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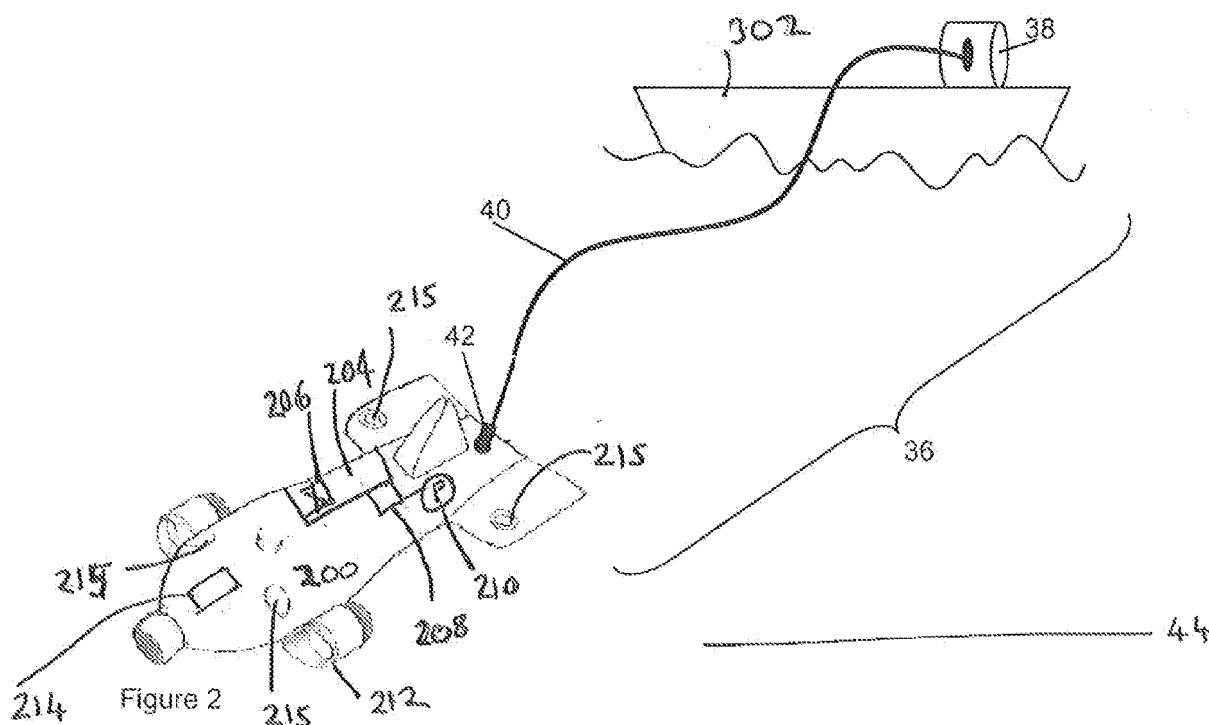
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(54) **Buoyancy control in an unmanned underwater vehicle**

(57) An autonomous underwater vehicle is described comprising a body portion, a processing device and a propulsion device mounted within the body portion, and sensor mounted on or within in the body portion. The autonomous underwater vehicle includes buoyancy control means configured to enable adjustment of the position of the vehicle during operation. The buoyancy control

is achieved through adjustment of the mass or volume of the vehicle in response to signals from the sensor.

A method of operating an unmanned underwater vehicle (UUV) is also described. The vehicle with buoyancy control means enhances the functionality of the vehicle and movement during operation both in littoral waters and also in open sea conditions.



**Description**

**[0001]** The present invention relates to unmanned underwater vehicles, in particular to a vehicle able to be operated in either a mobile or a static mode and able to alter vehicle position and vehicle buoyancy during an operation.

**[0002]** Remotely operated vehicles (ROVs) are known in the maritime field. One type (ROVI) can be considered to be a free-swimming, unmanned, underwater vehicle (UUV) 10 as shown in Figure 1a. The UUV 100 represents stand alone apparatus, configured to sense features in a local environment 1 and make assessments and decisions based on the output from in built or deployable sensors (not shown) in combination with a pre-determined mission received prior to launch of the vehicle 100.

**[0003]** Another type of remotely operated vehicle or device is illustrated in Figure 1b in a tethered system. A waterborne piece of equipment 2 (ROVII) is launched from a base station generally a vessel (parent vehicle 6) located at a surface of the sea (representing the operational field) or as shown here, a garage 8 located on the sea bed 10. The ROVII is shown permanently tethered by a cable 4 to the base station. Power and data are transferred between the ROVII 2 and the base station along cable 4 to enable permanent communication therebetween. The garage 8 is provided with power and a data transfer facility via a heavy cable 12 sourced from either a parent vehicle or from a mainland facility (not shown).

**[0004]** Another type of remotely operated vehicle (ROVIII) or device is illustrated in Figure 1c. ROVIII 14 comprises one or more guide wires 20, e.g. a copper wire or, more recently, fibre optic cables. The guide wires 20 play out as the ROVIII 14 is deployed. The guide wires 20 serve to enable two way, data only, communication between an operator (not shown) and the ROVIII 14.

**[0005]** The invention will be described in use with a ROVI but can be envisaged to be incorporated into either a system with ROVII or with ROVIII.

**[0006]** The capability of the UUV or ROV depends on the ability of the vehicle to move freely around the local environment and pick up details of the surroundings from sensors. It is therefore desirable to be able to increase the range and type of movement that can be executed by the vehicle in order to gather as much information as possible.

**[0007]** According to a first aspect, the present invention provides an autonomous unmanned underwater vehicle comprising:

a body portion,

a processing device mounted within the body portion;

a propulsion device mounted on or within the body

portion;

a sensor mounted on or within in the body portion; and

buoyancy control means configured to enable adjustment of the position of the vehicle during operation.

**[0008]** By providing an autonomous unmanned underwater vehicle with a buoyancy control feature that can be used during operation of the vehicle, the functionality of the vehicle is enhanced. The autonomous vehicle can be used in a number of positions and can respond to data and input from sensors and collected by the vehicle. The vehicle becomes reactive to its environment and provides an improvement in vehicle handling and in operational ability. The vehicle may be moved in response to a change in tidal flow or water depth, for example by moving to deeper water as the tide recedes at the vehicle's location.

**[0009]** In an embodiment the buoyancy control means is configured to enable the vehicle to move between a first and a second underwater depth position in response to an input from the group of; an external sensor, a sensor mounted on or within the vehicle, a mission plan or plan parameter and operator input.

**[0010]** The position of the autonomous underwater vehicle can be monitored and altered by an operator located at a base station or in response to a mission plan previously communicated to the UUV. The operator is able to monitor and interrogate the vehicle and, subsequently if desired, transmit alternative or more detailed instructions to the vehicle to change a mission strategy even during the mission itself.

