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(58) Field of Search:
INT CL **E21B, G01M, G01N**
Other: **WPI, EPODOC**

(54) Title of the Invention: **Underwater detection apparatus**
Abstract Title: **Underwater acoustic bubble detection**

(57) An underwater detection apparatus for detecting a presence of one or more bubbles 270 within an aquatic environment includes a first structure 210 including a lower peripheral edge 220 defining an area operable to collect the bubbles, a second structure 230 for spatially concentrating the bubbles received within the defined area into a detection region 240, and a detection arrangement for detecting the bubbles in the detection region and generating an output signal indicative of the bubbles passing through the detection region. The apparatus may be mounted upon an aquatic remotely operated vehicle for investigating sources of bubbles in aquatic environments, for example from oil exploration or oil production leaks, from damaged electrical subsea cables, or from leaks from seabed gas pipelines. The detector may be a passive acoustic sensor such as a microphone or an active ultrasound sensor with acoustic transmitter and receiver.

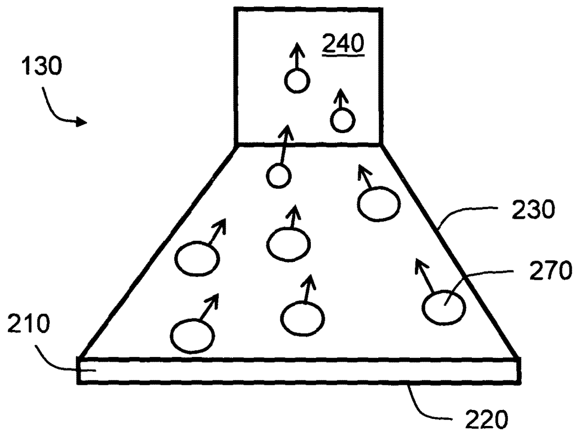

FIG. 3

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 2007.

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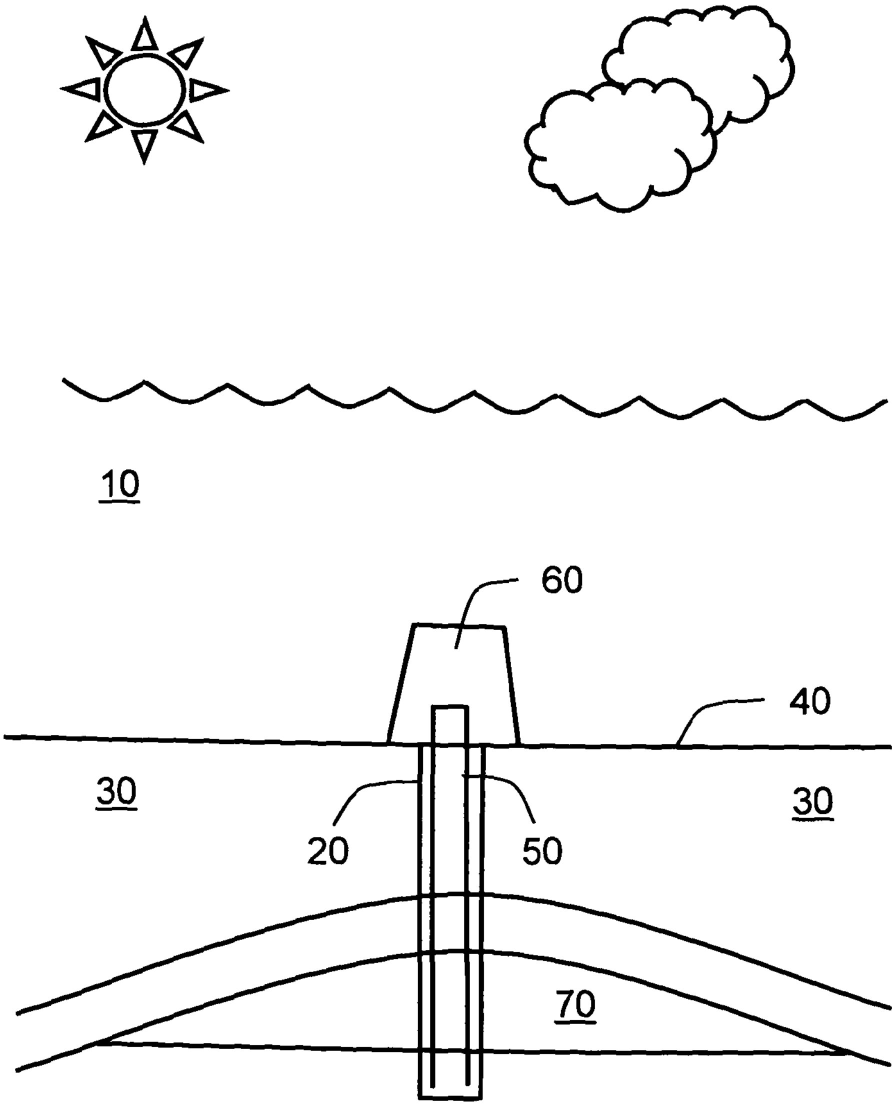

