(12) UK Patent (19) GB (11) 2579615 (13) B

(45) Date of B Publication 23.12.2020

(54) Title of the Invention: Data acquisition method and system

(51) INT CL: ***G01V 1/38*** (2006.01)

(21) Application No: **1819925.7**

(22) Date of Filing: **06.12.2018**

(43) Date of A Publication **01.07.2020**

(56) Documents Cited:
GB 2424954 A **US 20110228635 A**

(58) Field of Search:
As for published application 2579615 A viz:
INT CL **B63B, G01V**
Other: **EPODOC, WPI**
updated as appropriate

Additional Fields
Other: **None**

(72) Inventor(s):
Peter Hanssen

(73) Proprietor(s):
Equinor Energy AS
Stavanger 4035, Norway

(74) Agent and/or Address for Service:
Marks & Clerk LLP
Fletcher House (2nd Floor), Heatley Road,
The Oxford Science Park, OXFORD, OX4 4GE,
United Kingdom

GB 2579615 B

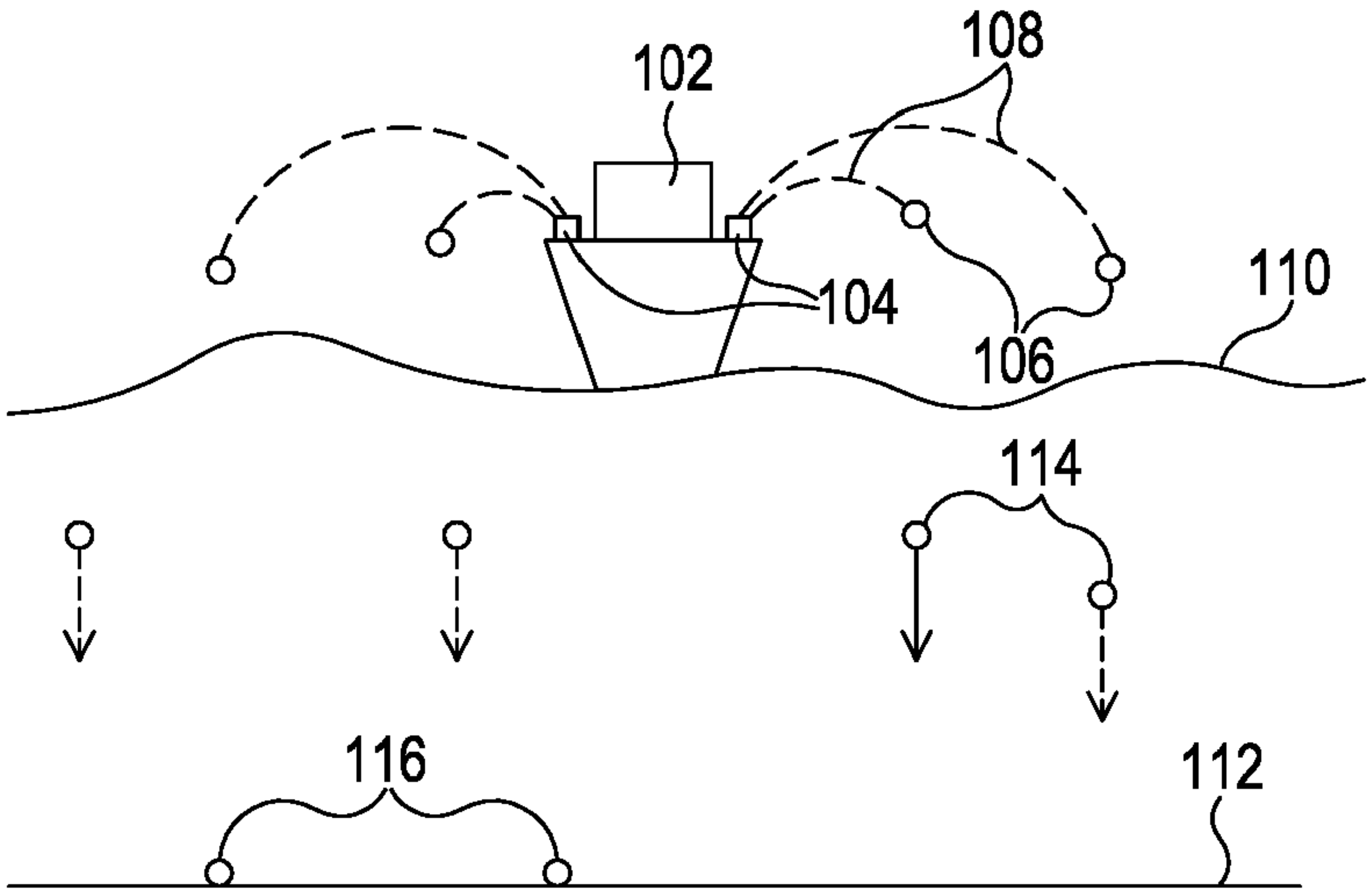

Figure 1A

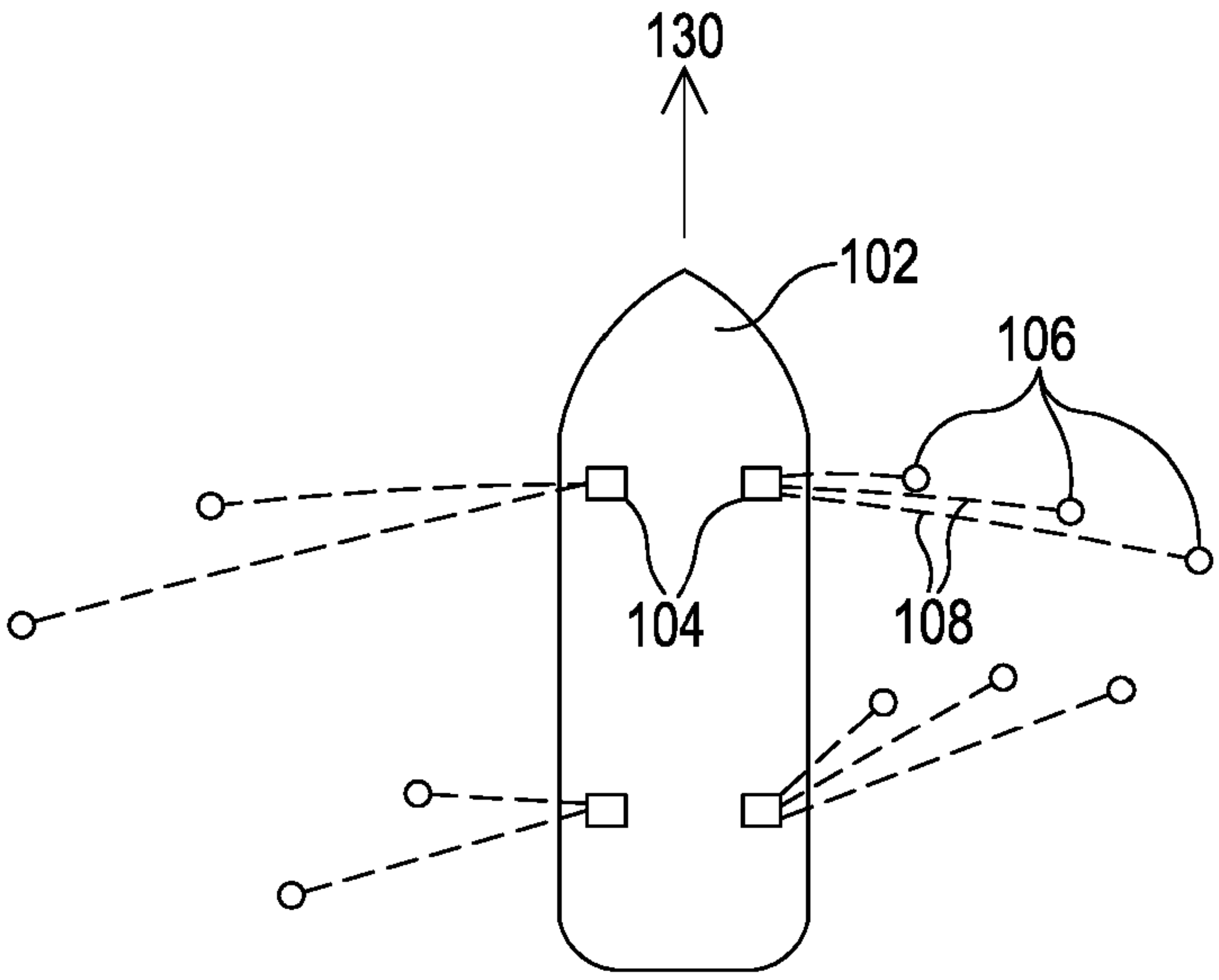

Figure 1B

25 01 19

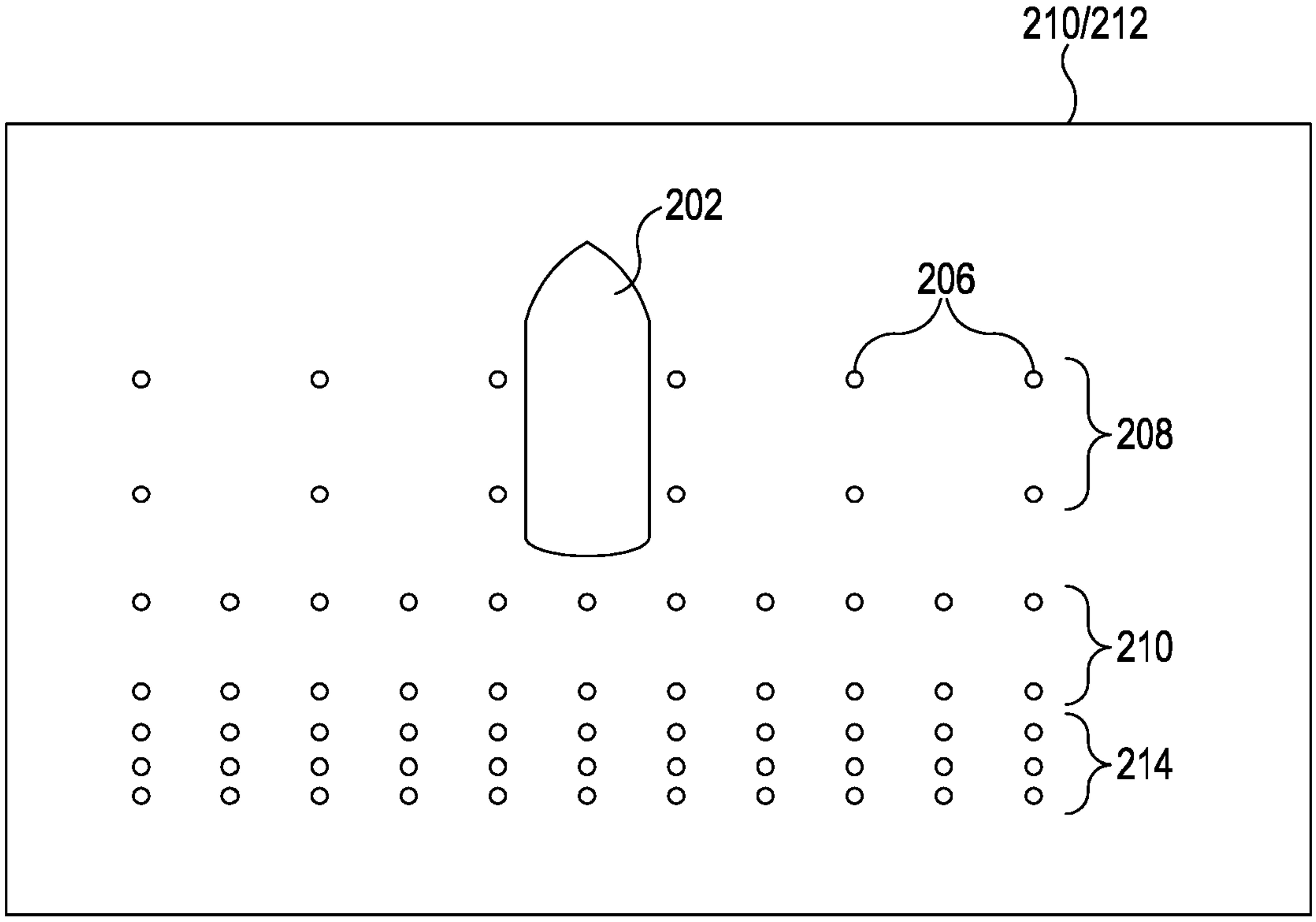

Figure 2

25 01 19

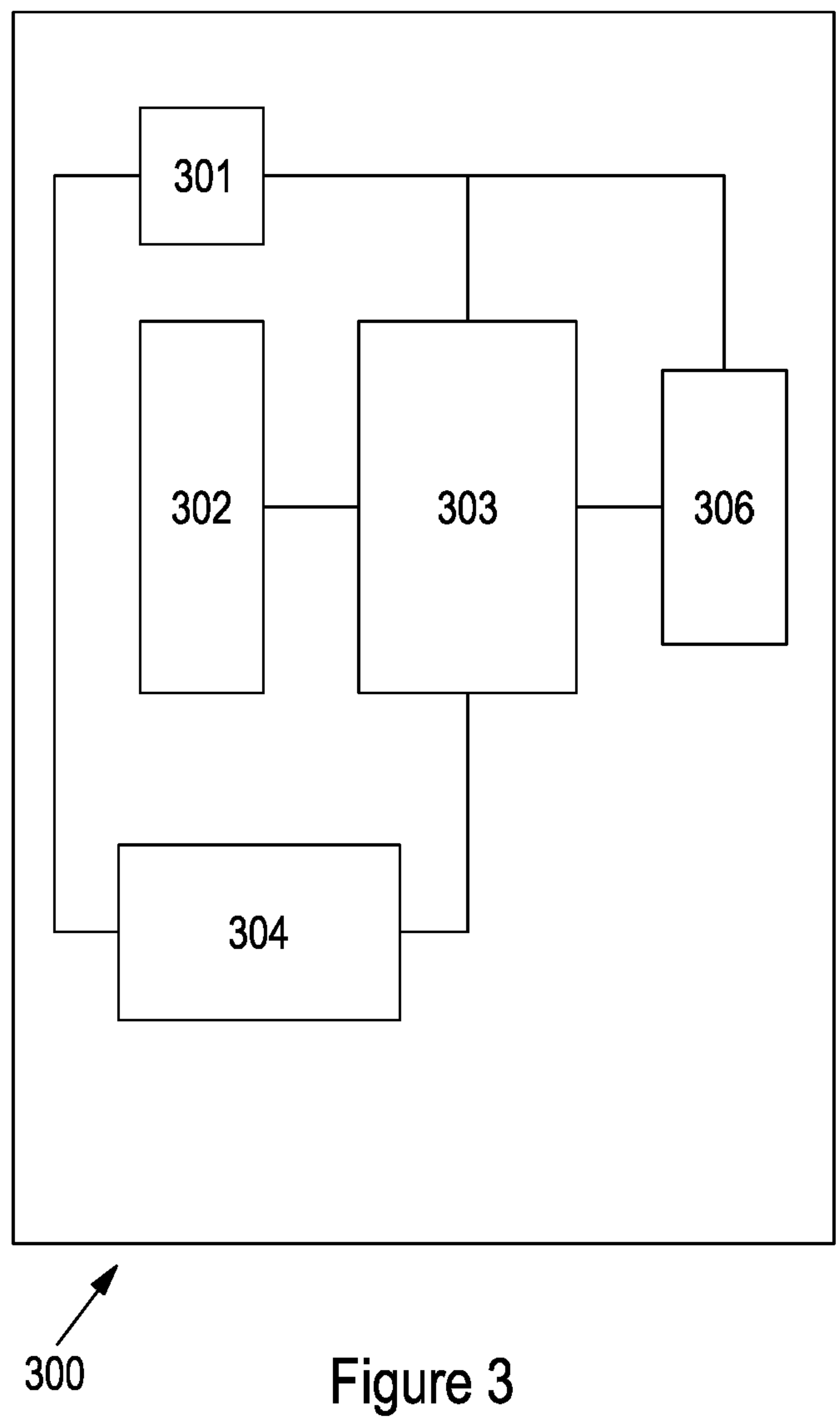

Figure 3

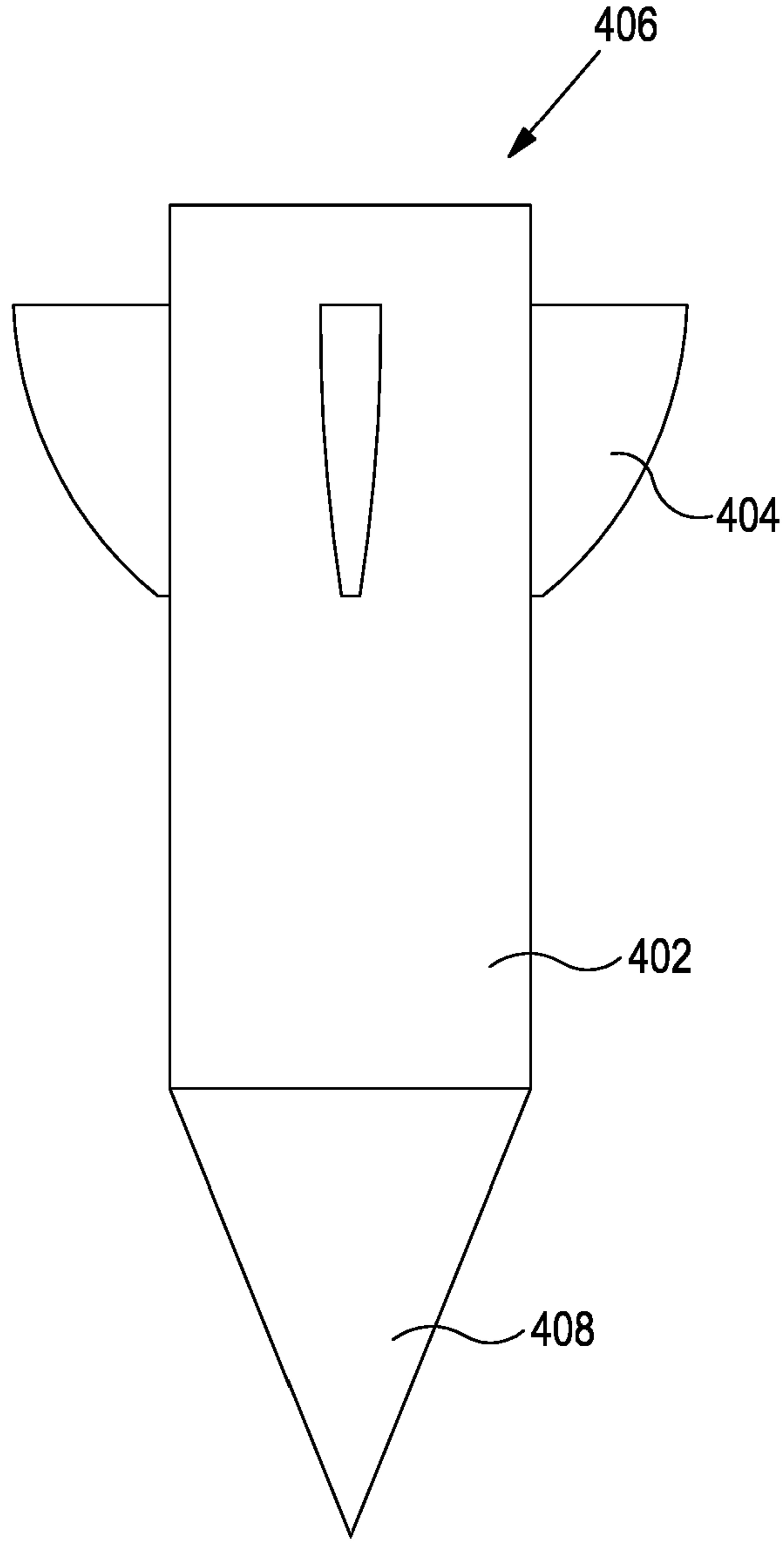

Figure 4

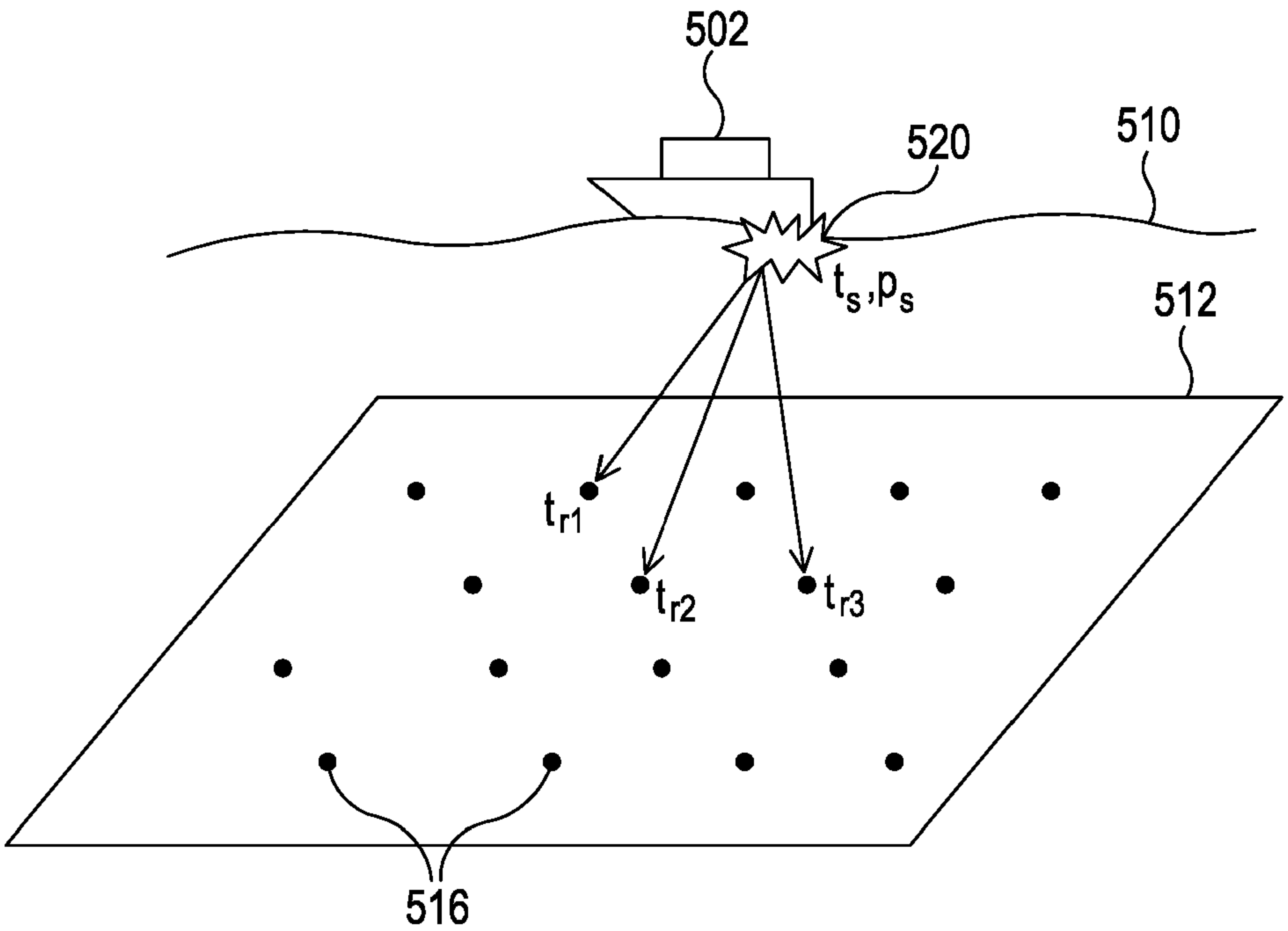

Figure 5

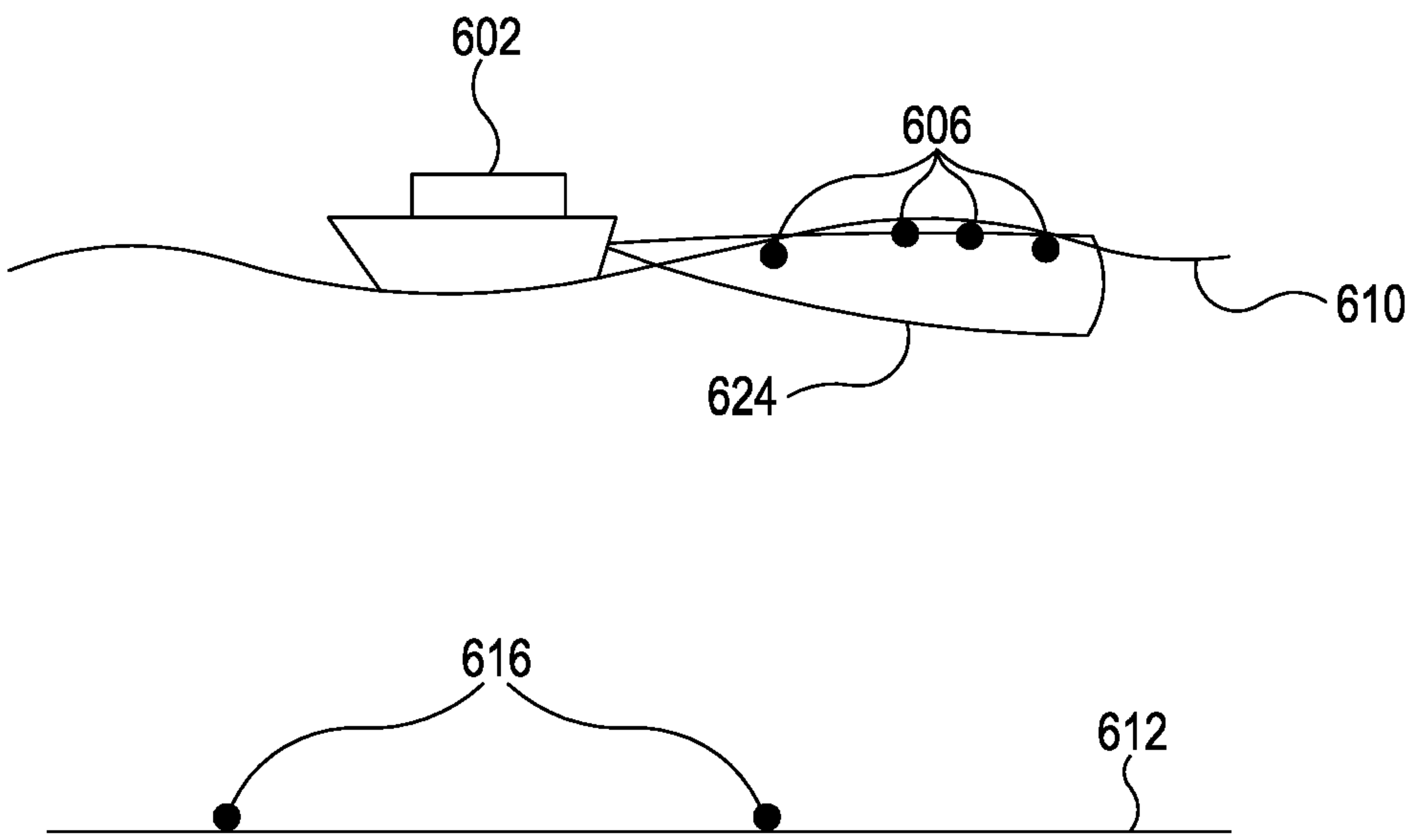

Figure 6

25 01 19

702

SEPARATELY LAUNCH EACH OF AT LEAST SOME OF A PLURALITY OF NODES FROM A SEA-SURFACE VESSEL, THROUGH THE AIR IN A DIRECTION HAVING AT LEAST A COMPONENT THAT IS TRANSVERESE TO THE VESSEL'S DIRECTION OF MOTION, USING ONE OR MORE LAUNCHING DEVICES.

Figure 7

DATA ACQUISITION METHOD AND SYSTEM

Technical Field

