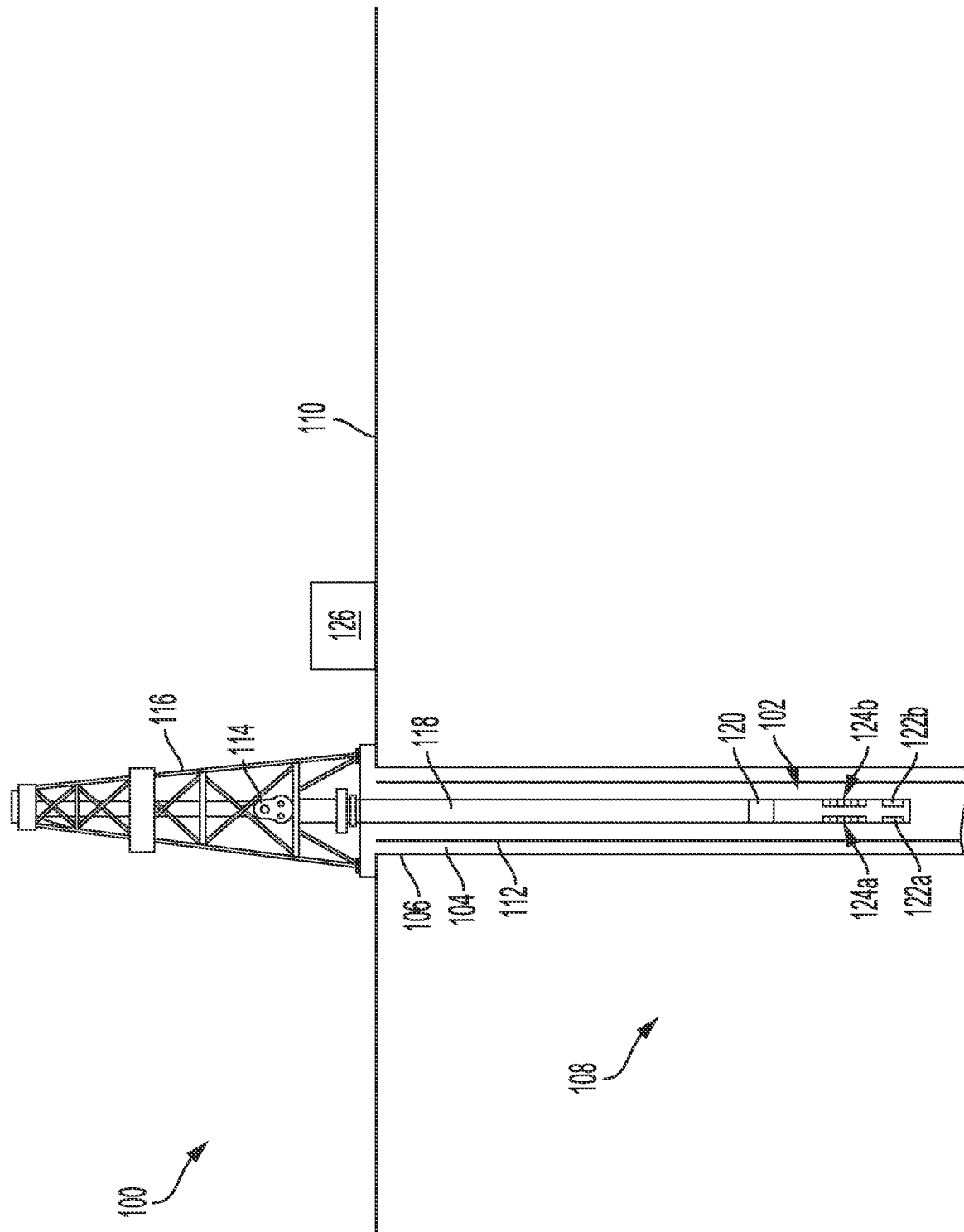
in response to detecting the anomaly, determining, based on the anomaly in the cement layer, an adjustment to the wellbore operation associated with the wellbore; and

subsequent to determining the adjustment, automatically controlling the wellbore operation to perform the adjustment to address the anomaly in the cement layer.

20. The non-transitory computer-readable medium of claim 16, wherein the predetermined dimensionality of the dimension-reduced dataset is determined by:

determining a respective variance corresponding to each dimension of the number of dimensions associated with the plurality of acoustic data, wherein each variance indicates an amount of variation in the plurality of acoustic data that is attributed to a corresponding dimension; and

selecting, based on a variance threshold, a subset of the number of dimensions to determine the predetermined dimensionality of the dimension-reduced dataset, wherein a collective variance of the subset meets the variance threshold.



