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(54) **DOWNHOLE DRILLING SYSTEM**

(57) The present invention relates to a downhole drilling system (100), comprising: a drill string (1) having a drill head (6) configured to drill a borehole (2) having a borehole wall (3) forming an annulus (4) between the drill string and the borehole, a plurality of sensor units (10) forming a mesh network, wherein each one of said sensor units is distributed in a drilling fluid flowing in the annulus

and in the drill string, and at least one of said sensor units is provided with a detector (14) for measuring position data. The present invention also relates to a method for providing a downhole drilling system according to the present invention and to a method for determining drilling direction.

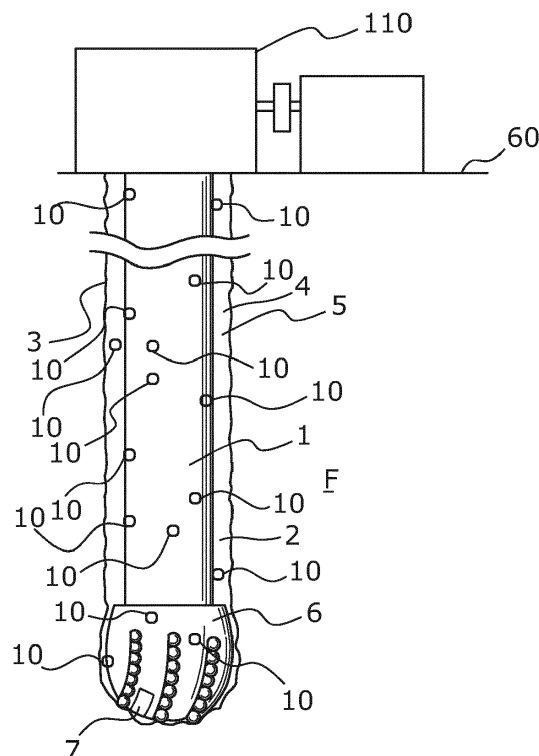


Fig. 2

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DescriptionField of the invention

5 **[0001]** The present invention relates to a downhole drilling system, to a method for providing a downhole drilling system according to the present invention and to a method for determining drilling direction.

Background art

10 **[0002]** Wells are formed by drilling a borehole in the ground for retrieving e.g. natural gas or petroleum. Depending on the formation to be drilled, various concerns need to be taken into account such as e.g. the drilling technique, the drill bit to be used, the actual structure of the formation etc.

15 **[0003]** During drilling, a drilling fluid, in particular a drilling liquid commonly denoted "drilling mud", is used to assist in the drilling process. The use of drilling mud provides a lower density fluid in the drilled borehole, whereby formation fluids are prevented from flowing into the borehole. Also, the drilling fluid is preferably selected in order to provide efficient cooling and cleaning of the drill bit.

20 **[0004]** The drilling fluid is normally conducted by the drill string carrying the drill bit, and apertures in the drill string will allow the drilling fluid to flow into the borehole for achieving the functionalities mentioned above. As cuttings are released downhole, these are carried upwards by the flow of the drilling fluid through the annular space between the drill string and the drilled borehole until they reach the surface. Hence, recirculation of the drilling fluid is possible.

25 **[0005]** The shape of the borehole is defined by a bottom hole assembly, forming the most distal part of the drill string. The bottom hole assembly may be equipped with one or more tools for performing measurement while drilling (MWD). These tools are configured to measure properties of the drilling process, such as the trajectory of the borehole.

30 **[0006]** The MWD tools provide data to the surface, preferably via mud pulse telemetry, whereby an operator can evaluate the drilling process. However, the bandwidth of mud pulse telemetry drops rapidly with increasing well depth, and transmitting mud pulses may, in such situations, require interruption of the drilling process.

35 **[0007]** In order to solve these problems it has been suggested to use electromagnetic telemetry. However, also this technique shows some limitations in terms of signal strength, especially for deep wells.

40 **[0008]** In view of the above, it would be advantageous to provide a solution allowing for measurements of the drilling process while ensuring sufficient signal strength and bandwidth, also for exceptionally deep wells.

Summary of the invention

45 **[0009]** It is an object of the present invention to wholly or partly overcome the above disadvantages and drawbacks of the prior art. More specifically, it is an object to provide an improved method and system for real time measurements of the drilling process.

50 **[0010]** Thus, it is also an object to provide an improved method and system for real time communication with the drill head for adjusting the drilling process, e.g. the drilling direction.

55 **[0011]** The above objects, together with numerous other objects, advantages and features, which will become evident from the below description, are accomplished by a solution in accordance with the present invention by a downhole drilling system, comprising:

- a drill string having a drill head configured to drill a borehole having a borehole wall forming an annulus between the drill string and the borehole,
- a plurality of sensor units forming a mesh network,

wherein each one of said sensor units is distributed in a drilling fluid flowing in the annulus and in the drill string, and at least one of said sensor units is provided with a detector for measuring position data.

[0012] All said sensor units may be provided with a detector for measuring position data.

60 **[0013]** The detector may comprise an accelerometer and/or a magnetometer, and position data may comprise inclination and/or azimuth.

[0014] The downhole drilling system according to the present invention may further comprise a sensor module comprising additional sensors.

[0015] Said sensor module may comprise a temperature sensor and/or a pressure sensor.

65 **[0016]** Moreover, each sensor unit may be configured to receive wirelessly transmitted data from an adjacent sensor unit, and to forward the received data to adjacent sensor units.

[0017] The downhole drilling system as described above may further comprise a surface system configured to receive downhole data from said sensor units.

[0018] Also, said surface system may further be configured to determine the position of at least one sensor unit in relation to the surface system, and to associate said determined relative position with associated position data.

[0019] Further, the surface system may be configured to determine the relative position of at least one sensor unit by Monte Carlo simulation and/or Shortest Path simulation.

[0020] The present invention also relates to a method for providing a downhole drilling system as described above, said method comprising:

- entering a plurality of sensor units in a drilling fluid, and
- entering said drilling fluid in a borehole annulus via a drill string during drilling, whereby each sensor unit is positioned in said annulus.

[0021] Each sensor unit may be flowing randomly in said annulus.

[0022] The present invention further relates to a method for determining drilling direction, comprising:

- providing a downhole sensor system by performing the method for providing a downhole sensor system as described above,
- activating at least one sensor unit for measuring position data of said sensor unit,
- transmitting data corresponding to said measured position data from the activated sensor unit to a surface system via at least one adjacent sensor unit, and
- analysing the received data in order to determine drilling direction.

[0023] Said method for determining drilling direction may further comprise determining the position of said activated sensor unit in relation to the surface system, and associating said determined relative position with the corresponding position data received by said surface system.

[0024] Moreover, activating at least one sensor unit may comprise measuring inclination and/or azimuth.

[0025] The method for determining drilling direction may further comprise comparing the determined drilling direction with an intended drilling direction, and optionally adjusting the current drilling direction based on the comparison.