The present invention relates to the field of data acquisition. In particular, it relates to a method for deploying data acquisition nodes and a system for deploying data acquisition nodes and acquiring data, which may be geophysical data, in a marine or other water-covered environment.

Background

Geophysical methods may be applied to determine details of the subsurface of the Earth. In one such method, currently the main geophysical method used in the oil and gas industry, active seismic data is recorded. In the method, a downward-propagating seismic wavefield is generated by a source, for example an airgun. The seismic wavefield travels into a region of the Earth being studied. Subsurface inhomogeneities in the region of the Earth cause part of the seismic wavefield to be reflected back up towards the surface. This is due to the acoustic impedance contrast provided by the inhomogeneities. In particular, the acoustic impedance contrast results from the differing densities and seismic velocities of adjacent rock bodies. The reflected wavefields are recorded by receivers at any location (or locations) close to or distant from the source, and the travel time and changes in the seismic wavefield may be determined. Seismic data obtained in this way are processed to obtain information about the inhomogeneities in the subsurface by, for example, building an image of subsurface structures. This image is often in three dimensions (3D), which refer to the three spatial dimensions "illuminated" by the seismic data.

A typical arrangement for performing such studies in a marine or other water-covered environment comprises a vessel towing an array of seismic sources (for example air guns) and one or more recording devices, usually streamers. This is a fast and efficient method to record seismic data at the surface of a water body, but it comes with three major disadvantages: First, direct recording of shear waves (S-waves) travelling through the rocks beneath the seabed is not possible, because water can only transmit pressure waves (P-waves). Second, towing a receiver system through the water adds noise to the recordings, and the data may not be suitable for detecting weak responses from important subsurface inhomogeneities. Third, the data is not a perfect three-dimensional recording, because only a small fraction of the produced wavefields (shots) are recorded at all positions in the acquisition area, producing a limited set of azimuths and offsets.

If better data is needed, one solution is to record the seismic wavefield directly on the seabed. In this case, ambient noise in the active seismic frequency range is reduced and all wave types can easily be recorded from all directions and offsets. This is typically done by deploying receivers, each receiver including three-component geophones and a hydrophone, but systems also exist which record fewer or more ‘components’ than these four-component (4C) instruments. These receivers may come in a seabed cable, as a single free-falling ocean-bottom seismometer (OBS), or as an ocean-bottom node (OBN).

Recording seismic data on the seabed incurs greater costs than using a towed streamer behind a vessel, because the receivers and equipment are more expensive to produce than a streamer, and because deploying and recovering the instruments requires additional time and labour.

There have been efforts to automate single receivers by adding more complex electronics, self-propulsion and more powerful batteries. However, these systems are only commercially viable for small specific tasks, not for large-scale acquisition. Their disadvantages are multiple: A weak power supply means weak propulsion. The form factor is a magnitude bigger than that of a simple receiver node, reducing storage and the number of receivers that can be carried on a vessel. Like data from a seabed cable, the data quality from autonomous receivers is worse compared with a standard OBS or OBN, because of the relatively lower weight of such receivers and the consequent reduction in physical coupling to the seabed. The lower weight is necessary because the receiver must be able to lift off the seabed when data recording is completed without leaving weight behind, and autonomous receivers must be close to buoyancy to facilitate efficient propulsion through the water. The production and maintenance of the instruments is also more costly than a simple node, and the complexity of the system means that technical problems are more likely during operations.