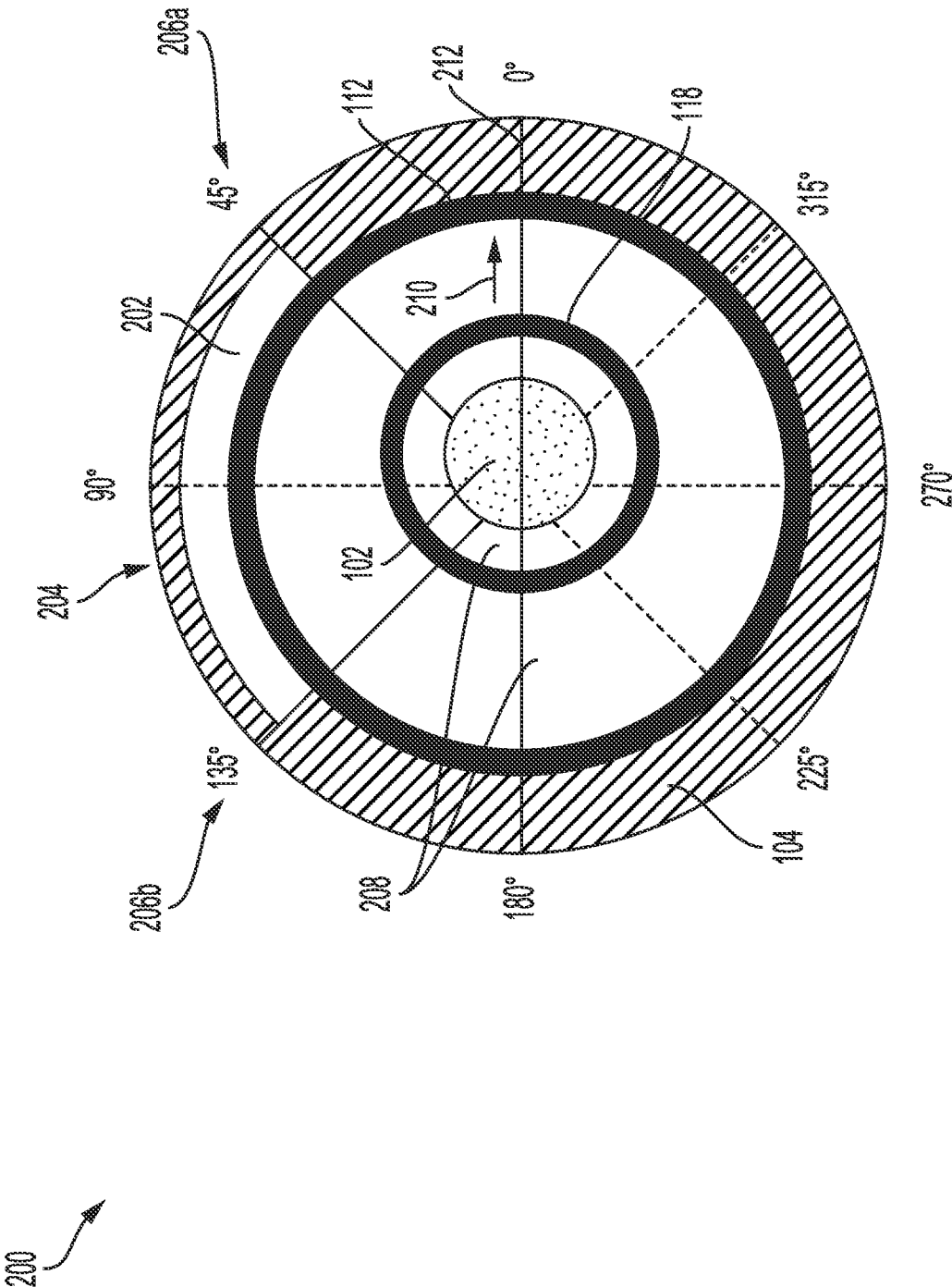


FIG. 2