Brief description of the drawings

[0026] The invention and its many advantages will be described in more detail below with reference to the accompanying schematic drawings, which for the purpose of illustration show some non-limiting embodiments and in which

Fig. 1 shows a drilling operation according to prior art,

Fig. 2 shows a drilling operation according to an embodiment,

Fig. 3 is a schematic view of a sensor system according to an embodiment,

Fig. 4 is a schematic view of a sensor unit for use with a sensor system according to an embodiment,

Fig. 5 is a diagram showing data communication between different sensor units of a sensor system according to an embodiment,

Fig. 6 is a schematic view of a method of providing a downhole sensor system according to an embodiment,

Fig. 7 is a schematic view of a method of determining drilling direction according to an embodiment,

Fig. 8 is a schematic view of a self-powering device of a sensor unit, and

Fig. 9 shows a cross-sectional view of a drilling system.

[0027] All the figures are highly schematic and not necessarily to scale, and they show only those parts which are necessary in order to elucidate the invention, other parts being omitted or merely suggested.

Detailed description of the invention

[0028] Fig. 1 schematically shows a drilling operation according to prior art solutions. A drill string DS is provided for

drilling a borehole in an underground formation F from a surface level S. The distal end of the drill string DS is equipped with a drill bit DB configured to mechanically cut through the formation. As the diameter of the drill bit DB is larger than the diameter of the drill string DS, an annulus A will be formed between the drill string DS and the walls W of the borehole. During drilling, a drilling mud DM is provided at the drilling area, i.e. at the current position of the drill bit DB. As drilling is performed, the drilling mud DM will flow upwards through the annulus A back to the surface level S. The drilling mud DM can then be re-circulated back to the drill string DS, optionally after intermediate cleaning or modification of the used drilling mud DM.

[0029] Now turning to Fig. 2, a drilling process according to an embodiment of the present invention is schematically shown. Although the general principle of drilling is identical to the process shown in Fig. 1, a significant difference is that a drilling fluid 5, e.g. drilling mud, is provided with a plurality of individual sensor units 10 which are conducted by the drilling fluid along the drilling string and out through the drill head and along the annular space to surface. Each sensor unit 10 is positioned arbitrarily in the flowable drilling fluid, e.g. drilling mud, and the distribution of sensor units 10 is thus random. As the drilling fluid flows in the annulus 4 around the drill bit and drill string 1, the sensor units 10 will follow the drilling fluid as it flows upwards and towards the surface level S. The position of the sensor units 10 will thus not be fixed, but instead randomly distributed in the annulus 4 both in the axial direction, i.e. the longitudinal extension of the borehole 2, in the radial direction, and in the circumferential direction. Preferably, the drilling fluid 5 is supplied through the drill string 1 and enters the annulus 4 via one or more outlet ports 7. These ports may be arranged at the drill bit 6 as illustrated in Fig. 2.

[0030] The sensor units 10 are entered in the drilling fluid in order to form "smart drilling mud", i.e. to provide information to the surface relating to the drilling direction over time, i.e. during the entire drilling process as long as drilling fluid 5 is present. As will be explained in the following, this is realised by configuring the sensor units 10 to establish a physically distributed independent and localised sensing network, preferably with peer-to-peer communication architecture. As will be understood from the following description, the mesh network being established by the sensor units 10 as a self-healing mesh network will automatically provide for a reliable and self-healing data path, even though at least some of the sensor units 10 are out of range from the final destination, i.e. the data collection provided at the surface level 60. In this way a very reliant communication network is established which is independent of the depth of the borehole, since the sensor units communicate with the adjacent sensor unit communicating again with the adjacent sensor unit all the way up and down the well while drilling.

[0031] All sensor units 10 are preferably identical, although provided with a unique ID. An example of a sensor system 100 is schematically shown in Fig. 3. The sensor system 100 comprises a surface system 110 and a sub-surface system 120. The sub-surface system 120 comprises a plurality of sensor units 10, although only one sensor unit 10 is shown in Fig. 3. Each sensor unit 10 is provided with a number of components configured to provide various functionality to the sensor unit 10. As is shown in Fig. 3, each sensor unit 10 includes a power supply 11, a digital processing unit 12, a transceiver 13, a detector 14, and optionally a sensor module comprising additional sensors 15. The sensor module may e.g. comprise a temperature sensor 15a and/or a pressure sensor 15b (shown in Fig. 4). The detector 14, together with the digital processing unit 12, form a detecting unit for determining position data of the sensor unit 10. In particular, the detector 14 comprises an accelerometer 14a and/or a magnetometer 14b (shown in Fig. 4).

[0032] For example, the accelerometer 14a is configured to measure the inclination, or tilt angle, of the sensor unit 10 according to well known principles, while the magnetometer 14b is configured to measure the azimuth, or projected angle, of the sensor unit 10. The measured inclination and/or the azimuth form/ forms position data. The digital processing unit 12 is configured to receive the position data and to perform various analysing algorithms in order to provide an output representing the current position of the sensor unit 10. Alternatively, the analysing algorithms are provided at the surface level, i.e. by means of the surface system 110.

[0033] As the sensor units 10 are in motion due to the flow of the drilling fluid 5, the digital processing unit 12 may be configured to apply a compensation algorithm to the position data such that the exact orientation of the sensor unit 10 does not affect the resulting position data value. Hence, such compensation algorithm could e.g. be programmed to calculate a delta position, i.e. a change in position from a previously determined position. The position data determined by means of the detector 14 may therefore represent the motion of the sensor units 10, rather than the exact position.

[0034] As is evident, different algorithms may be used in order to determine the trajectory of the borehole during drilling. For example, each sensor unit 10 may be programmed to measure position data continuously, or at given sample intervals. These intervals may be pre-set and dependent on the flow rate of the drilling fluid 5 in order to ensure sufficient resolution of the detected position data. As the sensor units 10 will flow into the borehole, and change its flowing direction when they exit the drill string, it may be possible to detect this change in direction and determine the associated position data (i.e. the inclination and azimuth) at this point in time. Accordingly, as this position data is measured at the longitudinal end of the borehole, the trajectory of the borehole can be determined.

[0035] The power supply 11 is configured to supply power to the other components 12-15 of the sensor unit 10, either by means of an internal power storage, such as one or more batteries, or by converting energy of the surrounding fluid to electrical energy and thus the power supply 11 may be in the form of a self-powering device. For the latter, the power

supply 11 may include a piezo element being configured to convert mechanical vibrations of the surrounding fluid, i.e. drilling fluid, to electrical energy. Optionally, a capacitor may be included in the power supply 11 for temporarily storing harvested energy. As the sensor units 10 are arranged in a moving fluid, it is also possible to provide the power supply with a generator converting mechanical motion to electrical power. Such generator may e.g. include a turbine or similar.

[0036] In Fig. 8, the self-powering device 11 is shown in further detail. The self-powering device 11 is configured to provide electrical power to the various electrical components of the sensor unit by harvesting energy from the downhole environment while flowing in the drilling fluid. The self-powering device 11 therefore comprises an energy harvesting module 1100. The harvesting module 1100 may be selected from the group comprising a vibrating member 1101, a piezoelectric member 1102, a magnetostrictive member 1103, and a thermoelectric generator 1104. As is shown in Fig. 8, any of these members is possible. In case of a vibrating member 1101, a piezoelectric member 1102, or a magnetostrictive member 1103, the energy harvesting module 1100 is configured to convert mechanical vibrations of the surrounding environment, such as in the downhole fluid or drilling fluid, to electrical energy. In the case of a thermoelectric generator 1104, such as a Peltier element, the harvesting module 1100 is configured to convert thermal energy of the surrounding energy to electrical energy.