**[0011]** The sensors may comprise communication means for transferring data to the processing device. In an embodiment the communication means comprises one of the group of acoustic, radio frequency communications including satellite communication, optical, electronic an optical fibre communication means.

**[0012]** In an embodiment the propulsion means is configured to enable adjustment of one of the group of translational, lateral, vertical, and rotational position of the vehicle. The adjustment in the rotational position may be rotation in one of the pitch plane and the yaw plane, allowing full adjustment of the vehicle's position. In an alternative embodiment the propulsion means is configured to enable adjustment of position of the vehicle in response to an input from the group of; an external sensor, a sensor mounted on or within the vehicle, a mission plan or plan parameter and operator input. The propulsion means may be coupled to the buoyancy control means, and may be coupled to drive means arranged to create vertical thrust. The sensors and sensor connections to the propulsion means provide versatility and full range of movement of the UUV.

**[0013]** Alternatively, the buoyancy control means is

coupled to means for reducing suction force between the vehicle and the seabed.

**[0014]** In an embodiment the buoyancy control means comprises means for altering the mass or volume of a part of the vehicle, and the buoyancy control means may comprise a piston in communication with a hollow part of the vehicle. The buoyancy control means may comprise a vent arranged to operate an opening part of the vehicle to take water into the vehicle in response to an input from one of the group of; an external sensor, a sensor mounted on or within the vehicle and processing means. The buoyancy control means may comprise a pump device to pump and expel onboard water from a part of the vehicle.

**[0015]** The vehicle buoyancy can be altered by use of mechanical means such as by pumping with a pump. This provides for a simple adjustment with a part that can be serviced and supplied in a standard manner from well known stocks or well established supply lines.

**[0016]** In an embodiment the processing device can be arranged in communication with a base station, in the embodiment the processing device is configured to activate the propulsion means and the buoyancy control means in response to an instruction from a base station, in response to a detected behaviour of the vehicle, or both a detected behaviour and an instruction from a base station.

**[0017]** According to a second aspect, the present invention provides a method of operation of an unmanned underwater vehicle (UUV) comprising the steps of:

determining a mode of operation of the vehicle, dependent upon mission criteria;

supplying instructions to the vehicle;

launching the vehicle;

collecting data from sensors located on board the vehicle;

collecting data from external sensors; and

adjusting the position of the vehicle during operation in response to an input from the sensors.

adjusting the buoyancy of the vehicle in response to an input from the sensors.

**[0018]** In an embodiment the method of operation may include the step of deploying one or more external sensors from the vehicle. In an embodiment the method includes the step of adjusting the buoyancy of the vehicle in response to an input from the sensors.

**[0019]** A UUV that is able to move and relocate to a different position on the seabed improves the functionality and operational ability of the vehicle and by allowing the UUV to land and dock on the seabed energy is not

expended in maintaining the vehicle's position in the open water and within a tidal flow.

**[0020]** The present invention is now described in more detail, with reference to the accompanying drawings, in which:

Figure 1 illustrates three different types of remotely operated vehicles;

Figure 2 illustrates a first embodiment of an UUV with buoyancy control;

Figure 3a illustrates a second embodiment of an UUV with buoyancy control of the present invention;

Figure 3b illustrates the buoyancy control of Figure 3a in further detail;

Figure 4 illustrates a data carrier in more detail;

Figure 5 illustrates a schematic arrangement of a UUV and sensors of the present invention;

Figure 6 illustrates a communications system in use with the autonomous unmanned underwater vehicle of Figures 2 and 3;

Figure 7a illustrates a first alternative arrangement of a communication system in use with the autonomous unmanned underwater system of Figure 5; and

Figure 7b illustrates a second alternative arrangement of a communication system in use with the autonomous unmanned underwater system of Figure 5.

Figure 1a illustrates a ROV operating as a conventional UUV 100, the vehicle's autonomy allows it to achieve a freedom of movement to enable comprehensive use of its sophisticated design.

**[0021]** In circumstances whereby it is beneficial to operate the UUV 14 in a supervised mode, such a mode can be achieved as illustrated in Figures 1 b and 1c whereby data collected by the UUV may be monitored by and/or passed back to a base station or operator (not shown) for further analysis and/or assessment. Consequently, decision making can be undertaken by the operator and high level mission changes can be considered. Instructions to implement these changes can then be returned to the vehicle for exploitation.

**[0022]** Figures 2 and 3 each represent an unmanned underwater vehicle (UUV) 200, 300 with buoyancy control, each configured to pass through a body of water and collect data from the underwater environment via one or more onboard or deployable sensing devices (not shown).

**[0023]** Each UUV 200, 300 is able to operate in a fully

autonomous mode in isolation or (as illustrated) each UUV 200, 300 may be tethered to a respective base station (e.g. a parent vehicle 302, 502 located at a surface of the body of water) or to another UUV via a data transfer cable mechanism 20 as described in co-pending application GB0916062.3.

**[0024]** In a first embodiment shown in Figure 2 the buoyancy control means comprises a floodable tank 204 located within the vehicle 200. Fluid communication established between the tank 204 and a valve or vent 206, allows ingress and egress of water, in particular sea water, therebetween. The valve 206 is configured to open to admit water into the tank 204 and to open to allow water to be expelled from the tank 204. The buoyancy control means also comprises a means to expel water from the tank 204 comprising a store 208 of pressurised gas or a pump P and pump control. The water expulsion means such as the pump P, or the reservoir of compressed gas is configured, when activated, to pump or expand gas into the floodable tank, which on expansion causes displacement of the water therein. The pump P can be activated upon receipt of suitable instruction from an operator, the vehicle mission plan or vehicle sensors. The water pump P and the store 208 of pressurised gas allow the flow of water to be reversed and the tank 204 can be emptied.

**[0025]** The valve and tank arrangement illustrated in Figure 2 creates a constant volume portion of the vehicle 200 having a variable mass, thus altering the buoyancy of the vehicle 200. The vehicle 200 becomes heavier and less buoyant, and can sink towards the seabed with floodable tank 204 full of water. In contrast, the vehicle 200 becomes more buoyant with air or other pressurised gas released from the store 208 into the tank 204. In this scenario the vehicle has less mass and weight in the water and will rise towards the surface.

**[0026]** In a second embodiment shown in Figure 3a and Figure 3b the buoyancy control means comprises a compressible cylinder 302, holding a constant mass and providing a variable volume. A fluidic operated cylinder, such as a pneumatic or a hydraulic cylinder is provided.