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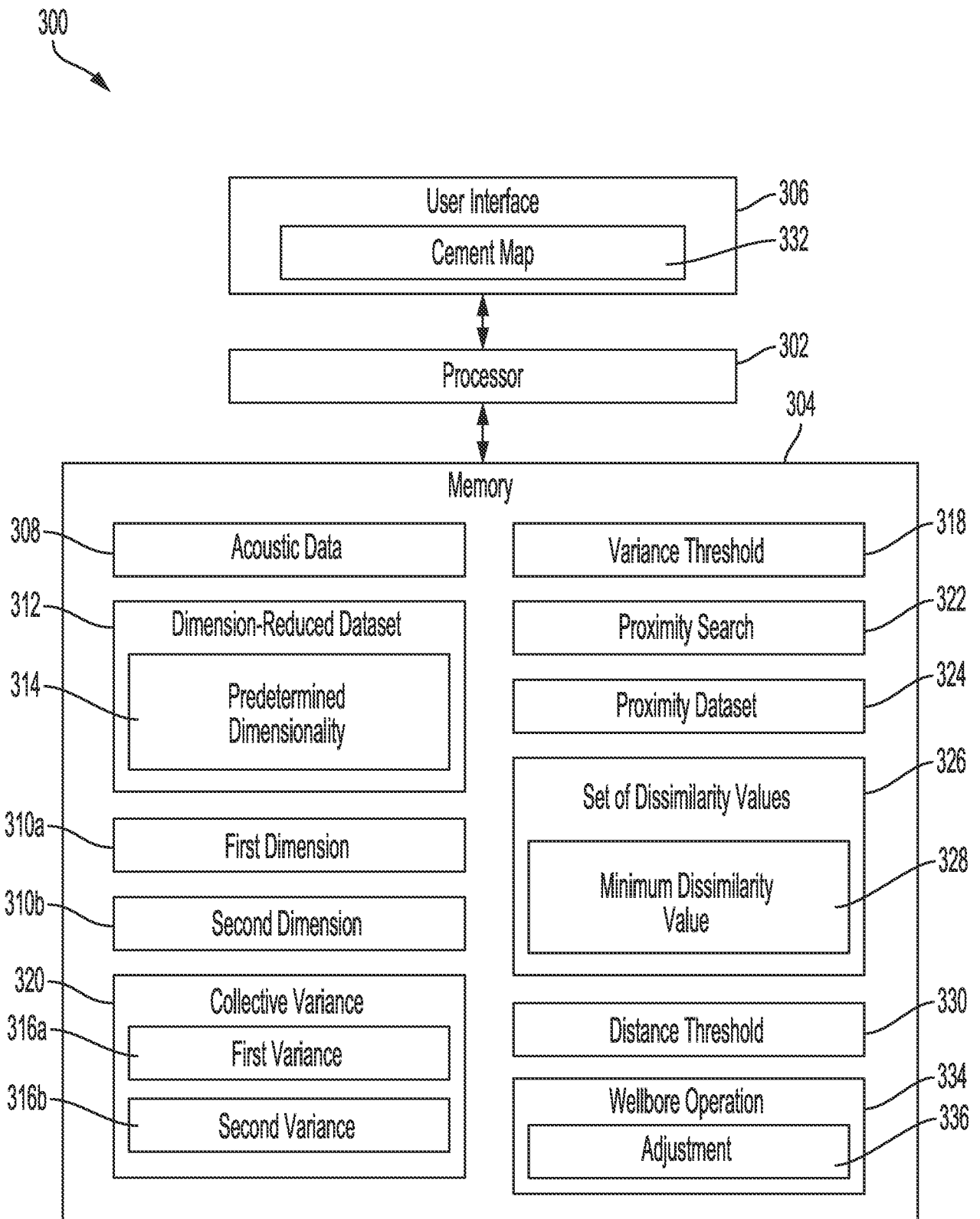