[0037] The harvested energy is preferably supplied to a rectifier 1105. The rectifier 1105 is configured to provide a direct voltage and comprises a switching unit 1106 and a rectifier 1107. It should be noted that the position of the switching unit 1106 and the rectifier 1107 could be changed, such that the rectifier 1107 is directly connected to the harvesting module 1100. As is shown in Fig. 8, the rectifier 1107 is preferably connected to a capacitor 1108 for storing the harvested energy; the electrical components 12-15 of the sensor unit are therefore connected to the capacitor 1108 to form the required power source or storage buffer. Optionally, the self-powering device 11 is further provided with an amplifier (not shown), and/or control electronics (not shown) for the switching unit 1106. Additional capacitors may also be provided.

[0038] The digital processing unit 12 comprises a signal conditioning module 21, a data processing module 22, a data storage module 23, and a micro controller 24. The digital processing unit 12 is configured to control operation of the entire sensor unit 10, as well as temporarily storing sensed data in the memory 23 of the data storage module 23.

[0039] The transceiver 13 is configured to provide wireless communication with transceivers of adjacent sensor units 10. For this, the transceiver 13 comprises a radio communication module and an antenna. The radio communication module 13 may be configured to communicate according to well-established radio protocols, e.g. IEEE 801.1aq (Shortest Path Bridging), IEEE 802.15.4 (ZigBee) etc. The radio communication module may also be configured to position the sensor units in relation to each other, i.e. configured to perform a distance measurement. In this way a very reliable communication network is established which is independent of the depth of the borehole, since the sensor units communicate with the adjacent sensor unit communicating again with the adjacent sensor unit all the way up and down the well while drilling.

[0040] The surface system 110 also comprises a number of components for providing the desired functionality of the entire sensor system 100. As is shown in Fig. 3, the surface system 110 has a power supply 31 for providing power to the various components. As the surface system 110 may be permanently installed, the power supply 31 may be connected to mains power, or it may be formed by one or more batteries. The surface system 110 also comprises a transceiver 32 for receiving data communicated from the sensor units 10, and also for transmitting data and control signals to the sensor units 10. Hence, the transceiver 32 is provided with a radio communication module and an antenna for allowing for communication between the surface system 110 and the sensor units 10 of the sub-surface system 120. The surface system 110 also comprises a clock 33, a human-machine interface 34, and a digital processing unit 35. The digital processing unit 35 comprises the same functionality as the digital processing unit 12 of the sensor unit 10, i.e. a signal conditioning module, a data processing module, a data storage module, and a micro controlling module.

[0041] Before describing the operation of the drilling system 100, a sensor unit 10 is schematically shown in Fig. 4. The sensor unit 10 has a housing 19 which is configured to enclose the components previously described, as well as to form a protective casing which is capable of withstanding any impact with the drilling fluid and/or potential collisions with the borehole wall or the drill string. Although shown as rectangular, the shape of the housing 19 may of course be chosen differently. For example, it may be advantageous to provide the housing 19 with only rounded corners. The housing 19 may for such embodiment have a spherical shape. Inside the housing 19 the following is fixedly mounted: the power supply 11, the digital processing unit 12, the transceiver 13, the detector 14, and optionally the sensor module, e.g. additional sensors 15. These components are preferably the same as those described with reference to Fig. 3, i.e. the detector 14 preferably comprises an accelerometer 14a and/or a magnetometer 14b.

[0042] Now turning to Fig. 5, the configuration of the drilling system 100 will be described further, and in particular the downhole or sub-surface system 120. The sensor units 10A-F, representing parts of a sub-surface system 120, are randomly distributed in the annulus while flowing with the drilling fluid DM. The communication between the sensor units 10A-F is preferably based on a relay model, which means that the surface system communicates with the sensor units 10A-F via a sensor unit network. Preferably, each signal being transmitted from a sensor unit 10A-F comprises information relating to a unique ID of the sensor unit 10A-F. Further, data echoing and cross-talk are reduced by limiting the number of possible re-transmissions between the sensor units 10A-F. By reducing data echoing, the possibility of one sensor

unit sending the same data more than once to the same neighbouring sensor unit is eliminated. The network knows its neighbours by their unique IDs, and hereby the transmitter can target the transmission of data, and thus the situation in which data is sent back and forth can be avoided in that the neighbouring sensor unit "knows" from which sensor unit the data is received and will consequently not send that data back again.

[0043] Each sensor unit 10A-F is preferably configured to operate in two different modes. The first mode, relating to activation for the purpose of receiving data relating to the position, or trajectory of the borehole, preferably comprises a step of gathering data (optionally including data from the additional sensors 15, 15A, 15B shown in Fig. 4), and to transmit the data upon request. In the second mode, the sensor units 10A-F are configured to re-transmit received signals.

[0044] The axial location of each sensor unit 10A-F may also be determined by a round-trip elapsed time measured by the surface system 110. The surface system 110 may thus be configured to ping a specific sensor unit 10A-F using the unique ID, whereby the specific sensor unit 10A-F replies by transmitting a response signal with a unique tag. The surface system 110 receives the transmitted signal with elapsed times, and either Monte Carlo simulation and/or Shortest Path simulation may be used to determine the specific position of the sensor unit 10A-F.

[0045] Using Monte Carlo simulation, a simulated sensor unit location model may be created having a uniform probability distribution. For such method it may be possible to assume that the sensor units 10A-F are randomly distributed over a specific borehole length, and that these locations, for a given time, are known in the simulated model. The simulated model also includes a relay model with specific individual sensor processing delays.

[0046] For each distribution, the shortest round-trip travel time is calculated for each of the sensor units 10A-F. This results in a map of travel time versus location of sensor units 10A-F. It is then possible to compare the measured elapsed time with the map to determine the location of the sensor units 10A-F. The number of sensor units 10A-F may preferably be selected such that it is likely that at any given time, at least one sensor unit 10A-F will be positioned at the end of the borehole (i.e. at the position close to the drill bit 6). Once it has been determined which sensor unit 10A-F is arranged at this position (e.g. by selecting the sensor unit(s) 10A-F being most remote from the surface system 110), it is possible to fetch the position data measured by the determined sensor units 10A-F at this point in time, and to determine the inclination and the azimuth from these data in order to obtain the correct trajectory of the drilling operation.

[0047] For Shortest Path simulation, once the surface system 110 pings a sensor unit 10A-F, the round-trip times of multiple received signals, each one from a specific relay path, are recorded. The shortest time for the particular sensor unit 10A-F is then determined by calculating the distance from the surface system 110 using the speed of light.

[0048] In the example shown in Fig. 5, each sensor unit 10A-F forms a node in the mesh network 130. Each node is configured to receive and transmit data signals, as well as adding ID and timestamp with each data package. Each node will send a signal corresponding to its current state (i.e. the detected signals representing cement characteristics) asynchronously with respect to other nodes. In the table below, data communication in the mesh network 130 is explained further. In the table, nX represents the node ID, TnX represents the timestamp for the particular node, and sX represents the sensed data from the particular node.