**[0027]** The valve and tank arrangement illustrated in Figure 3b creates a portion 304 of the vehicle 300 with constant mass having a variable volume, thus changing the density of that region and altering the buoyancy of the vehicle 300. With the cylinder 302 in compression the displacement caused by the constant mass portion 304 is less, thus the vehicle 300 becomes less buoyant, and can sink towards the seabed. In contrast, the vehicle 300 becomes more buoyant with the cylinder 302 in expansion such that the same constant mass portion 304 can be considered to have displaced a greater volume within the water. In this scenario the vehicle 300 has less effective weight in the water, is more buoyant and will rise towards the surface of the sea. The expansion and contraction or compression of the cylinder that would occur in operation is indicated by the double-headed arrow A in Figure 3b.

**[0028]** In operation, the valve 206 in combination with the pump P and store 208 arrangement of Figure 2, or the cylinder 302 can be used to control buoyancy of the vehicle 200, 300 and enable an adjustment of the underwater depth position.

**[0029]** The UUV 200, 300 additionally comprises propulsion means 212, 312 providing fore and aft motion and manoeuvring in the yaw plane for driving and directing the UUV, a sensor 214, 314 mounted on or within in the body portion and one or more vertical thrust means 215, 315 located at the outer surface of the vehicle and capable of thrusting a jet of water in a direction away from the vehicle either towards the seabed or towards the surface. The force equal and opposite to the thrust force of water jetted out from the thrust means 215, 315 provides lift and upward force to raise the vehicle a distance towards the surface or push the vehicle a distance towards the seabed. In particular, the vertical thrust means 215, 315 are configured to provide sufficient lift and upward force to move a vehicle 200, 300 upwards should the vehicle become submerged or stuck on the floor of the seabed. In such circumstances the buoyancy control means may be insufficient to provide the lift necessary to adjust the underwater depth position of the vehicle and to raise the vehicle. The propulsion means 212, 312 and thrust means 215, 315 jetting water towards or away from the seabed are arranged in communication with the buoyancy control means and are responsive to the buoyancy control providing adjustment of the vertical depth position and orientation. In an embodiment the UUV 200, 300 comprises reducing the suction force between the vehicle and the seabed to further aid propulsion and lift of the vehicle in a situation where the vehicle may have become trapped or stuck to material on the seabed.

**[0030]** In the vehicle shown in Figures 2, 3a and 3b, sensors 214, 314 are located on the upper, middle, front (fore) portion of the vehicle. Sensors may be located on other parts of the vehicle, or have been deployed from the vehicle, as appropriate. The sensors 214, 314 are acoustic sensors but other types of sensors may be used and various numbers of sensors may be used on each vehicle in a group of vehicles if necessary. The sensors such as the acoustic sensors described detect the height above the seabed or from the seafloor other sensors such as optical sensors could be used for this height measurement. The depth below the surface can also be monitored by sensors such as optical means, pressure sensitive means and acoustic sensors. Different operational and external conditions may exist at different depths and positions and accurate sensing techniques are required.

**[0031]** Preferably a number of sensors are laid down or deployed by the vehicle, for example around 15 to 40 sensors, to collect information and data on the surrounding environment and operational or functional details of the vehicle 200, 300 itself. Fewer sensors may be provided in a situation where resource and/or space is limited, for example. The sensors may be deployed and linked via a cable such as a fibre optic cable such that

communication is provided between the sensors and the vehicle and between the sensors themselves. Figure 4 illustrates a vehicle 400 configured to deploy a robust cable 40 comprising sensors 415 to 417. The sensors 415, 416, 417 are arranged to rest on the seabed. The cable 40 is preferably a fibre optic cable having a diameter in the range of 0.1 to 5 mm, preferably approximately 0.25 mm. The diameter of the spool assembly 42 used to dispense the cable 40 is matched to the cable 40, so that the spool assembly 42 can accommodate the bent diameter of the cable 40. The spool assembly 42 is located at the rear of the vehicle 400 and arranged so as to cause minimum disruption to the trim of the vehicle 400. The length of cable 40 is preferably up to approximately 1 km but may readily exceed this and be in a range up to 10 or 20 km. Thus sensors can be located over a significant area of the seabed and a significant body of water and target region can be monitored. The sensors are set out in a physically connected relationship and communication, for example with a TCP/IP link, is established between the sensors along the cable and with a base station as appropriate.

**[0032]** A proximal portion of the cable 40 is permanently connected to the spool assembly 42 whilst a distal end of the cable 40 comprises a sensor 417. In an alternative embodiment (not shown) a distal end of the cable 40 comprises an end cap portion. In a further alternative the cable 40 may have been deployed and separated from a deploying vehicle at an earlier time leaving the sensors to be stand alone sensors or connected as a group. In that instance a plug and socket arrangement provide for release of a sensor from the cable 40 to rest on the seabed 44. A plug is provided at a releasable sensor and a socket provided at a portion of the cable 40 is configured to receive the plug in a releasable manner.

**[0033]** In an alternative, the sensors may be deployed by a manned vehicle individually or by an airborne asset such that sensors external to the UUV are stand alone. The sensor may be provided in operable communication with the UUV by acoustic methods underwater or may provide surface sensing by radio communications above the surface of the water. The limits of individual sensors will be determined by their type, for example surface sensors will be limited to a line of sight communication, around 14km for an antenna at 1 m above the surface of the water. Communications to the satellite will be limited to the data rate accepted and detected by the satellite.

**[0034]** The sensors described above mounted on the vehicle or deployed from a vehicle are arranged in communication with a processing device. The sensor arrangement will be described with reference to Figure 4 and Figures 5a and 5b. A first sensor 51 and a second sensor 52 are arranged in communication with a processing device (represented as 420 and 520 in Figures 4 and 5) and a buoyancy control means 512 such that the position of the vehicle 400 in depth and the orientation of the vehicle may be adjusted in response to input received from the sensors 51, 52. In one embodiment illustrated

in Figure 5a the sensors are arranged in direct communication with the processing device.

**[0035]** In addition the processing device may be capable of receiving input from other sources or sensors external to the system and suitable for use when assessing the vehicle and environment conditions for adjusting the position of the vehicle. In response, for example, to a threat or an input signal or information on a target under surveillance. Other types of sensor include surface mounted sensors such as buoys having acoustic or optical communication means such as by IR (from an infra-red optical source) or a blue/green laser with output in the visible range. Communication between sensors and from the vehicle to the sensors can be by optical, acoustic, IR signals and other known means as appropriate.