FIG. 3

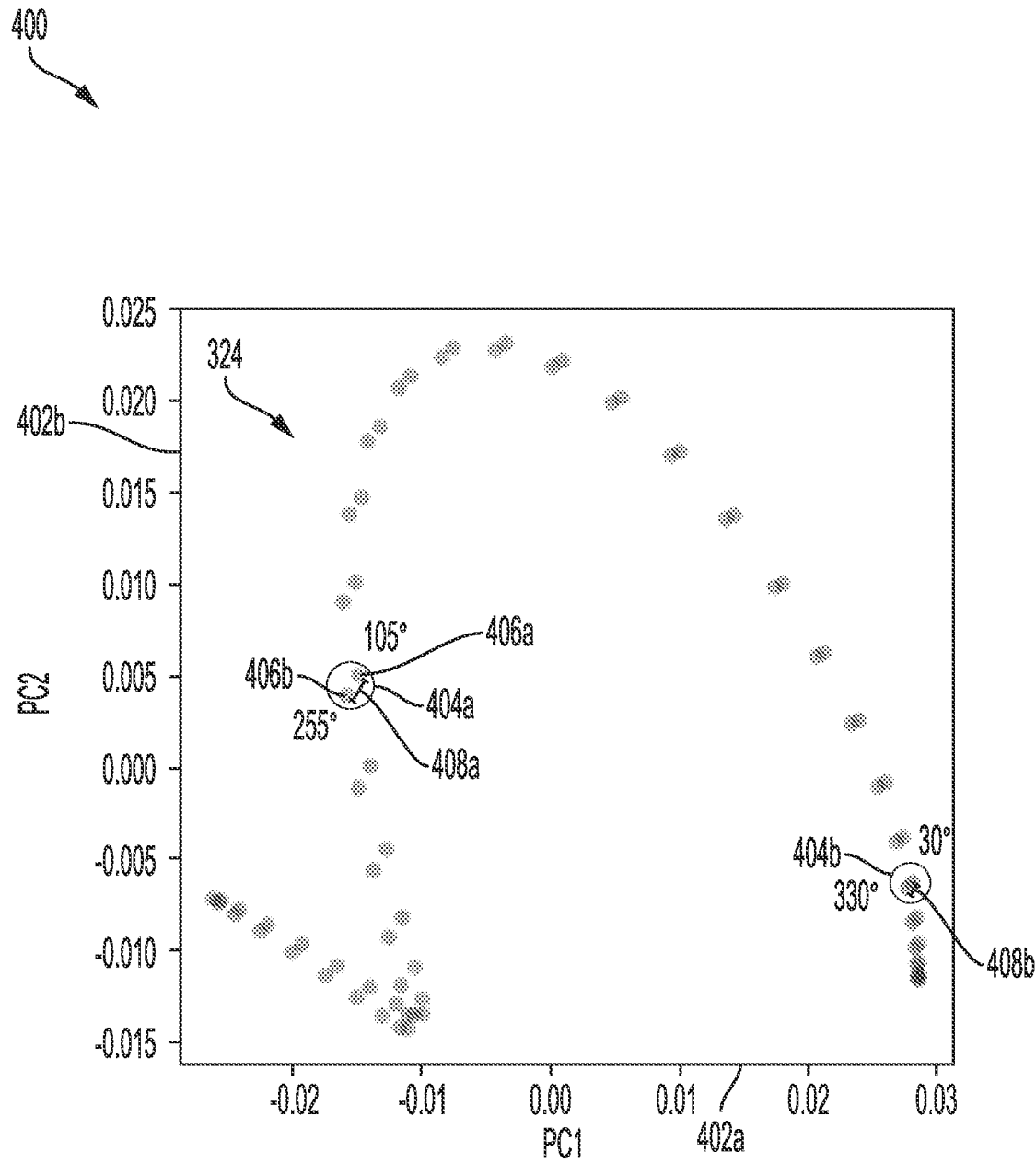


FIG. 4

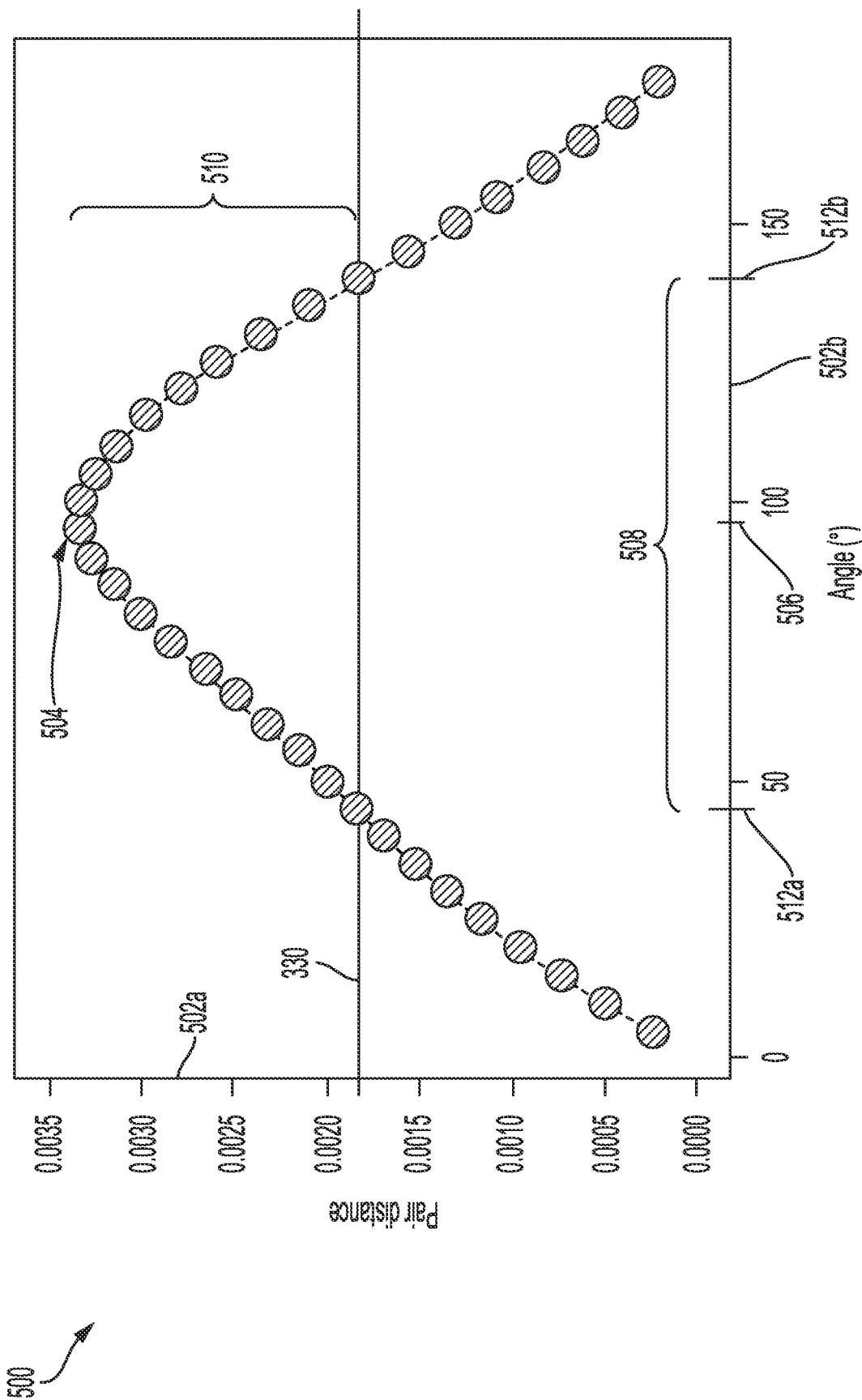