Node	Forwarded signal	Received signal
10A	nA:TnA:sA	
10B	nB:TnB:nA:TnA:sA	nA:TnA:sA
10C	nC:TnC:nA:TnA:sA	nA:TnA:sA
10D		nB:TnB:nA:TnA:sA
		nC:TnC:nA:TnA:sA
	nD:TnD: nB:TnB: nA:TnA:sA	
	nD:TnD: nC:TnC: nA:TnA:sA	
10E		nB:TnB:nA:TnA:sA
		nC:TnC:nA:TnA:sA
	nE:TnE:nB:TnB:nA:TnA:sA	
	nE:TnE:nC:TnC:nA:TnA:sA	
		nD:TnD: nB:TnB: nA:TnA:sA
		nD:TnD:nC:TnC:nA:TnA:sA
		nE:TnE:nB:TnB:nA:TnA:sA

(continued)

Node	Forwarded signal	Received signal
		nE:TnE:nC:TnC:nA:TnA:sA

[0049] Accordingly, data is communicated through the mesh network 130 until the signals are received by the surface system 110.

[0050] Now, with reference to Fig. 6, a method 200 for providing the downhole sensor system 100 will be described. The method 200 is performed by a first step 202 of providing a plurality of sensor units 10, and by entering these sensor units 10 in a drilling fluid. In a subsequent step 204, the drilling fluid having sensor units 10 therein is conducted by the drill string, having a drill bit/head 6 arranged downhole in a borehole. In a following step 206, the drilling operation is started, whereby the drill bit/head will be activated to drill downhole. During this step, the drilling fluid will flow downhole through the drill string, and exit close to the position of the drill bit, thereby flowing out in the annulus formed between the borehole wall and the drill string. The sensor units 10 will thereby be distributed, in step 208, randomly in the annulus as they flow upwards with the drilling fluid.

[0051] As explained above, the sensor units 10 are activated to monitor and determine position data corresponding to the trajectory of the borehole and thus also the position of the drill head. A method 300 performed for the purpose of such monitoring is schematically shown in Fig. 7. As the method 300 requires the provision of a downhole drilling system, initially the method 200 described above is performed.

[0052] Additionally, in step 302 a surface system 110 is provided. The surface system 110, described above with respect to Fig. 3, is configured to communicate with the sub-surface system 120, i.e. the drilling system provided by performing the method 200, and comprises the downhole sensor units 10 flowing with the drilling fluid.

[0053] In step 304, the surface system 110 is linked to the sub-surface system 120. Linking is preferably performed during configuration and programming of the respective sensor units 10 as well as the surface system 110, and step 304 may thus correspond to a confirmation step. As described above, step 304 may be performed by sending a verification signal from the surface system 110, and requesting replies from each sensor unit 10. Once the replies are received, the sensor system 100 is verified and ready for operation. Each reply signal is routed via the sensor units 10 in accordance with the description relating to Fig. 5. The sensor units 10 thus form a mesh network.

[0054] During operation of the drilling system 100, at least one of said sensor units 10 is activated in step 306. Activation may either occur as a response to a control signal transmitted from the surface system 110, or the sensor units 10 may be programmed to be activated at pre-determined time intervals. For example, each sensor unit 10 may be programmed to "wake up" at specific times, such as every 10 seconds, every one minute etc. Determining the time intervals between subsequent activations may preferably be done prior to arranging the sensor units 10 downhole, or by transmitting a control signal from the surface system 110. When a sensor unit 10 is activated, in step 308 it measures the current position, e.g. the inclination and the azimuth, by means of the detector. The detected data is preferably processed by the sensor unit 10, e.g. by executing one or more of the above mentioned position data algorithms, and the resulting data, corresponding to position data, is transmitted by means of the wireless transceiver. As is evident, during activation further parameters may be measured as well such as temperature and/or pressure, and data corresponding to such measurements may be included in the transmitted signal in step 308.

[0055] As the data signal is transmitted, the method 300 includes a step 310 of routing the data signal such that it eventually reaches the surface system 110. If the sensor units 10 are distributed the entire way up to the location of the surface system 110, routing may be achieved entirely by the sensor units 10. However, in some cases the drill string may be arranged in a sealed-off part of the borehole, such that the drilling fluid is only present in this sealed-off part. In such case, a data collecting tool may be provided downhole, either temporarily or permanently, which receives the routed data signals and forwards the received data signals to the surface system 110, either by wire or wirelessly.

[0056] Each sensor unit 10 is therefore programmed to, upon activation, also listen for transmitted signals and, upon receiving an already transmitted signal, re-send the signal. Any transmitted data signal will automatically be routed through the mesh network until it is received by the surface system 110. Efficient routing may e.g. be achieved by utilising a protocol as described in the above table, whereby any data signal transmitted will not only contain the measured data, but also timestamps and information about which sensor units 10 are being used for routing. Each sensor unit 10 is thereby configured to relay data for the mesh network. In order to ensure the integrity of the data path, the network formed by the sensor units 10 is configured to apply a self-healing algorithm, e.g. Shortest Path Bridging. Should one or more sensor units 10 for some reason be damaged or by other means become non-functional, the network is configured to automatically self-heal by re-routing the data to existing and functional data paths.

[0057] In step 312, the data signals are received by the surface system 110, and data processing may be performed in order to convert the information of the data signal to readable values corresponding to the trajectory of the borehole.

[0058] Hence, in step 314 the data is analysed, which also may include a comparison with an intended drilling operation.

The intended drilling operation normally includes an intended trajectory of the borehole, and by analysing the measured data, indicating the actual trajectory, it is possible to provide real-time feedback and to make appropriate adjustments in the control of the drilling operation, i.e. the drive of the drill string and the associated drill bit. Such adjustment of the drilling operation may be performed in step 316.

[0059] Fig. 8 discloses the downhole drilling system in a partly cross-sectional view. As can be seen, the sensor units are conducted by the drill string and flow with the drilling fluid 5 down to the drill head 6 and out through the ports 7 into the annular space between the drill string 1 and the borehole wall and upwards to surface. The sensor units are thus distributed all along the borehole providing a mesh network to provide real time measurements of the trajectory of the borehole and thus measurements of the direction in which the drill head drills at present. Thus, the sensor units 10 provide real time monitoring and communication from surface to the drill head to adjust the drilling direction in a much faster way than in the known methods and without the drilling process having to be stopped in order to communicate or send measured data.

[0060] By drilling fluid or well fluid is meant any kind of fluid that may be present in oil or gas wells downhole, such as natural gas, oil, oil mud, crude oil, water, etc. By gas is meant any kind of gas composition present in a well, completion, or open hole, and by oil is meant any kind of oil composition, such as crude oil, an oil-containing fluid, etc. Gas, oil, and water fluids may thus all comprise other elements or substances than gas, oil, and/or water, respectively.

[0061] In the event that the tool is not submergible all the way into the casing, a downhole tractor can be used to push the tool all the way into position in the well. The downhole tractor may have projectable arms having wheels, wherein the wheels contact the inner surface of the casing for propelling the tractor and the tool forward in the casing. A downhole tractor is any kind of driving tool capable of pushing or pulling tools in a well downhole, such as a Well Tractor®.

[0062] Although the invention has been described in the above in connection with preferred embodiments of the invention, it will be evident for a person skilled in the art that several modifications are conceivable without departing from the invention as defined by the following claims.

Claims

1. A downhole drilling system (100), comprising:

- a drill string (1) having a drill head (6) configured to drill a borehole (2) having a borehole wall (3) forming an annulus (4) between the drill string and the borehole,
- a plurality of sensor units (10) forming a mesh network (130),

wherein each one of said sensor units (10) is distributed in a drilling fluid (5) flowing in the annulus (4) and in the drill string (1), and at least one of said sensor units (10) is provided with a detector (14) for measuring position data.