FIG. 1

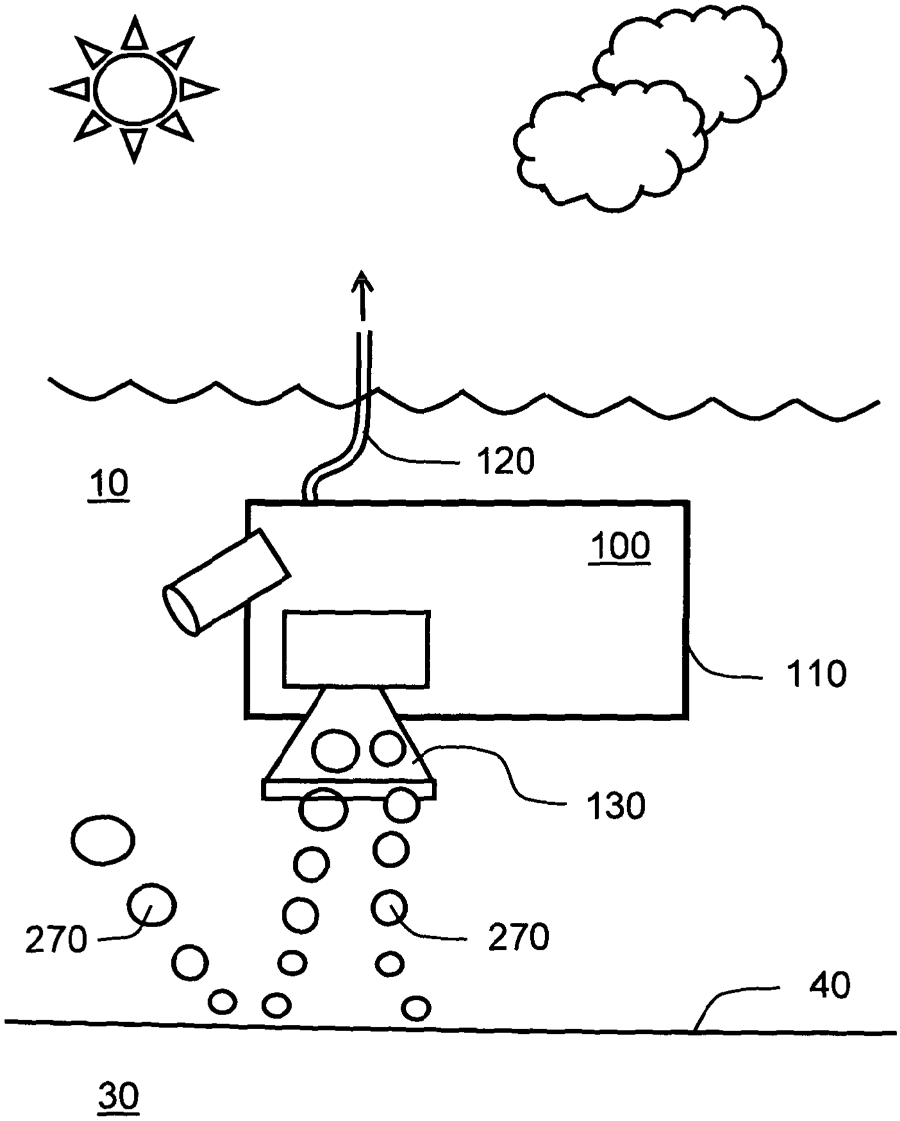

FIG. 2