FIG. 5

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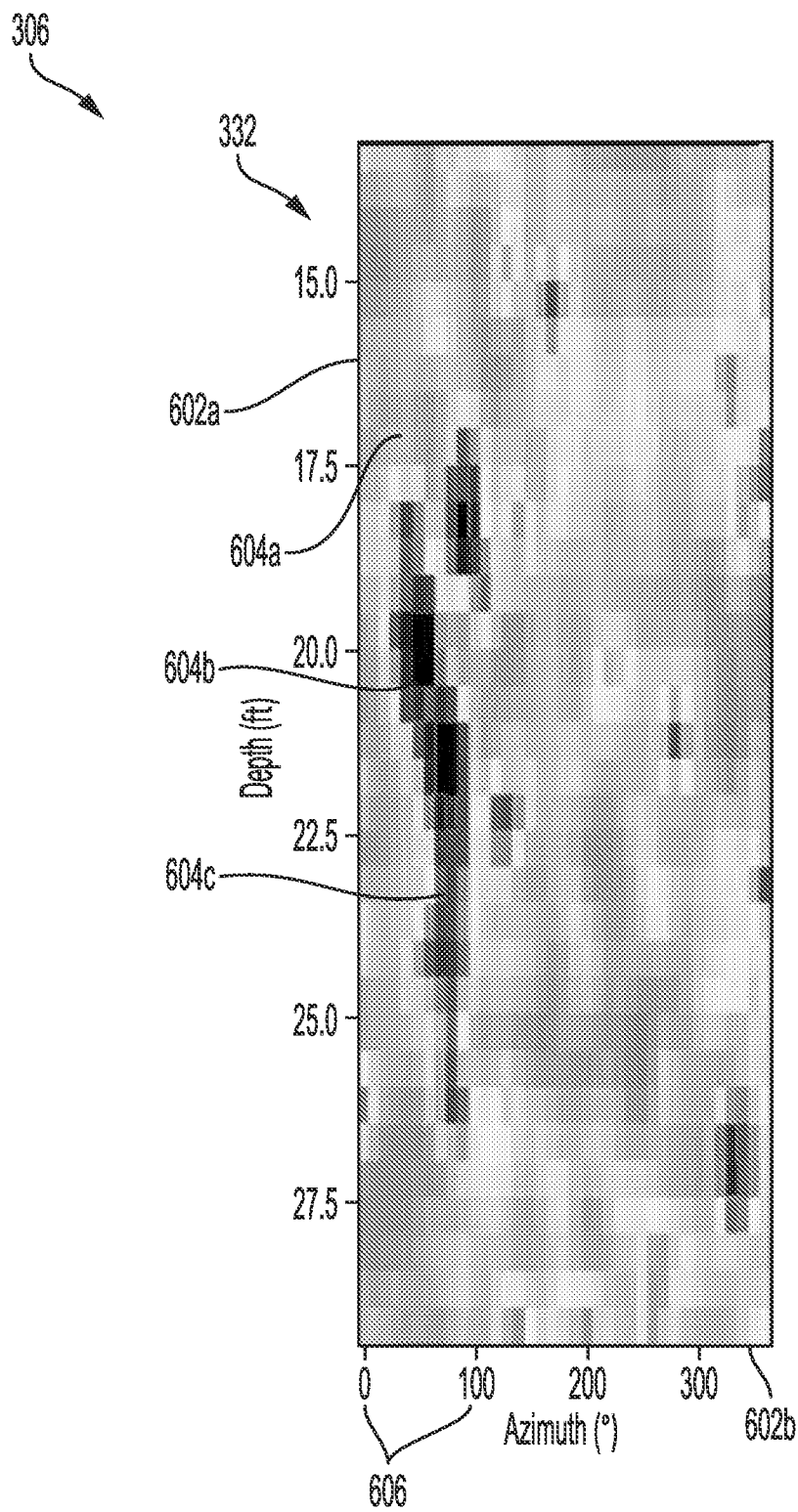