**[0036]** A communication and command control system used with the embodiment described above is illustrated in Figure 6, with like numbers representing like features in the Figures, including communication means, satellite 600, and in Figure 7a, a gateway buoy 650, both provided in communication with a base station 700. The sensors 614a, 614b, 614c, 614d, 614e, 614f are mounted on a series of UUVs located, for example within a narrow stretch of water or at the mouth of a harbour. Additional sensors (not shown) may be located on or within the UUVs. The sensors may monitor acoustic signatures, pressure waves from passing ships and vehicles, magnetic details and signatures, chemical traces such as hydrocarbons in the grease and oil from passing ships, variations in electric fields, CBRN signatures and signals, or combinations of two or more of these characteristics. Illustrated in Figure 6 is an arrangement with each sensor is arranged in communication with its' immediate neighbours and with those sensors located across the water to be monitored. For example, sensor 614b is arranged in communication with sensors 614a and sensor 614c and with sensor 614e opposite. The communication may be by any one of IR, optical or acoustic means or by line of sight communication. In this scenario the UUVs act as a monitoring 'web' and can be arranged to detect and respond to traffic and movement within the stretch of water they occupy. The communications system can be arranged such that all the sensors are in communication with each other, as represented by the dashed lines in the Figures. The embodiment of Figure 6 and Figure 7a illustrate an ad hoc network system. Other network arrangements may be used, for example as shown in Figure 7b, with surface vessels 6, static and moving objects 720 such as rocks or fish, and airborne assets or sensors 750 or comprising an arrangement of full connectivity or a sub set of the connectivity shown and described herein.

**[0037]** An ad hoc network is a known operational arrangement for a network however, this is resource intensive and can be complex requiring significant processing power. In addition physical and operational parameters limit the communication possible between sensors and this needs to be taken into account when setting out the

monitoring system. Such physical operational limits include the limit of the communication bandwidths used, for example the satellite data link or, for acoustic and sonar signals, the bandwidth limitations dictated by the operating depth below the surface of the water as communication signals pass through bands, or thermoclines, of different temperature, the temperature change is marked and can be significant at around depths between 100m and 200m, limiting communication while the vehicle is at or around these depths.

**[0038]** In addition the sensors 614a, 614b, 614c, 614d, 614e and 614f can be arranged to share information and signals to build a model and picture of the monitored region for assessment and processing back at a command or base station implemented using an Ethernet architecture, whereby the supervised link or "command station" becomes an extra node on a managed network (represented by the UUV and sensors) over which the acquired data is shared. In so doing, the command station is able to monitor/eavesdrop/gain access to data that is moving around the network. The data may be logged additionally at the UUV and, in addition, some or all of the data can be transmitted to the command station so that the data is in two places, substantially simultaneously. An operator then has the ability to influence an activity of the vehicle 200, 300 by submitting an instructing signal down the communications channel such as a satellite, or via a data cable using standard Ethernet and transmission control protocol (TCP) processes. Alternatively, data and signals stored in a stand alone sensor and may be saved and collected by a 'drive by' vehicle (either manned or a UUV) at a designated time or may be communicated to the network or to a base station using a communication channel at a predetermined time.

**[0039]** In use, the sensor 214, 314, 614 detects and senses features in a local environment and with signals from an operator or with a predetermined mission plan received prior to launch of the vehicle communicates with the processing device 520 and with the propulsion device 512. The buoyancy control means responds to a command to raise or lower the depth of the UUV by expanding or compressing the cylinder 302 or flooding or emptying the tank 204 as appropriate. In addition the propulsion means 512 is activated to propel the UUV in a particular direction as required. In this way the UUV is able to operate such that sometimes it is mobile, moving by the action of the propulsion means 512, and sometimes in a stationary or static mode of operation.

**[0040]** The processing device is responsive to the sensors 214, 314, 614 and is configured to activate the propulsion means and the buoyancy control means in response to instructions received also from a controller or commander controlled base station from which the vehicle is launched. The operator may be a human operator or may be a computer, depending on the type of analysis and/or decision making involved. The UUV could also be launched from any other type of vehicle.

**[0041]** The sensor system would complement the op-

eration and mobility of the UUV with the buoyancy control means.

**[0042]** In addition to the preferred embodiments described above alternatives and modifications to the buoyancy control means may be envisaged without departing from the scope of the present invention. For example, the cylinder creating a variable volume portion with constant mass could comprise any form of hydraulics, pneumatics or piston, or could comprise a piston driven by drive means or from a battery run from an energy extraction means such as from a trickle charge generated by current flowing over the seabed. Operation by electric motor may include gears and a drive train. Other ways of controlling and expanding and compressing a cylinder could be used, such as an expanding screw mechanism, or worm drive. The cylinder could comprise a pressurised cylinder. It is envisaged that the vehicle with buoyancy control means would enhance the function and movement of a maritime vehicle operating in littoral waters and also in open sea conditions.

## Claims

1. An autonomous underwater vehicle comprising:
  - a body portion;
  - a processing device mounted within the body portion;
  - a propulsion device mounted on or within the body portion;
  - a sensor mounted on or within in the body portion; and
  - buoyancy control means configured to enable adjustment of the position of the vehicle during operation.
2. A vehicle according to Claim 1, wherein the buoyancy control means is configured to enable the vehicle to move between a first and a second underwater depth position in response to an input from the group of; an external sensor, a sensor mounted on or within the vehicle, a mission plan or plan parameter and operator input.
3. A vehicle according to Claim 1 or Claim 2, wherein the sensors comprise communication means for transferring data to the processing device.
4. A vehicle according to Claim 3, wherein the communication means comprises one of the group of acoustic, radio frequency communications including satellite communication, optical, electronic and optical fibre communication means.
5. A vehicle according to any preceding claim, wherein the propulsion means is configured to enable adjustment of one of the group of translational, lateral, ver-

tical and rotational, in one of the pitch plane and the yaw plane, position of the vehicle.

6. A vehicle according to Claim 5, wherein the propulsion means is configured to enable adjustment of position of the vehicle in response to an input from the group of; an external sensor, a sensor mounted on or within the vehicle, a mission plan or plan parameter and operator input. 5
7. A vehicle according to any preceding claim, wherein the propulsion means is coupled to the buoyancy control means. 10
8. A vehicle according to any preceding claim, wherein the buoyancy control means is coupled to drive means arranged to create vertical thrust. 15
9. A vehicle according to any preceding claim, wherein the buoyancy control means is coupled to means for reducing suction force between the vehicle and the seabed. 20
10. A vehicle according to any preceding claim, wherein the buoyancy control means comprises means for altering the mass or volume of a part of the vehicle, preferably . 25
11. A vehicle according to Claim 10, wherein the buoyancy control means comprises a piston in communication with a hollow part of the vehicle. 30
12. A vehicle according to Claim 10 or Claim 11, wherein the buoyancy control means comprises a vent arranged to operate an opening part of the vehicle to take water into the vehicle in response to an input from one of the group of an external sensor, a sensor mounted on or within the vehicle and processing means. 35
13. A vehicle according to any one of Claim 10, Claim 11 or Claim 12, further comprising a pump device to pump and expel onboard water from a part of the vehicle. 40
14. A vehicle according to any preceding claim wherein, the processing device is configured to activate the propulsion means and the buoyancy control means in response to an instruction from a base station and/or in response to a detected behaviour of the vehicle. 45
15. A method of operating an unmanned underwater vehicle (UUV) comprising the steps of: 50

determining a mode of operation of the vehicle, dependent upon mission criteria;  
supplying instructions to the vehicle;

launching the vehicle;  
collecting data from sensors located on board the vehicle;  
collecting data from external sensors; and  
adjusting the position of the vehicle during operation in response to an input from the sensors.