Motivated by the problems with the technologies described above, the industry has concentrated mainly on building cheaper instrumentation which can be deployed and recovered more efficiently, reducing unit and vessel costs. Whilst initially it was necessary to place OBNs using a remotely operated vehicle (ROV), most operations now use a node-on-the-rope system to deploy and recover the receivers in a fast and precise-enough fashion. Because space limitations on deployment vessels necessarily limit the number of OBNs that can be carried, and because it is typically desirable to reduce vessel use times, the spacing between the nodes is in most cases bigger than the spacing used on land or in a cable. Additionally, the spacing may be dense along the rope in the in-line direction, but is typically sparse between each rope; the spacing is often up to several hundred meters in the cross-line direction. This reduces vessel use times, but the decrease in vessel costs comes with a decrease in data quality.

Summary

It is an object of the present invention to solve or at least mitigate the problems described above.

In accordance with a first aspect of the present invention there is provided a method of deploying a plurality of data acquisition nodes across a seabed. The method comprises separately launching each of at least some of the plurality of nodes from a sea-surface vessel, through the air in a direction having at least a component that is transverse to the vessel's direction of motion, using one or more launching devices, wherein each node is launched to land at a predetermined position on the sea-surface; and before said launching, calculating a trajectory for each node to land at its predetermined position, and adjusting a launch angle and launch power of the one or more launching devices to launch each node using the calculated trajectory .

At least some of the plurality of nodes may be launched simultaneously or in close temporal succession to create a pattern of nodes at the sea-surface in a cross-line direction.

The predetermined position may be between 5 m and 1 km from the vessel, between 25 m and 1 km from the vessel, or between 50 m and 1 km from the vessel. The trajectory may be calculated based at least on a wind speed and a wind direction. The method may further comprise, before launching each node to land at a predetermined position, calculating the predetermined position based on a desired seabed position of each node in a desired acquisition layout. The predetermined position may be calculated based at least on a measured or estimated water current in a water column.

The method may further comprise automatically controlling an azimuthal angle of launch and a horizon angle of launch to compensate for at least one of movements of the vessel, wind conditions, wave movements and water column flow.

The launch direction may have a vertical component.

The motion of each node through air may be ballistic.

The method may further comprise individually registering each of the plurality of nodes before launch.

All or part of the node may be configured to degrade over time in seawater.

The node may include one or more of a geophone, a hydrophone, a seismometer, an accelerometer, a tilt meter, a chemical sensor, an absolute or differential pressure gauge, and a temperature sensor.

Each of the plurality of nodes may include a body and a releasable anchor. The releasable anchor may be degradable in seawater. The body may be positively buoyant. The releasable anchor may comprise a seawater-based battery configured to supply electrical power to one or more electrical devices included in the body.

The data acquisition nodes may be seismic data acquisition nodes.

The one or more launching devices may be air-powered launching devices or electrically powered launching devices. In the case that the one or more launching devices are air-powered launching devices, the air-powered launching devices may be powered using pressurised air, and the pressurised air may be obtained from a reservoir which is configured to also provide pressurised air for the operation of a seismic shooting air gun of the vessel. In the case that the one or more launching devices are electrically powered launching devices, the electrically powered launching devices may be powered using a generator, wherein the generator may be configured to also provide electrical power for a seismic vibrator of the vessel.

In accordance with a second aspect of the present invention there is provided a vessel for deploying a plurality of data acquisition nodes across a seabed, the vessel comprising one or more launching devices configured to launch, using a launch angle and launch power, at least some of the plurality of nodes through the air in a direction having at least a component that is transverse to the vessel's direction of motion, wherein the launch angle and launch power of the one or more launching devices is adjusted to launch each node using a calculated trajectory, wherein each node is launched using the calculated trajectory to land at a predetermined position on the sea-surface.

The data acquisition nodes may be seismic data acquisition nodes.

The vessel may further comprise: a net for collecting nodes at or near the surface of the sea following data acquisition by the nodes; and/or an ROV for collecting nodes following data acquisition by the nodes.

The one or more launching devices may be air-powered or electrically powered. In the case that the one or more launching devices are air-powered, the vessel may further comprise an air gun for seismic shooting and a reservoir of pressurised air, wherein the reservoir of pressurised air is configured to selectively provide pressurised air to the one or more launching devices and the air gun. In the case that the one or more launching devices are electrically powered, the vessel may further comprise a seismic vibrator for emitting seismic signals and a generator, wherein the generator is configured to selectively provide electrical power to the one or more launching devices and the seismic vibrator.

The launch direction may have a vertical component.

The one or more launching devices may be configured to launch each of the plurality of nodes ballistically.

In accordance with a third aspect of the present invention there is provided a method of acquiring data, comprising: using the method of the first aspect of the invention to deploy a plurality of data acquisition nodes across a seabed; and acquiring data using the plurality of data acquisition nodes.

The data acquisition nodes may be seismic data acquisition nodes and the acquired data may be seismic data.

Embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Brief Description of Drawings

Figure 1A shows an elevation view of a vessel distributing data acquisition nodes.

Figure 1B shows a top-down view of a vessel distributing data acquisition nodes.

Figure 2 shows examples of patterns of data acquisition nodes.

Figure 3 shows a block diagram illustrating the components of a data acquisition node.

Figure 4 shows a schematic illustration of an exemplary data acquisition node.

Figure 5 illustrates how timing data can be used to determine the position of data acquisition nodes on the seabed.

Figure 6 shows a vessel collecting nodes after data collection is complete.

Figure 7 shows a high-level flow diagram describing a method of deploying a plurality of nodes in accordance with the invention.

Detailed Description

The present invention aims to overcome the problems set out in the Background section, and in particular the cost and cross-line sampling problems associated with OBN surveys. The method of the invention does not use a cable, rope or ROV, but instead employs single compact nodes, which may be seabed seismic data acquisition nodes, and, in particular, receiver nodes. Several of these nodes may be “sprayed” several hundreds of metres, or over 1 km, from each side of the ship using one or more distribution devices. In this case, “several” means up to tens or hundreds of thousands of individual nodes. Single or multiple nodes may also be released along the sailline of the vessel. Catapulting several nodes in a sideways direction from the vessel allows the nodes to sink into positions on the seabed to cover the crossline positions in the seismic spread. Distributing more nodes on the seabed not only increases the subsurface image quality, but may also reduce the environmental impact of the dense shooting that is typically necessary to compensate for the sparse receiver spread associated with existing OBN survey techniques.

Given the large number of nodes that the invention envisages, the nodes are preferably small and simple, to reduce costs and complexity.

To retrieve the nodes and their data, an anchor is released by each node, or becomes disengaged from each node. This decouples each node from the seabed, and the nodes passively rise to the sea surface where they can be collected by a vessel. Alternatively, the nodes are collected from the seabed.