FIG. 6

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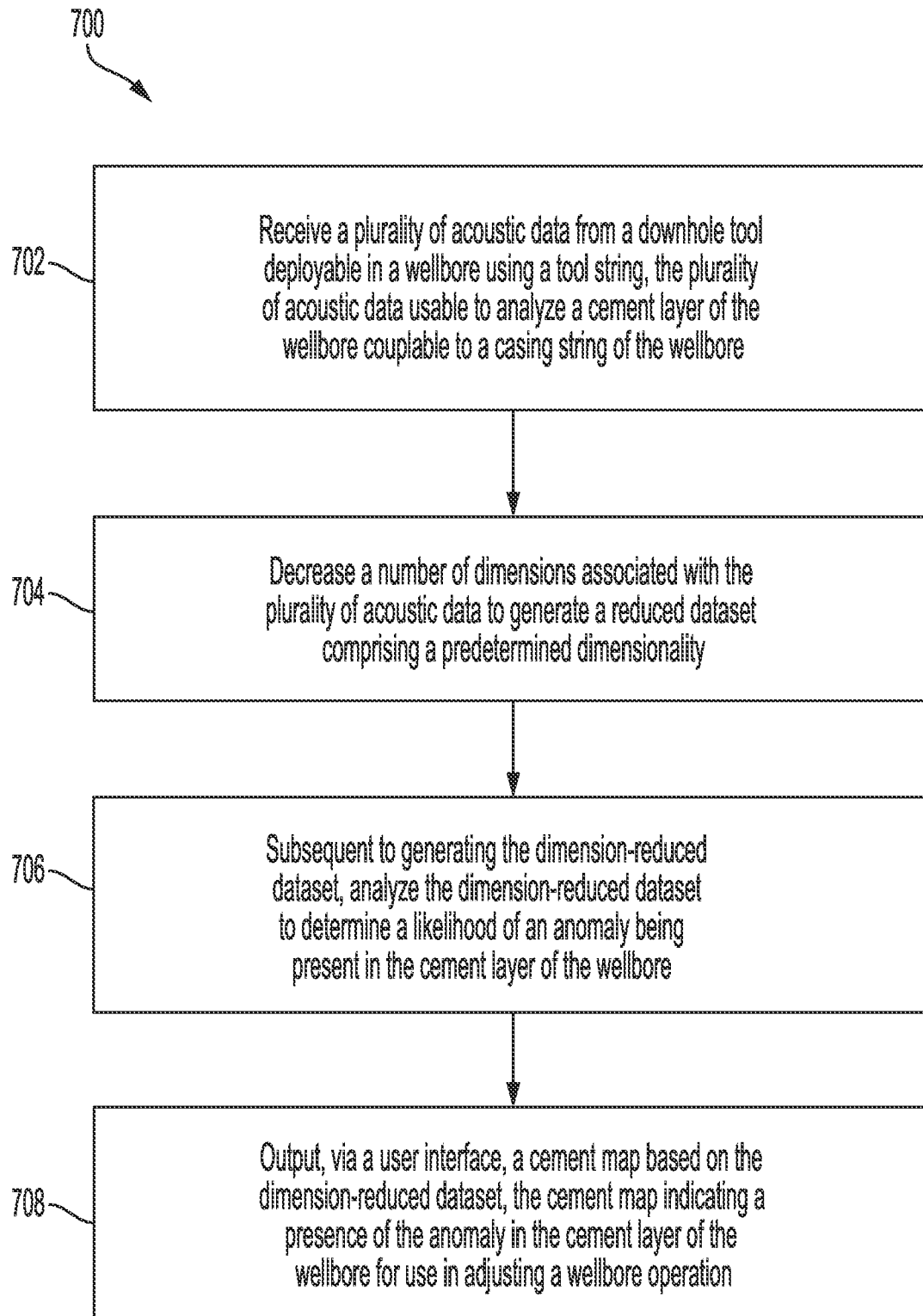