16. A method according to Claim 15, further comprising the step of:

adjusting the buoyancy of the vehicle in response to an input from the sensors.

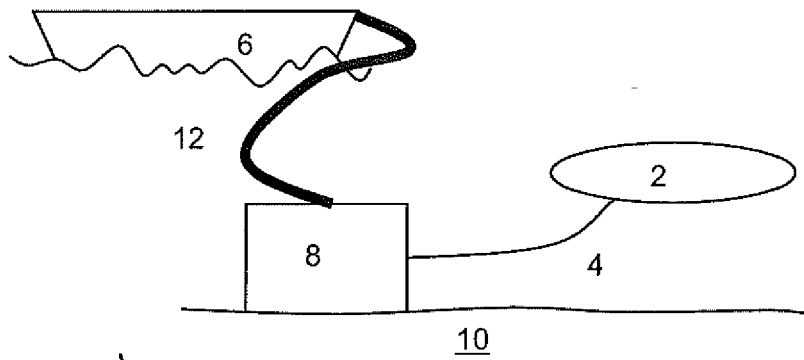


Figure 1b

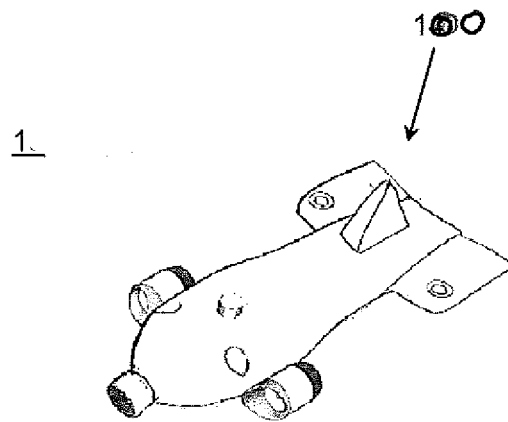


Figure 1a

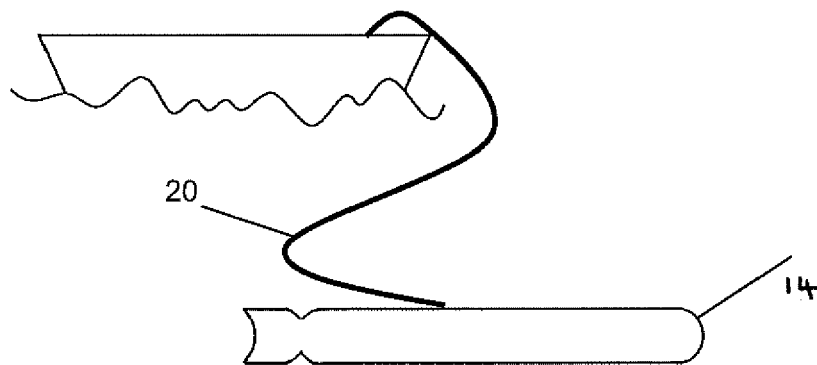
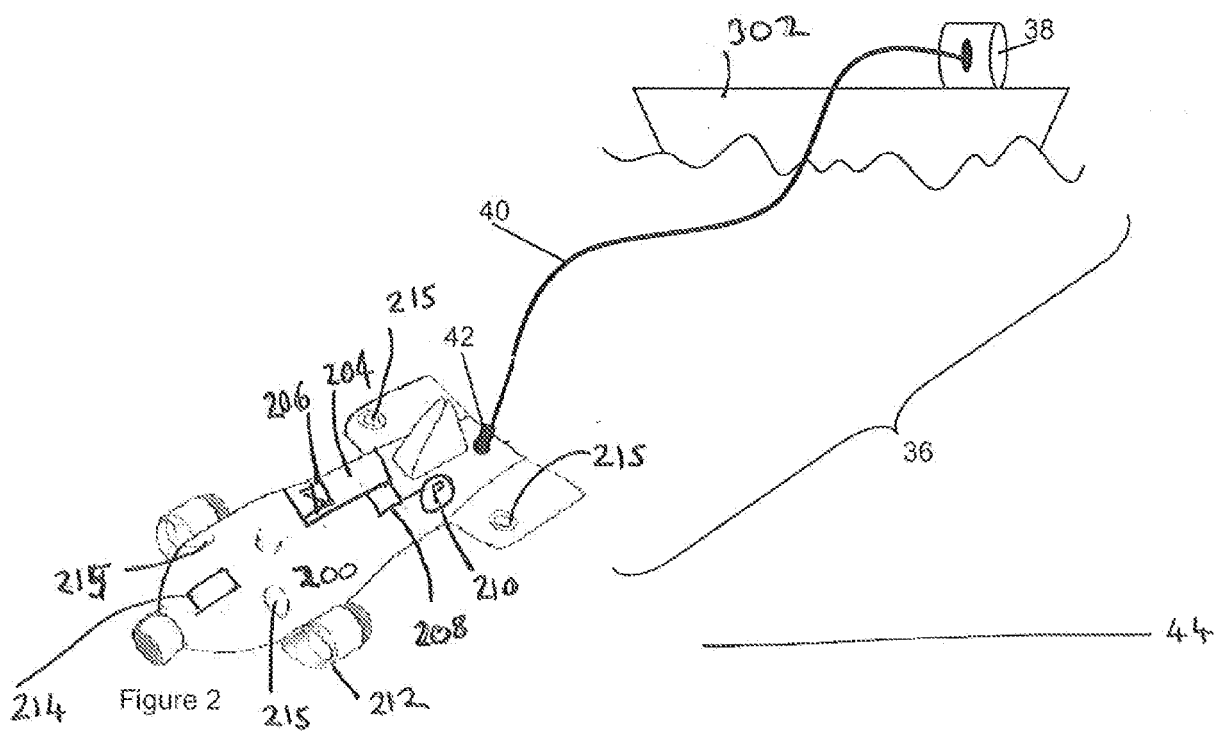