Figure 1A shows a vessel 102 at a surface 110 of a sea or other body of water. The vessel 102 may be a seismic surveying vessel having an air gun for seismic shooting, or any other suitable vessel. One or more launching devices 104 are located on the vessel 102, e.g. on a deck of the vessel 102. Figure 1A shows two launching devices on each side of the vessel, but of course any suitable configuration of devices is possible. For example, there may be one or more launching devices on one side of the vessel and none on the other side, or there may be launching devices on both sides of the vessel but more on one side than the other. The launching devices are used to launch nodes 106 through the air to land on the sea surface 110. The nodes 106 follow a trajectory 108 through the air. In Figure 1A, each of the nodes is launched through the air in a direction having at least a component that is transverse to the vessel’s direction of motion. At least some of the nodes, and typically all or most of the nodes, are launched with an upward, i.e. positively vertical, component of motion. In this embodiment, a node that is launched through the air is not physically connected or physically coupled in any way to the vessel following launch, and in particular between launch and the node entering the water. Preferably, each node is physically independent of any other node and is not physically connected or physically coupled to any other node by a cable or any other physical coupling means. The trajectory 108 of each node through the air is therefore ballistic. The one or more launching devices 104 may be catapults, or any other devices suitable for launching nodes 106 to land on the sea surface 110 a sufficient distance from the vessel 102 without critically damaging nodes 106. Each node is preferably launched to land in the sea at a distance of between 5 m and 1 km from the vessel, between 25 m and 1 km from the vessel, between 50 m and 1 km from the vessel, or between 100 m and 1 km from the vessel. Smaller distances, for example distances of between 1 m and 5 m, and larger distances, for example distances of between 1 km and 5 km from the vessel, are also possible. Figure 1A shows nodes being launched from both sides of the vessel. Alternatively, nodes may be launched from one side of the vessel. One or more of the launching devices may be air-powered launching devices, powered using pressurised air obtained from e.g. a reservoir of pressurised air on the vessel. Where the vessel 102 is a seismic surveying vessel having an air gun for seismic shooting, the pressurised air supply used to operate the air gun may also be used to operate the air-powered launching devices. In this case the vessel includes a reservoir of pressurised air from which pressurised air is selectively provided to the air gun and the at least one launching device. One or more of the launching devices may be electrically powered launching devices, for example rail gun or rail gun-type launching devices, powered using electrical power obtained from e.g. a generator on the vessel. Where the vessel 102 is a seismic surveying vessel having a seismic vibrator for emitting seismic signals, the electrical power supply used to operate the seismic vibrator may also be used to operate the electrically powered launching devices. In this case the vessel includes a generator from which electrical power is selectively provided to the seismic vibrator and the at least one launching device. After landing at the surface 110, the nodes 106 sink through the water, as shown by reference numeral 114 and arrows, and land on the seabed 112. The arrows show substantially vertical motion of the nodes 106 as they sink through the water, but of course the nodes' trajectory and direction of motion may vary as they sink due to, for example, currents in the water column. The nodes 106 that have landed on the seabed are shown using reference numeral 116.

Figure 1B shows a top-down view of the vessel 102 of Figure 1A traveling with a direction of motion 130, i.e. along a sail-line 130. In this embodiment the sail-line 130 is the vessel's course along a deployment path. The deployment path may be predetermined. The one or more launching devices 104 may launch the nodes at the same time, in a specific sequence, continuously or randomly, perpendicular to the sailline 130, ahead or backwards in any angle to the direction of motion 130 of the vessel. The launch power and speed, and the vertical and/or horizontal angle of launch, can be adjusted for each launching device. In practice adjusting the angle of launch vertically means adjusting the angle relative to the horizon or relative to the deck of the vessel (i.e. adjusting the altitude), and adjusting the angle of launch horizontally means adjusting the angle relative to the vessel's direction of travel or relative to an angular bearing (i.e. adjusting the azimuth). The angle of launch may be adjusted to compensate for the motion of the vessel. For example, the angle of the launching device may be controlled automatically to compensate for one or more of pitch, roll, yaw, heave, sway and surge of the vessel, to thereby maintain an absolute angle of launch relative to a given bearing or the vessel's course, and/or the horizon. Figure 1B shows launching devices 104 that are each launching nodes 106 with a different trajectory 108 relative to the other launching devices. The launching devices may however launch the nodes using identical launch power and angle of launch. One or more of the launching devices may be used to launch one or more nodes along the direction of travel 130, i.e. with an azimuth of zero or 180 degrees. Alternatively, nodes may be dropped from the vessel along the direction of travel, e.g. from the stern of the vessel, such that the nodes are dropped or launched with substantially no component of motion in a direction transverse to the direction of travel 130 of the vessel.

The nodes are launched from the vessel to create a pattern or array of nodes on the seabed. In particular, multiple nodes are launched to land in the water at different transverse distances from the vessel's path of travel to thereby create a pattern of nodes landing in the water and, subsequently, the pattern or array of nodes on the seabed. Subsets of the multiple nodes may be launched simultaneously or in close temporal succession. By "spraying" a large number of nodes outwardly in a transverse direction from the vessel to create a dense pattern of nodes, the pattern of nodes will provide good coverage in the cross-line direction as well as in the direction of travel of the vessel. A much higher rate of launch of nodes is possible using this method, and consequently it is possible to create patterns of nodes that are much more densely distributed on the seabed. Using this method, fewer passes of a vessel may be required to distribute nodes for the desired seismic acquisition, compared with existing OBN distribution techniques. It may be possible in some cases to create the desired pattern with one pass of a vessel. This method may significantly reduce the complexity and cost of distributing nodes for seismic data acquisition. In particular, vessel costs, which account for a large proportion of seismic surveying costs, will be significantly reduced.

Figure 2 shows examples of patterns of nodes 206 which have been launched from vessel 202. The nodes 206 are launched from the vessel 202 to create a predetermined pattern of nodes at the sea surface 210, i.e. the nodes 206 land in the sea in the predetermined pattern. In Figure 2 the pattern of nodes 206 alternatively illustrates a pattern of nodes 206 at or on the seabed 212 in a desired acquisition layout. To create a desired acquisition layout the nodes 206 are launched from the vessel 202 to create a pattern at the sea surface 210 that will result in the desired acquisition layout after the nodes 206 have sunk to the seabed 212. While sinking through the water column the nodes may of course experience drift caused by water currents. The water currents may be recorded or observed before or while nodes are being launched, to estimate the effect that the currents will have on the sinking nodes, and/or the position at which the nodes will land on the seabed. Wind and other weather conditions may also be measured to determine any effect on the trajectory 108 of the nodes through the air. To account for the effects of wind and water currents and create a pattern of nodes at the sea surface that will result in the desired acquisition layout, the angle and power of launch, and hence trajectory 108, may be adjusted for each node launched from the launching device(s). Such adjustment may also be required to compensate for movements of the vessel, especially in rough waters. Continuous correction of the launch angle and power may be necessary. The vessel may include a computerized, automatic control system to compute and adjust the launch angle and power for each launch device, to automatically adjust the trajectory of the nodes as required.

In some cases, for example if the nodes are launched to create a highly dense pattern, it may not be necessary to aim for a precise pattern of nodes at or on the seabed. In this case the nodes are launched to create a predetermined pattern of nodes at or on the sea surface, and the nodes are simply allowed to sink to the seabed and land at an undetermined (at that time) location. The location of the nodes on the seabed is of course determined later once the nodes have been collected, as set out below for Figure 5.

Figure 2 shows a first region 208 with a first pattern of nodes 206, a second region 210 with a second pattern of nodes 206, and a third region 214 with a third pattern of nodes 206. With the functionality set out above for Figure 1A and 1B it is of course possible to deploy the nodes in any pattern necessary for the desired acquisition layout. This layout could be a regular grid as shown in the first 208 and second 210 regions, a grid with different in-line and cross-line separations between the nodes as shown in the third region 214, a shifted grid, a random or quasi-random distribution as proposed by compressed sensing for example, or even a designed 2D pattern like a spiral or a fractal distribution. Any 2D distribution is possible, within limits typically imposed by the geological setting, the acquisition goal and the funding available. Such 2D distributions may include variations in the number density of nodes per unit area within the pattern, and consequent variations in the data sampling rate, and/or irregular patterns.