2. The downhole drilling system according to claim 1, wherein all said sensor units (10) are provided with a detector (14) for measuring position data.

3. The downhole drilling system according to claim 1 or 2, wherein the detector (14) comprises an accelerometer (14a) and/or a magnetometer (14b), and position data comprises inclination and/or azimuth.

4. The downhole drilling system according to any of the preceding claims, further comprising a sensor module comprising additional sensors (15).

5. The downhole drilling system according to claim 4, wherein said sensor module (15) comprises a temperature sensor (15a) and/or a pressure sensor (15b).

6. The downhole drilling system according to any of the preceding claims, wherein each sensor unit (10) is configured to receive wirelessly transmitted data from an adjacent sensor unit (10), and to forward the received data to adjacent sensor units (10).

7. The downhole drilling system according to any of the preceding claims, further comprising a surface system (110) configured to receive downhole data from said sensor units (10).

8. The downhole drilling system according to claim 7, wherein said surface system (110) is further configured to determine the position of at least one sensor unit (10) in relation to the surface system (110), and to associate said determined relative position with associated position data.

9. The downhole drilling system according to claim 8, wherein the surface system (110) is configured to determine the relative position of at least one sensor unit (10) by Monte Carlo simulation and/or Shortest Path simulation.

5 10. A method for providing a downhole drilling system (100) according to any of the preceding claims, said method comprising:

- entering a plurality of sensor units (10) in a drilling fluid (5), and
- entering said drilling fluid (5) in a borehole annulus (4) via a drill string (1) during drilling, whereby each sensor unit (10) is positioned in said annulus (4).

10 11. The method according to claim 10, wherein each sensor unit (10) is flowing randomly in said annulus (4).

12. A method for determining drilling direction, comprising:

- providing a downhole sensor system (100) by performing the method according to claim 10 or 11,
- activating at least one sensor unit (10) for measuring position data of said sensor unit (10),
- transmitting data corresponding to said measured position data from the activated sensor unit (10) to a surface system (110) via at least one adjacent sensor unit (10), and
- analysing the received data in order to determine drilling direction.

13. The method according to claim 12, further comprising:

- determining the position of said activated sensor unit (10) in relation to the surface system (110), and associating said determined relative position with the corresponding position data received by said surface system (110).

14. The method according to claim 12 or 13, wherein activating at least one sensor unit (10) comprises measuring inclination and/or azimuth.

15. The method according to any of claims 12-14, further comprising comparing the determined drilling direction with an intended drilling direction, and optionally adjusting the current drilling direction based on the comparison.