Figure 1c



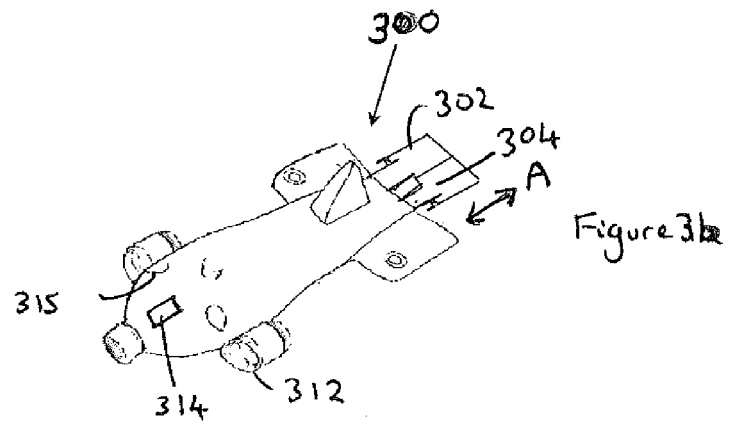
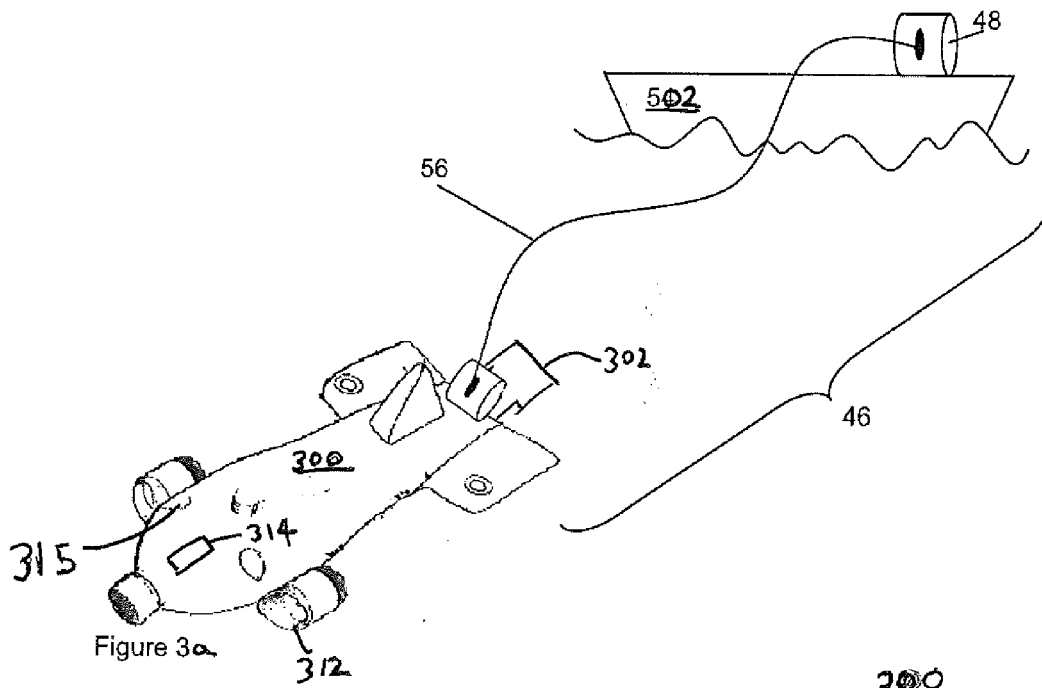
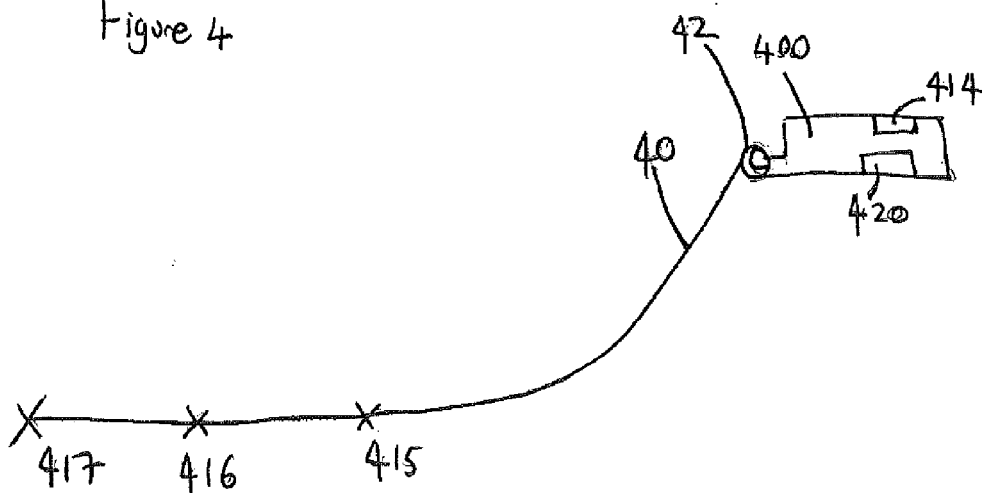