For most cases of standard seismic acquisition, the spacing between nodes is preferably between 5 m and 1 km in the in-line and/or cross-line direction, when landing at the sea surface or at the seabed. Typically a regular grid is preferred, and in this case the separation between nodes is the same in the in-line direction and the cross-line direction. The separation between nodes in the in-line and/or cross-line direction is more preferably between 5 m and 150 m, or between 25 m and 150 m, and still more preferably between 5 m and 50 m. Closer separations between nodes, for example a spacing of 1 m, may be preferable in some circumstances, for example a site survey in a shallow lake. Similarly, wider separations, for example a 5 km grid, may be preferable when, for example, creating a receiver array for passive seismic measurements. Such separations are also possible using the method of the invention.

Once at the seabed, each node in a desired acquisition pattern is ready to collect data. In an embodiment the nodes are seismic receivers and are used to acquire geophysical data, in particular seismic data. In this case a vessel emits seismic signals using an air gun (for seismic shooting) or a seismic vibrator, and the seismic data acquired by the seismic receivers includes the seismic signals received directly from the vessel, and reflections of the seismic signals from structures in a formation beneath the seabed.

The nodes may collect other geophysical data, for example magnetic, gravimetric, and/or electromagnetic data. Geochemical data might also be collected by the nodes, including geochemical data relating to the chemical composition of the water or seabed, in particular concerning hydrocarbon elements, CO_2, and/or other substances of interest. Additionally, the nodes may measure general parameters such as temperature, pressure, and/or salinity. To measure such geophysical, geochemical and/or general physical data, the measurement sensor of each node is, or includes, a sensor or measurement device capable of measuring the data. Such sensors and measurement devices are known to the skilled person.

Figure 3 shows a block diagram showing the data acquisition components of a node in accordance with the invention. In this embodiment the node is a receiver, in particular a seismic receiver configured to detect seismic energy. The node 300 includes a battery 301, a measurement sensor 302, a data recorder 303, a clock 304 and data storage 306. The battery 301 provides power for the measurement sensor 302, data recorder 303, clock 304, data storage 306 and any other components requiring electrical power. The measurement sensor 302 is configured to sense at least one component. The sensor 302 may be equipped to measure four components—i.e. motion in the x, y and z directions, and pressure—if space within the node, and functionality, permit. The measurement sensor may be configured to measure motion in at least one of the x, y and z directions, using e.g. an accelerometer. The measurement sensor may be configured to measure a pressure using e.g. a hydrophone. The inventors envisage that the node is kept as simple and as light as possible, and in one embodiment the measurement sensor is an accelerometer configured to measure motion in one of the x, y and z directions. It is envisaged that the high number density of nodes, i.e. the large number of nodes per unit area on the seabed, will compensate for the relative lack of data resulting from the measurement of one component. Measurement data in relation to the at least one component is recorded into data storage 306, which may be a non-transitory data storage medium, by the data recorder 303. Each piece of recorded measurement data is associated with a precise time provided by the clock 304. The node may also include other components such as a processor, an analog-to-digital converter and/or an amplifier, as necessary.

Figure 4 shows a schematic illustration of a node 406 in accordance with the invention. The node has an anchor 408 and a body 402, and may include fins 404. The anchor

408 is coupled to the body 402. In Figure 4 the node has an overall ‘rocket’ shape to facilitate flight of the node through the air and sinking of the node through water, but the node may have any other suitable shape depending on conditions. For example, the node may be cuboid, cylindrical or round. The body 402 of the node 406 contains the data acquisition components and is designed to be recovered. The anchor 408 has a density higher than the water through which the node sinks. The anchor 408 is configured to transport the node to the seabed under the influence of gravity, to retain the node at its landing point on the seabed, and to provide physical coupling of the node to the seabed for e.g. seismic measurements. The anchor is made from concrete or any other suitable material, e.g. metal. The anchor may have any shape and material properties suitable for the relevant conditions. For example, different shapes of anchor may be required depending on the hardness of the seabed, which will influence the physical coupling of the node to the seabed. The body 402 is buoyant. Alternatively, the body is close to buoyant or not buoyant, and the body includes a flotation device that causes the node to rise to the sea surface once the flotation device is deployed. The flotation device comprises, for example, a gas canister and a bladder, where the bladder is deployed and filled with gas when the flotation device is triggered. The anchor 408 is detachable from the body 402, and in the case of a buoyant body 402 the body 402 will float to the surface once the anchor has been detached. The anchor may be actively decoupled, for example, by a burn-wire or a hook. The decoupling may be triggered, for example, by a coded seismic signal sent from a vessel at the sea surface, or by a timer in the node. In this case the node 406 includes a transceiver or receiver for receiving the coded signal, and a release mechanism; a seismic sensor of the node may function as, or may include, such a transceiver or receiver. Alternatively, the anchor degrades in seawater over a certain period of time, and when the anchor has degraded to a sufficient extent the body floats to the surface. The node may also include an active positioning system to steer the node into position on the seabed and/or to record their position after landing on the seabed, but the inventors envisage the node as being as simple, cheap and “stupid” as possible. This allows for a smaller form factor, and hence an increased number of receivers on board the vessel and consequently on the seabed. In addition to or instead of the seismic sensor(s)—which may include one or more of a seismometer, a geophone, a hydrophone and an accelerometer—and associated equipment, each node may also include other measuring devices, for example one or more of a tiltmeter, a chemical sensor, a temperature sensor, an absolute or differential pressure gauge, and/or any

other suitable measuring device. The node may also be equipped with an LED to facilitate collection of the node at the sea surface by a vessel. The LED may be switched on only once the node reaches the surface.

In an embodiment a sea-water battery is used as the anchor 408, or the anchor 408 includes a sea-water battery. The sea-water battery provides a substantial part, or all, of the power needed for the node. This enables a smaller power supply to be used for the node, reducing the form factor of the body 402 of the node, and also reduces the weight and volume of the portion of the node that is to be recovered. This sea-water battery/anchor or a substantial part of it would be left on the seabed and would preferably disintegrate over time.

Figure 5 illustrates how the position of each node on the seabed is determined. The nodes 516 are distributed in a pattern on the seabed 512. A seismic shooting vessel 502 at the sea surface 510 emits a seismic signal or ‘shot’ 520 using e.g. an airgun at time t_s and position p_s. The seismic signal 520 travels through the water and is received at different nodes at different times, since the nodes are located at different distances from the vessel. For the three exemplary nodes shown in Figure 5, the seismic signal 520 is detected by the measurement sensor in each node at times t_{r1}, t_{r2} and t_{r3}, respectively, as determined by the clock in each node. In accordance with the description above in relation to Figure 3, the measurement data associated with the detection of the seismic signal is associated with the detection time t_{r1}, t_{r2} and t_{r3} when the measurement data is recorded. The actual position of each node is then calculated after the node is retrieved. In particular, the seismic data recorded by each node is analysed, and the position of each node on the seabed is determined using the known parameters t_s, p_s, the detection time t_{r1}, t_{r2} or t_{r3} etc. of one or several (up to thousands) of shots, and the velocity profile of the water column. Such techniques for positional determining using seismic timing data are known to the skilled person. Each node has a serial number which is read before deployment and after recovery and may be stored in the node’s data storage. The deployment time and deployment position of each node is recorded, and the position of each node on the seabed is determined via the recorded seismic from the shooting vessel as set out above. The precise clock included in each node enables the seabed position to be determined in this way.

In the case that the measurement sensor is not capable of detecting seismic signals, for example if the measurement sensor is not, or does not include, one or more of a seismometer, a geophone, a hydrophone and an accelerometer, then the position of each node on the seabed is determined using an alternative method. One possible alternative method is to observe of the point of recovery at the sea surface, e.g. record the GPS coordinates of each node when it is recovered at the sea surface as set out below for Figure 6, and preferably to estimate the drift of each node from its seabed position based on knowledge of subsea currents and surface conditions, including wind and wave conditions. Further possible alternative methods include the observation of the position of each node on the seabed using an ROV or autonomous underwater vehicle (AUV), where the ROV or AUV may be used to collect nodes from the seabed, and the inclusion in each node of an active positioning system which is configured to transport each node to a predetermined position on the seabed, using e.g. a GPS locator, a processor and a motor.