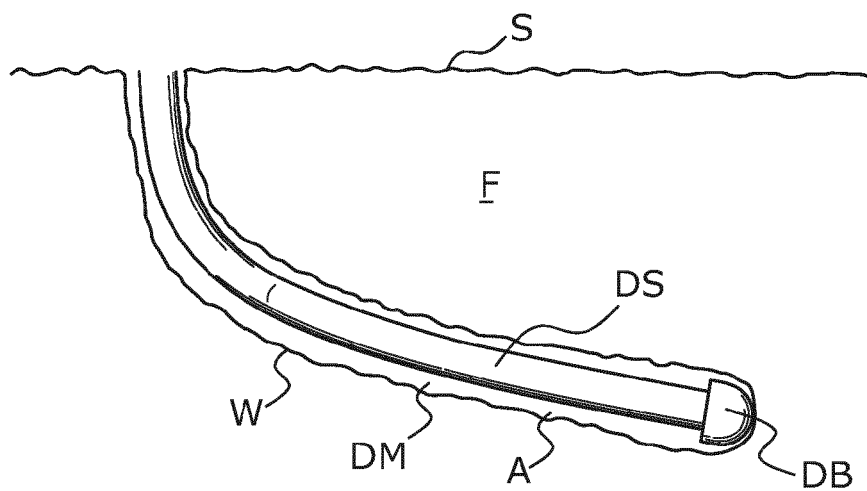


Fig. 1

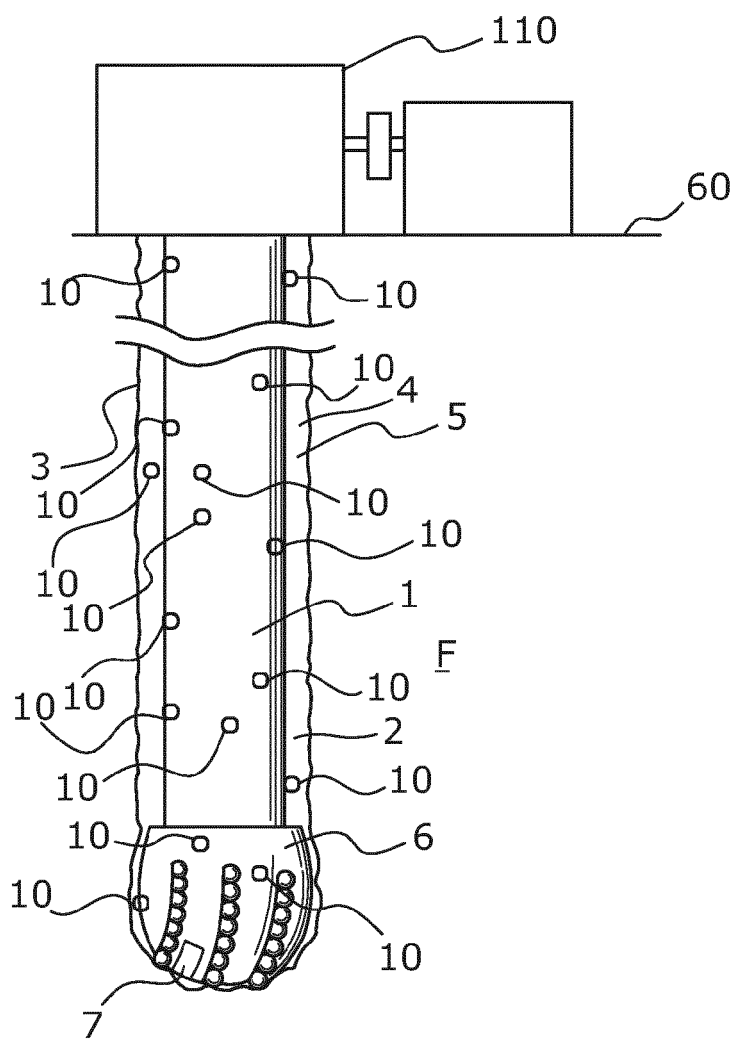


Fig. 2

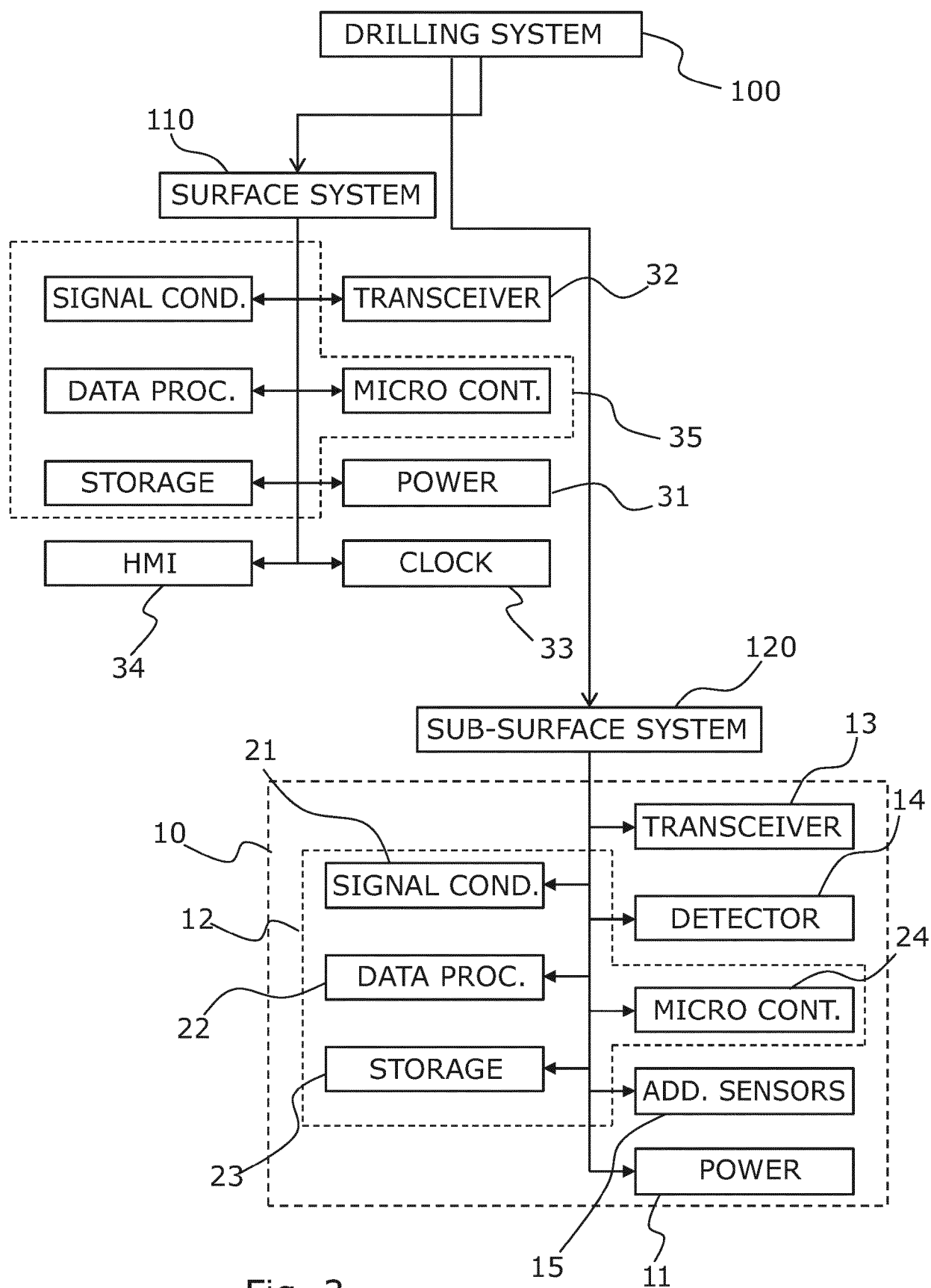
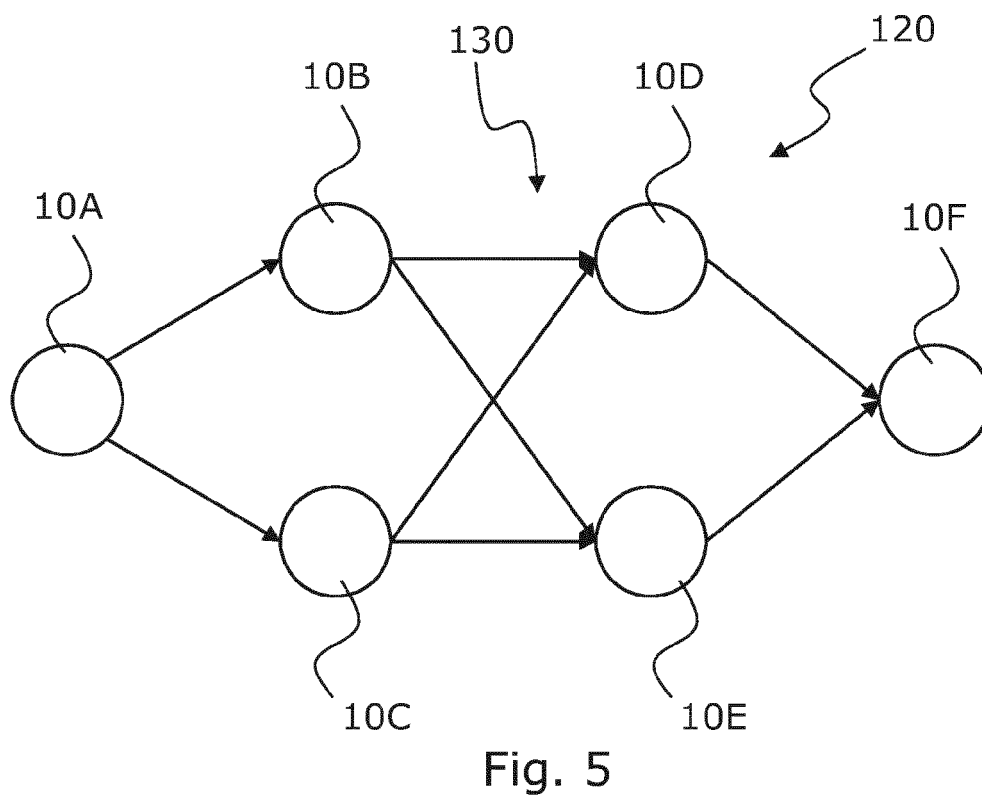
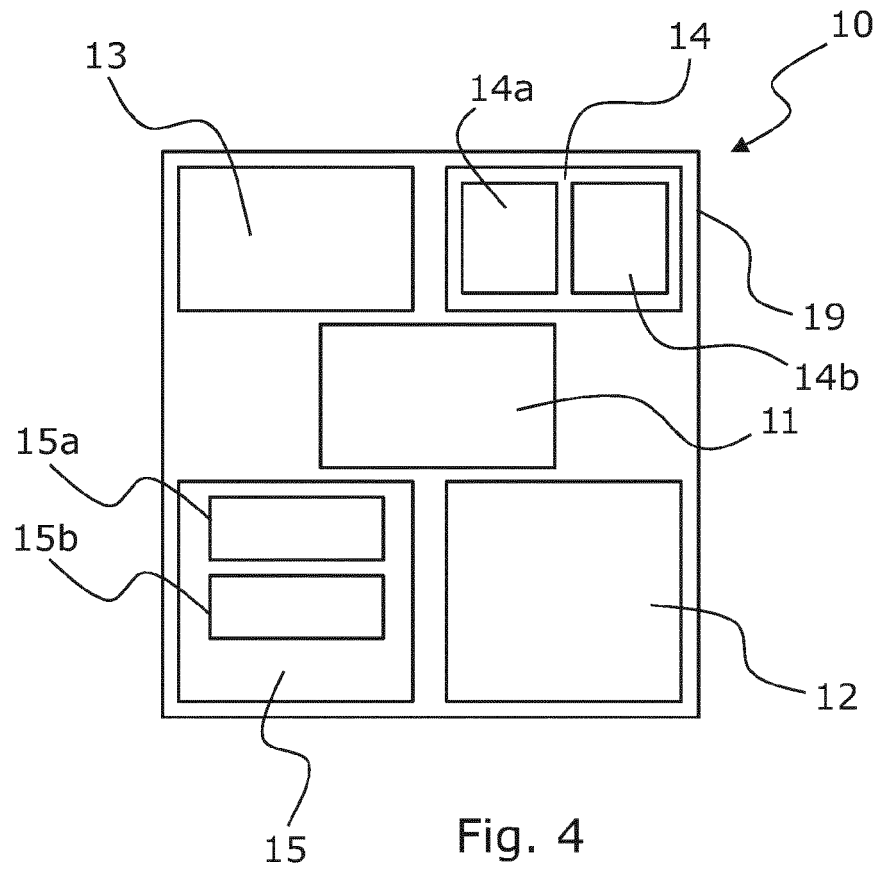