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/010133

A. CLASSIFICATION OF SUBJECT MATTER G01V 1/50(2006.01)i; E21B 47/005(2012.01)i 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) G01V 1/50(2006.01); E21B 47/107(2012.01); G01N 33/38(2006.01); G06N 3/08(2006.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models Japanese utility models and applications for utility models Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: wellbore, cement, dimension, anomaly, and map		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2021-0270127 A1 (SCHLUMBERGER TECHNOLOGY CORPORATION) 02 September 2021 (2021-09-02) paragraphs [0002], [0032]-[0060], [0079], [0103]-[0110] figures 1-4, 8, 17	1,6-9,14-16,19,20 2-5,10-13,17,18
Y	BRASIL DE SOUZA, LUIS PAULO at el., Machine learning-based cement integrity evaluation with a through-tubing logging experimental setup, Geoenergy Science and Engineering, 8 May 2023 (online publication date), Vol. 227, pages 1-16. pages 3-14 and figures 1-11	1,6-9,14-16,19,20
A	US 2022-0373706 A1 (HALLIBURTON ENERGY SERVICES, INC.) 24 November 2022 (2022-11-24) paragraphs [0024]-[0070] and figures 1A-12	1-20
A	HALDORSEN, JAKOB B. U. et al., Decomposing full-waveform borehole acoustic data with application to data from a North Sea well, GEOPHYSICS, 17 June 2016 (online publication date), Vol. 81, No. 4, pages IM71-IM95. pages IM71-IM95 and figures 1-46	1-20
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: “A” document defining the general state of the art which is not considered to be of particular relevance “D” document cited by the applicant in the international application “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 30 September 2024		Date of mailing of the international search report 02 October 2024
Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon 35208, Republic of Korea Facsimile No. +82-42-481-8578		Authorized officer PARK, Tae Wook Telephone No. +82-42-481-3405

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/010133

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RIBEIRO, MATEUS GHEORGHE DE CASTRO et al., Machine learning-based evaluation of eccentricity and acoustic impedance in oil well using VDL data, Geoenergy Science and Engineering, 1 September 2023 (online publication date), Vol. 231, pages 1-15. pages 1-14 and figures 1-13	1-20

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Information on patent family members

International application No.
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				NO	20201338	A1	07 December 2020
				WO	2019-236832	A1	12 December 2019

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				GB	2607120	A	30 November 2022
				GB	2607120	B	15 November 2023
				NO	20211139	A1	25 November 2022
				US	11662496	B2	30 May 2023
				WO	2022-250792	A1	01 December 2022