Figure 6 shows a schematic illustration of how the nodes are collected in a possible embodiment. A vessel 602 at the sea surface 610 includes a collection device 624 which is e.g. a net or any device suitable for deployment in water to gather nodes. The collection device 624 is deployed from the vessel 602. As the vessel 602 travels through the water the collection device 624 used to collect nodes 606 at or near the surface 610. The nodes 606 reach the surface via release or degradation of an anchor, as set out above in relation to Figure 4. The collection device is drawn in to the vessel and the nodes are thereby brought onto the vessel. Other nodes 616 may remain at the seabed 612. The inventors envisage the use of several tens or hundreds of thousands of nodes. It would not be feasible to collect such large numbers of nodes separately by hand, and multiple vessels may be required. It is preferable to release the nodes from the seabed in a controlled manner, so the nodes can be collected in swaths and not all at the same time or randomly. To enable this a programmed timer in a node may be used, or a coded signal to release from the seabed may be sent to the node. It is envisaged that each node will flash an LED light once it resurfaces, to help with the recovery. In an embodiment, a swath of nodes is released over time and one or more vessels collect the resurfaced nodes using a net. The vessels may be local fishing vessels, in which case health and safety requirements may be applied as strictly as they would be on a dedicated collection vessel. Alternatively, one or more dedicated collection vessels are used collect the instruments from the sea surface. In a further embodiment, the deployment vessel, which may be a shooting vessel, is also a collection vessel. Of course it is possible that each task (deployment, shooting and collection) is performed by a separate vessel.

After a node has been collected the measured seismic data is recovered from the node. The data can be recovered in a variety of ways. In one embodiment, a chip containing the data storage 306 is removed from the node and read. Alternatively the measured seismic data is read wirelessly from the data storage using, for example, Bluetooth, optical, or induction methods. Alternatively a data transfer cable is connected to the node and the measured seismic data is removed or read via the cable.

If a node does not release from the seabed, e.g. if the anchor release mechanism malfunctions or the anchor does not degrade to a sufficient degree, several options are available. A single node may be retrieved from the seabed using a hook, a net, an ROV or any other suitable device. If a node is released late and is found by a third party a reward may be offered for the return of the node. In an alternative embodiment the whole node, including the body and the data acquisition components, is biodegradable, so no traces are left on the seabed after a certain period of time. In this case no significant degradation of the node in seawater should occur within the timescale envisioned for seismic data acquisition. The complete degradation of the entire node would most likely mean the loss of recorded data from that node, but the density of the node distribution would likely compensate for this in the recovered seismic data.

Figure 7 shows a high-level flow diagram for a method of deploying a plurality of seismic data acquisition nodes across a seabed. In step 702, each of at least some of the plurality of nodes is separately launched from a sea-surface vessel, through the air in a direction having at least a component that is transverse to the vessel’s direction of motion, using one or more launching devices.

It will be appreciated by the person of skill in the art that various modifications may be made to the above described embodiments without departing from the scope of the present invention.

Claims

1. A method of deploying a plurality of data acquisition nodes across a seabed, comprising:

separately launching each of at least some of the plurality of nodes from a sea-surface vessel, through the air in a direction having at least a component that is transverse to the vessel's direction of motion, using one or more launching devices, wherein each node is launched to land at a predetermined position on the sea-surface; and

before said launching, calculating a trajectory for each node to land at its predetermined position, and adjusting a launch angle and launch power of the one or more launching devices to launch each node using the calculated trajectory.

2. The method of claim 1, wherein at least some of the plurality of nodes are launched simultaneously or in close temporal succession to create a pattern of nodes at the sea-surface in a cross-line direction.

3. The method of claim 1 or claim 2, wherein the predetermined position is between 5 m and 1 km from the vessel, between 25 m and 1 km from the vessel, or between 50 m and 1 km from the vessel.

4. The method of any one of the preceding claims, wherein the trajectory is calculated based at least on a wind speed and a wind direction.

5. The method of any one of claims 1 to 4, further comprising, before launching each node to land at a predetermined position, calculating the predetermined position based on a desired seabed position of each node in a desired acquisition layout.

6. The method of claim 5, wherein the predetermined position is calculated based at least on a measured or estimated water current in a water column.

7. The method of any one of the preceding claims, further comprising automatically controlling an azimuthal angle of launch and a horizon angle of launch to compensate for at least one of movements of the vessel, wind conditions, wave movements and water column flow.

8. The method of any one of the preceding claims, wherein the launch direction has a vertical component.

9. The method of any one of the preceding claims, wherein the motion of each node through the air is ballistic.

10. The method of any one of the preceding claims, further comprising individually registering each of the plurality of nodes before launch.

11. The method of any one of the preceding claims, wherein all or part of the node is configured to degrade over time in seawater.

12. The method of any one of the preceding claims, wherein the node includes one or more of a geophone, a hydrophone, a seismometer, an accelerometer, a tiltmeter, a chemical sensor, an absolute or differential pressure gauge, and a temperature sensor.

13. The method of any one of the preceding claims, wherein each of the plurality of nodes includes a body and a releasable anchor.

14. The method of claim 13, wherein the releasable anchor is degradable in seawater.

15. The method of claim 13 or 14, wherein the body is positively buoyant.

16. The method of any one of claims 13 to 15, wherein the releasable anchor comprises a seawater-based battery configured to supply electrical power to one or more electrical devices included in the body.

17. The method of any one of the preceding claims, wherein the data acquisition nodes are seismic data acquisition nodes.

18. The method of any one of the preceding claims, wherein the one or more launching devices are air-powered launching devices or electrically powered launching devices.

07 05 20

19. The method of claim 18, wherein the one or more launching devices are air-powered launching devices powered using pressurised air, wherein the pressurised air is obtained from a reservoir which is configured to also provide pressurised air for the operation of a seismic shooting air gun of the vessel.

20. The method of claim 18, wherein the one or more launching devices are electrically powered launching devices powered using a generator, wherein the generator is configured to also provide electrical power for a seismic vibrator of the vessel.

21. A vessel for deploying a plurality of data acquisition nodes across a seabed, the vessel comprising

one or more launching devices configured to launch, using a launch angle and launch power, at least some of the plurality of nodes through the air in a direction having at least a component that is transverse to the vessel's direction of motion, wherein the launch angle and launch power of the one or more launching devices is adjusted to launch each node using a calculated trajectory,

wherein each node is launched using the calculated trajectory to land at a predetermined position on the sea-surface.

22. The vessel of claim 21, wherein the data acquisition nodes are seismic data acquisition nodes.

23. The vessel of claim 21 or 22, further comprising:

a net for collecting nodes at or near the surface of the sea following data acquisition by the nodes; and/or

an ROV for collecting nodes following data acquisition by the nodes.

24. The vessel of any one of claims 21 to 23, wherein the one or more launching devices are air-powered or electrically powered.

25. The vessel of claim 24, wherein the one or more launching devices are air-powered, the vessel further comprising an air gun for seismic shooting and a reservoir

of pressurised air, wherein the reservoir of pressurised air is configured to selectively provide pressurised air to the one or more launching devices and the air gun.

26. The vessel of claim 24, wherein the one or more launching devices are electrically powered, the vessel further comprising a seismic vibrator for emitting seismic signals and a generator, wherein the generator is configured to selectively provide electrical power to the one or more launching devices and the seismic vibrator.

27. The vessel of any one of claims 21 to 26, wherein the launch direction has a vertical component.

28. The vessel of any one of claims 21 to 27, wherein the one or more launching devices are configured to launch each of the plurality of nodes ballistically.

29. A method of acquiring data, comprising:

using the method of any one of claims 1 to 20 to deploy a plurality of data acquisition nodes across a seabed; and

acquiring data using the plurality of data acquisition nodes.

30. The method of claim 29, wherein the data acquisition nodes are seismic data acquisition nodes and the acquired data is seismic data.