Fig. 3



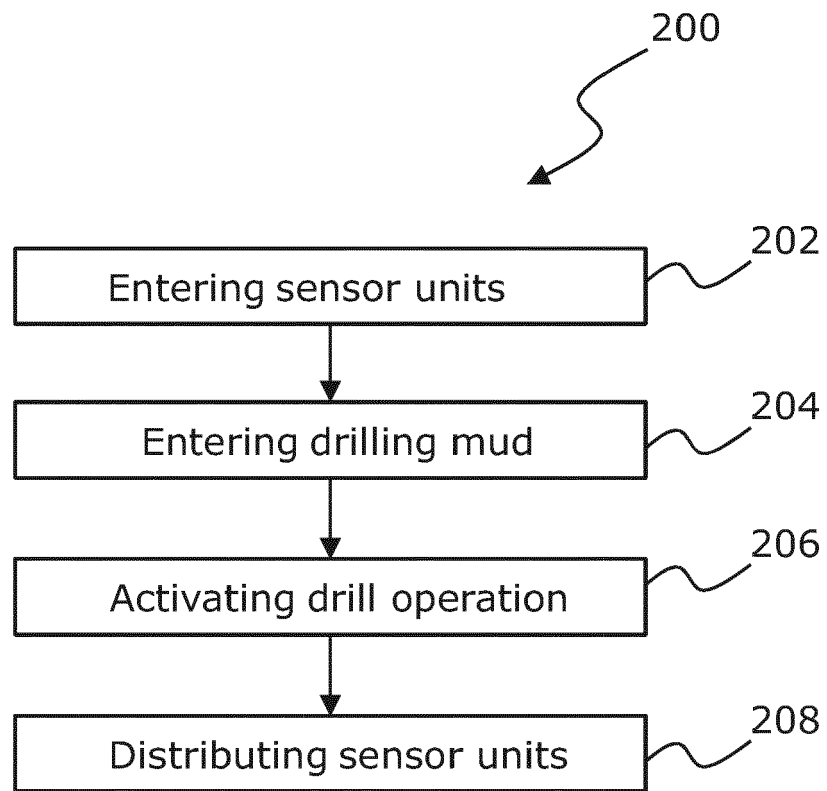


Fig. 6

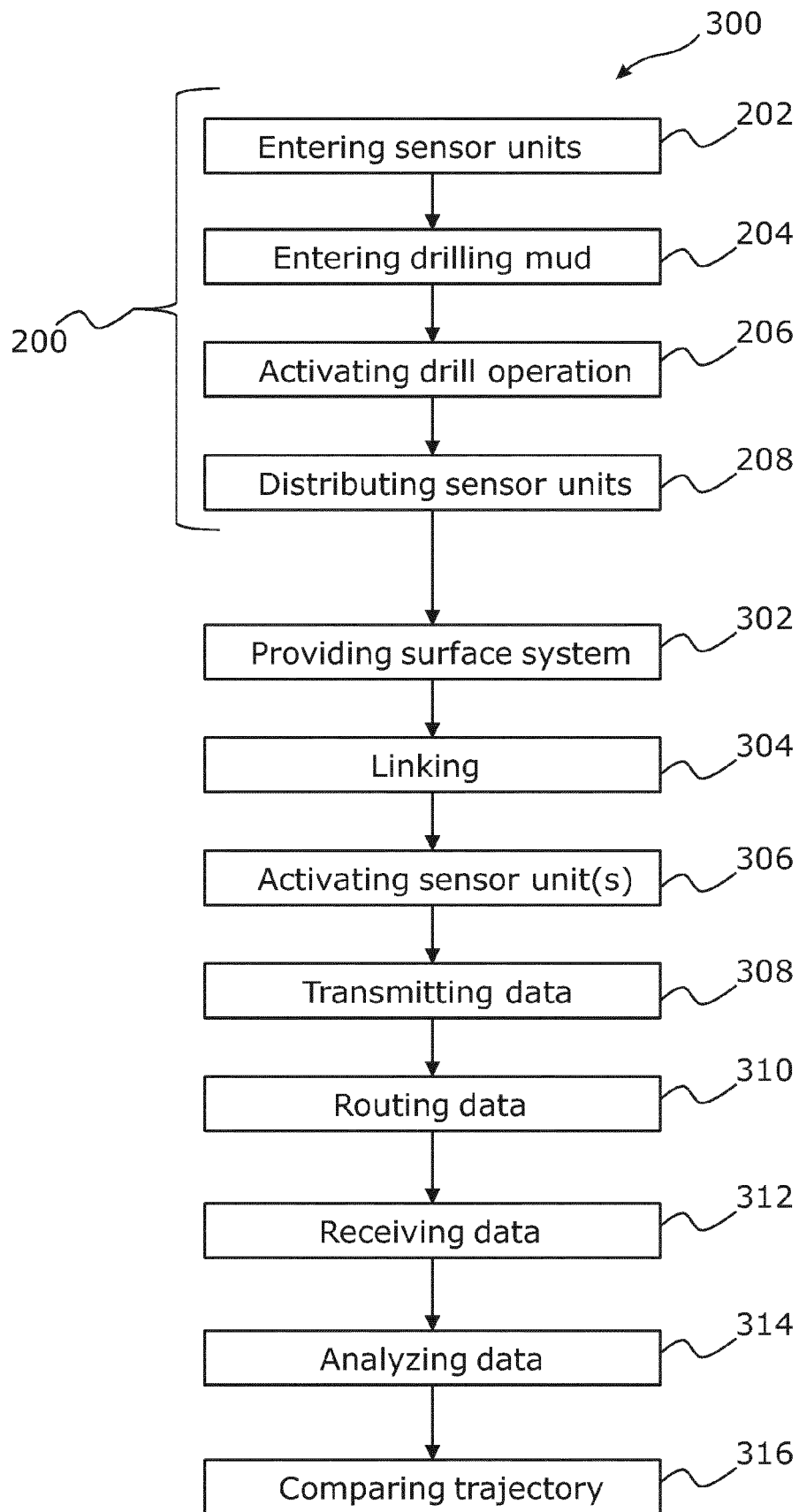


Fig. 7

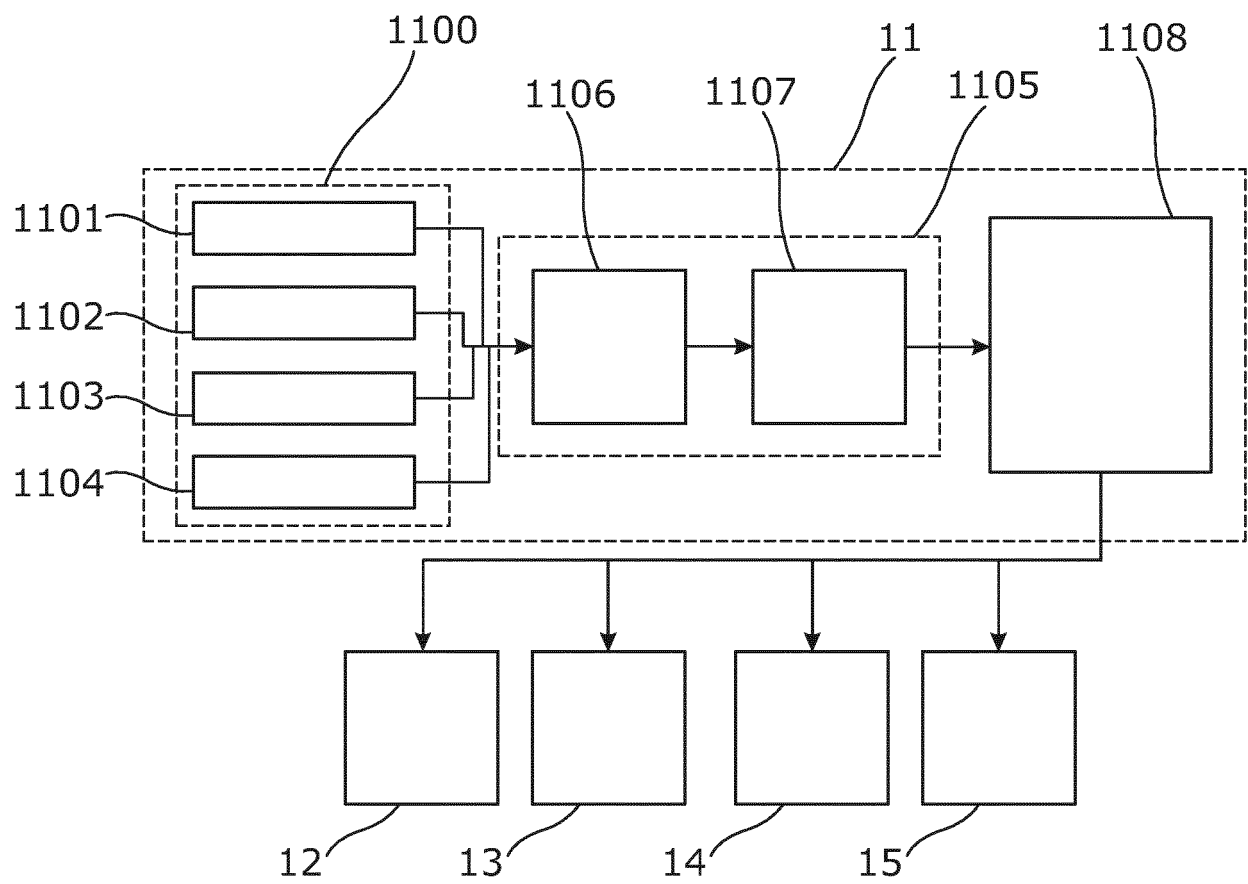


Fig. 8

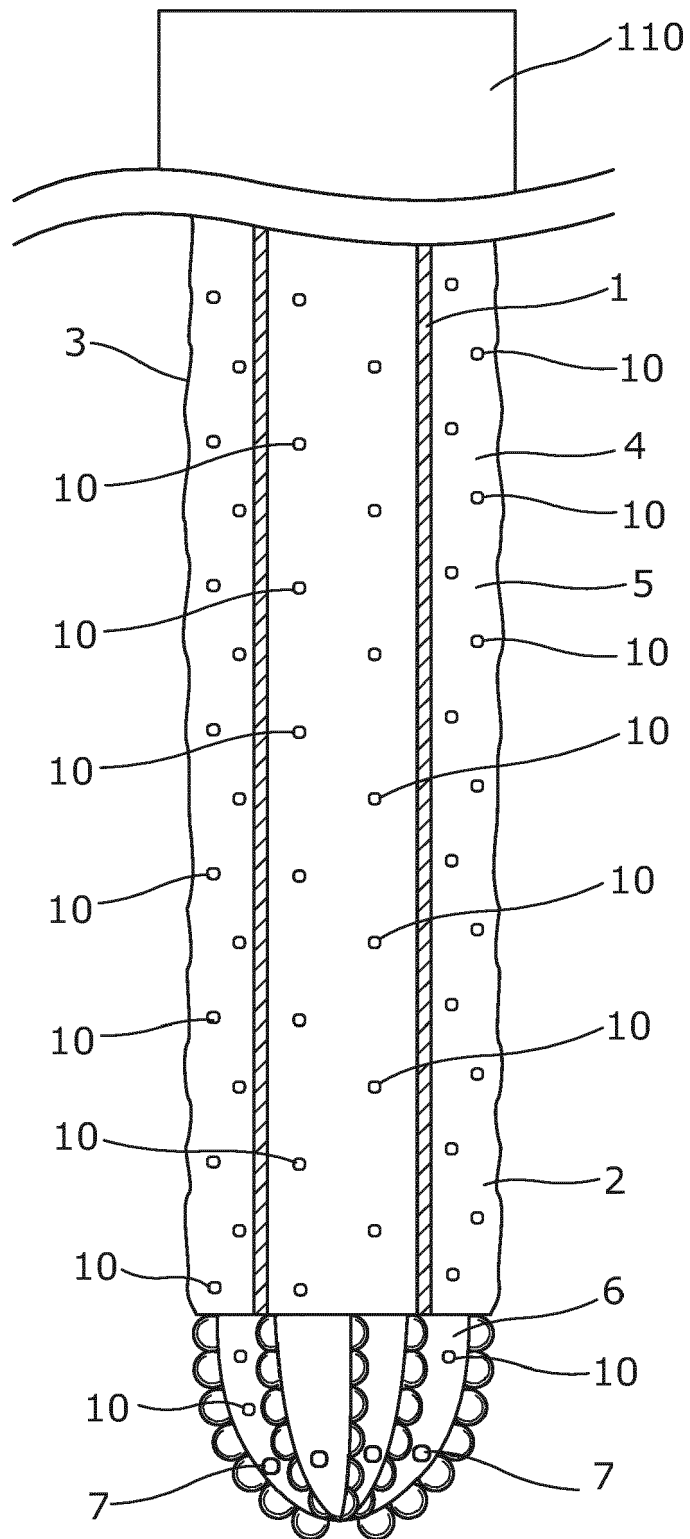


Fig. 9



EUROPEAN SEARCH REPORT

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Y	* abstract *		
A	* figures 1-5,31 * * column 2, line 2 - line 40 * * column 4, line 36 - line 57 * * column 5, line 25 - column 6, line 17 * * column 7, line 3 - line 13 * * column 8, line 23 - line 36 * * column 14, line 46 - line 61 * * column 19, line 24 - line 27 * * column 21, line 34 - line 54 *		
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 31 August 2017	Examiner Hustedt, Bernhard
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	

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The Hague		31 August 2017	Hustedt, Bernhard
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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