Figure 4



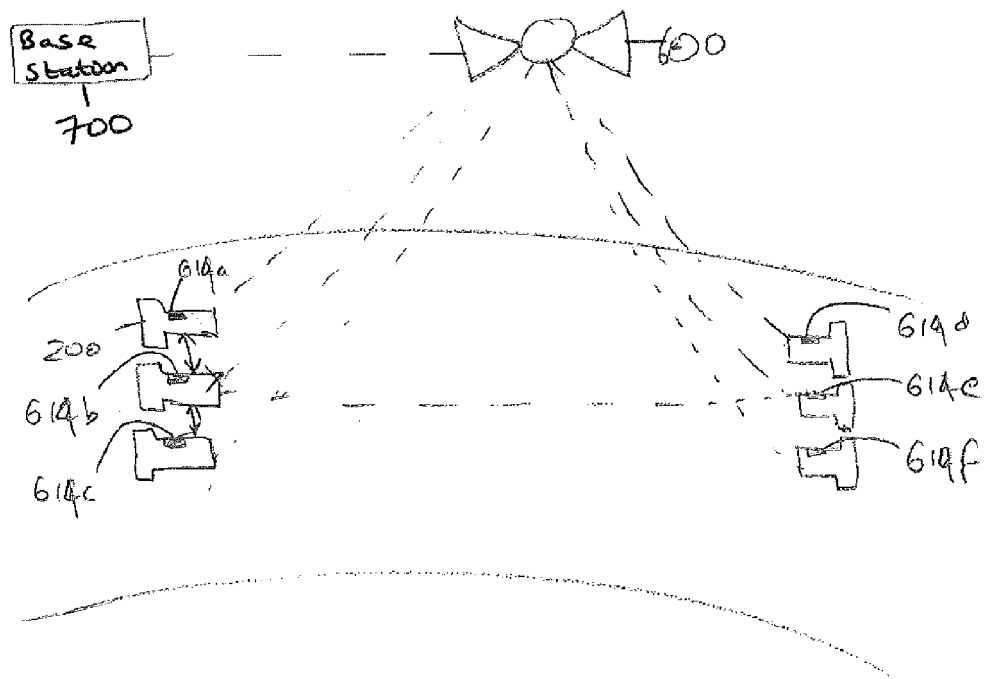
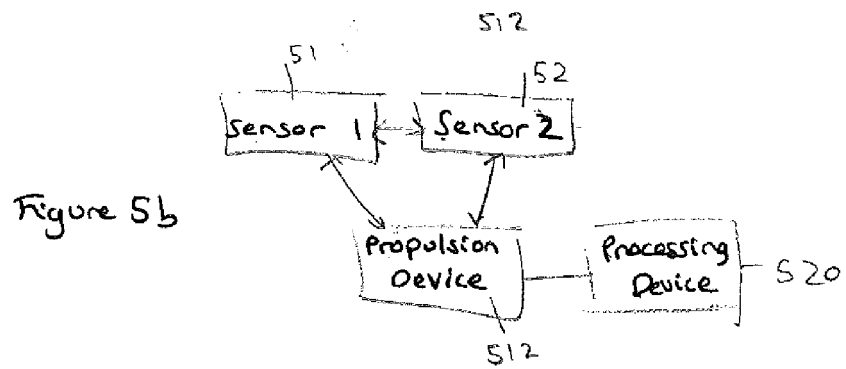
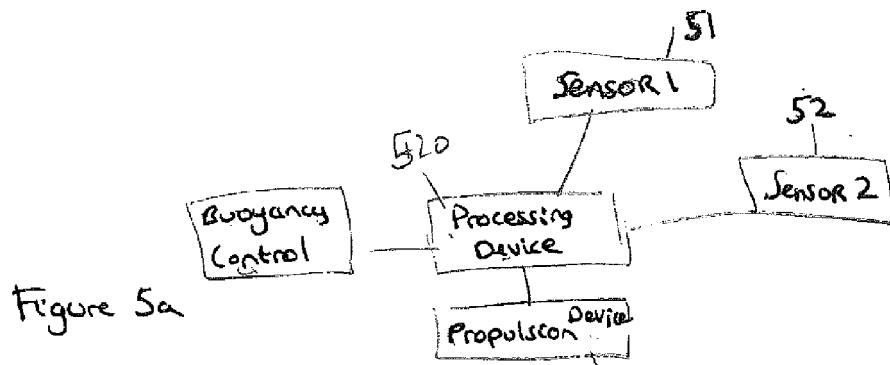


Figure 6

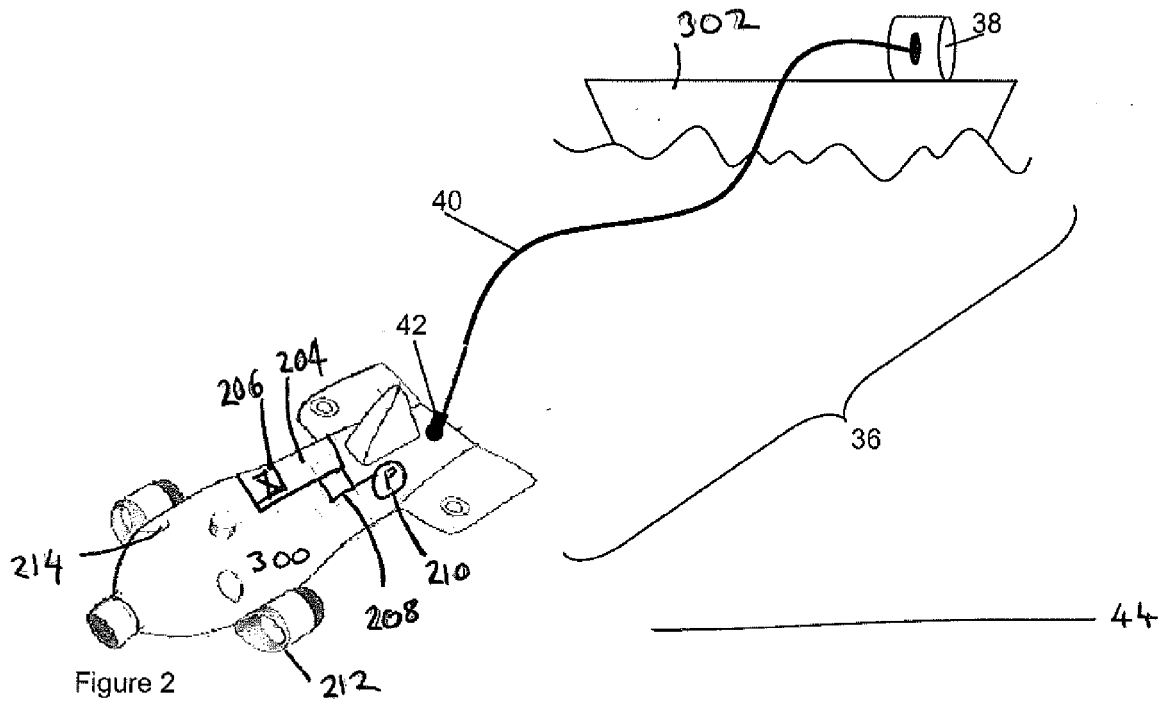
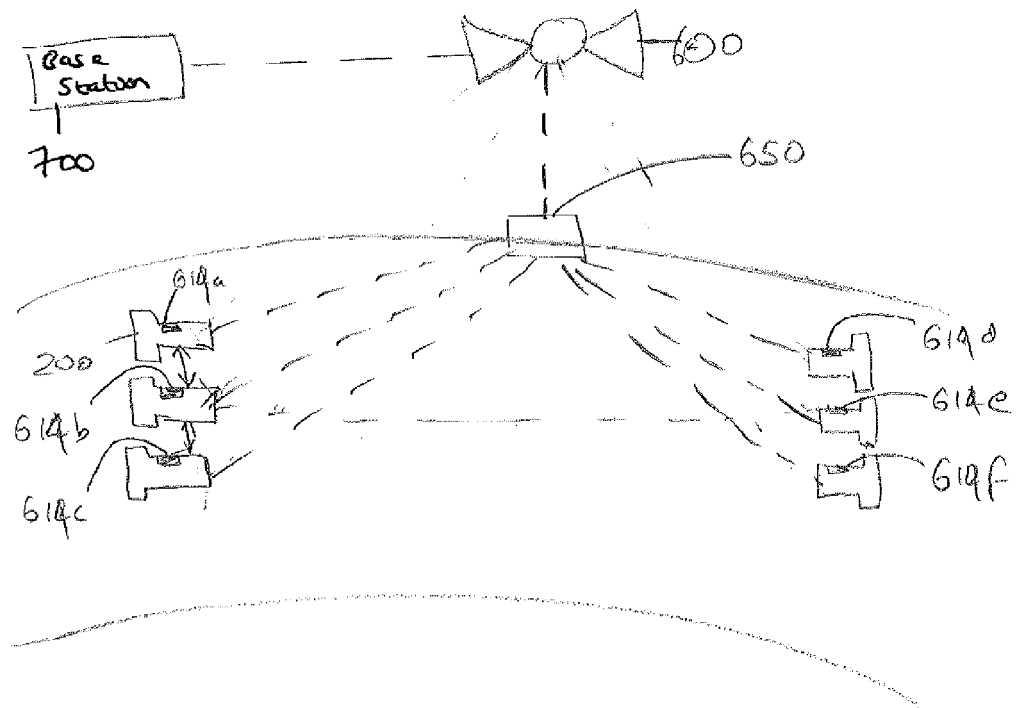