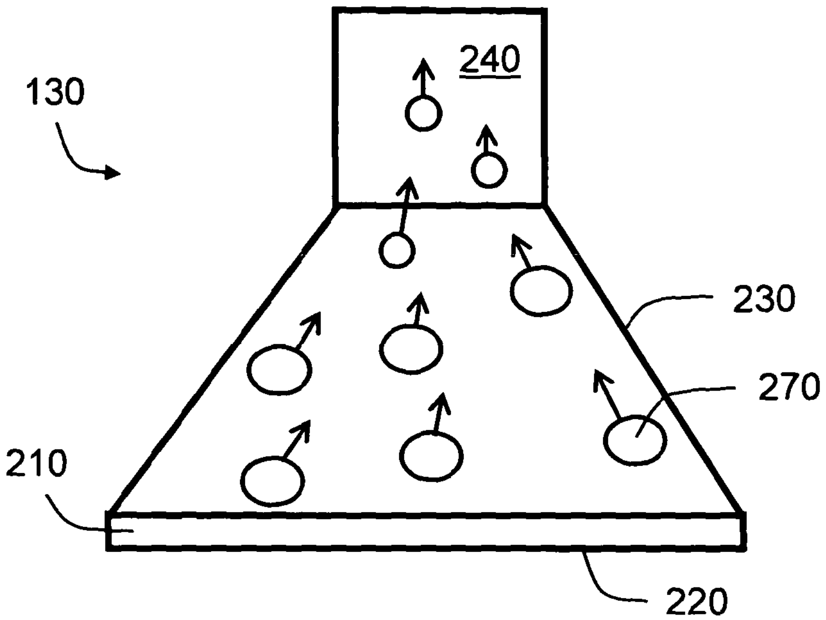

FIG. 3

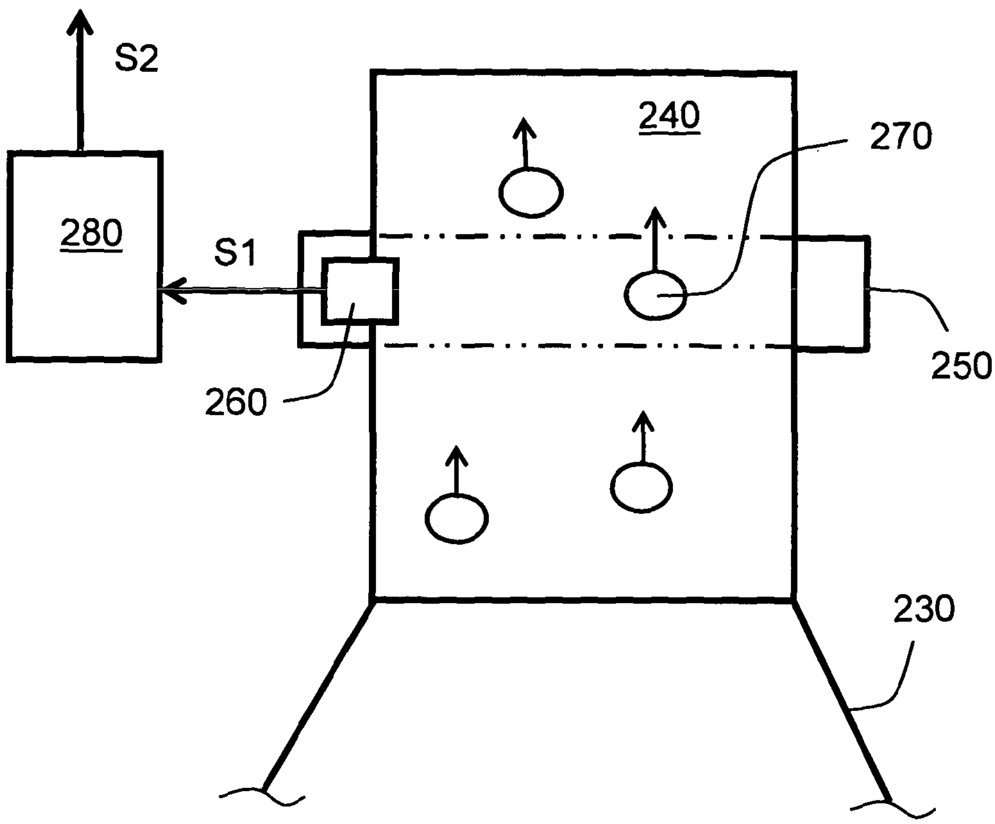