Figure 7a



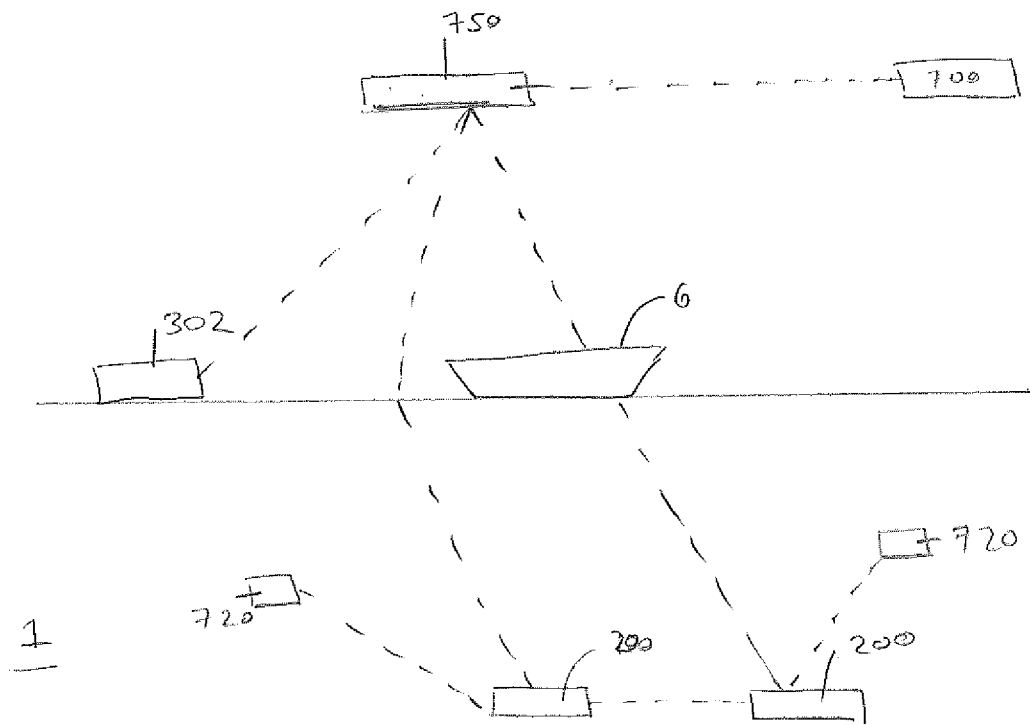


Figure 7b



## EUROPEAN SEARCH REPORT

Application Number  
EP 10 27 5079

| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                         |                                                     |                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|-------------------------------------------------|
| Category                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Citation of document with indication, where appropriate, of relevant passages                                                                                                                                                                                                                                                                                                           | Relevant to claim                                   | CLASSIFICATION OF THE APPLICATION (IPC)         |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | NEWMAN JAMES B ET AL: "TIBURON: DEVELOPMENT OF AN ROV FOR OCEAN SCIENCE RESEARCH", OCEANS '94. 'OCEANS ENGINEERING FOR TODAY'S TECHNOLOGY AND TOMORROW'S PRESERVATION.' PROCEEDINGS BREST, FRANCE 13-16 SEPT. 1994, NEW YORK, NY, USA, IEEE, vol. 2, 13 September 1994 (1994-09-13), pages 483-488, XP007916853, ISBN: 978-0-7803-2056-7                                                | 1-10,14,15                                          | INV.<br>B63G8/22<br>B63C11/42                   |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | * page 483 - page 487; figures 1,2; table 1 *                                                                                                                                                                                                                                                                                                                                           | 12,13,16                                            |                                                 |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -----<br>US 2009/178603 A1 (IMLACH JOSEPH [US] ET AL) 16 July 2009 (2009-07-16)                                                                                                                                                                                                                                                                                                         | 1-3,5,6,9-11                                        |                                                 |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | * paragraphs [0005], [0030] - [0044]; figures 5,6 *                                                                                                                                                                                                                                                                                                                                     | 15                                                  |                                                 |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -----<br>KIRKWOOD W J ET AL: "Active variable buoyancy control system for MBARI's ROV", OCEANS '94. 'OCEANS ENGINEERING FOR TODAY'S TECHNOLOGY AND TOMORROW'S PRESERVATION.' PROCEEDINGS BREST, FRANCE 13-16 SEPT. 1994, NEW YORK, NY, USA, IEEE, vol. 2, 13 September 1994 (1994-09-13), pages II/471-II/476, XP010125044, DOI: DOI:10.1109/OCEANS.1994.364090 ISBN: 978-0-7803-2056-7 | 12,13,16                                            |                                                 |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | * page 471 - page 475; figures 1,2 *                                                                                                                                                                                                                                                                                                                                                    | 1,15                                                |                                                 |
| The present search report has been drawn up for all claims                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                         |                                                     | TECHNICAL FIELDS SEARCHED (IPC)<br>B63G<br>B63C |
| Place of search<br>The Hague                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                         | Date of completion of the search<br>25 January 2011 | Examiner<br>Martínez, Felipe                    |
| <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone<br/>Y : particularly relevant if combined with another document of the same category<br/>A : technological background<br/>O : non-written disclosure<br/>P : intermediate document</p> <p>T : theory or principle underlying the invention<br/>E : earlier patent document, but published on, or after the filing date<br/>D : document cited in the application<br/>L : document cited for other reasons<br/>.....<br/>&amp; : member of the same patent family, corresponding document</p> |                                                                                                                                                                                                                                                                                                                                                                                         |                                                     |                                                 |

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**REFERENCES CITED IN THE DESCRIPTION**

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