FIG. 4

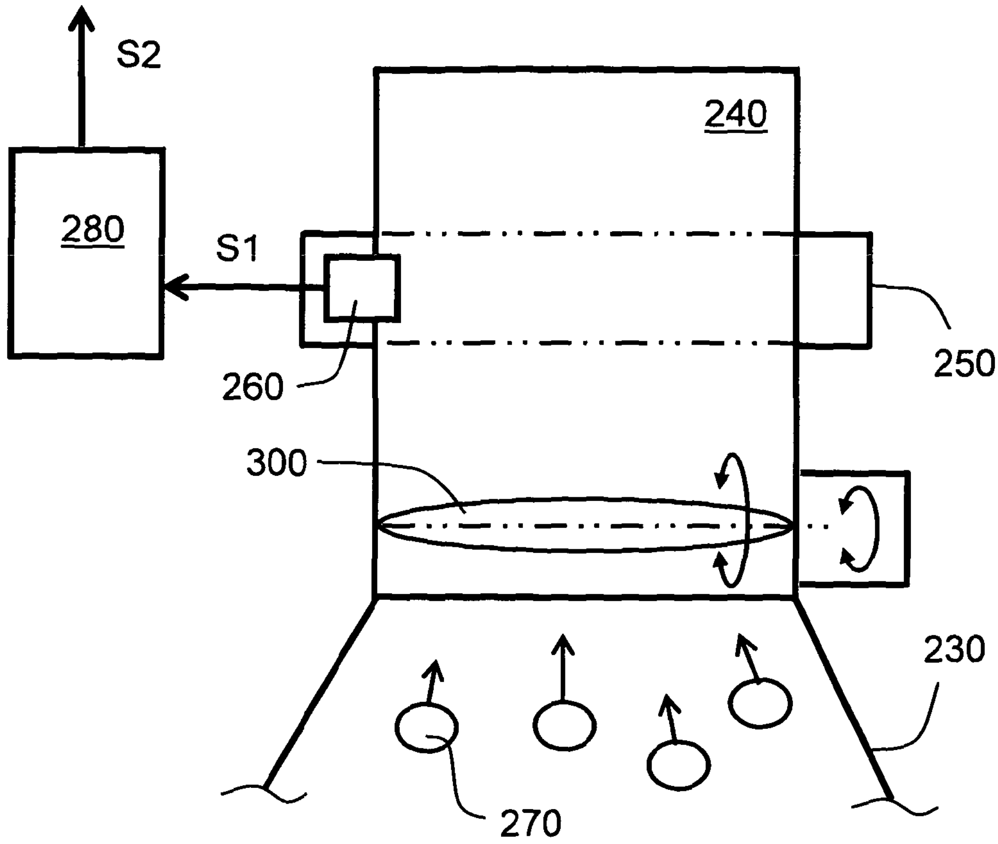

FIG. 5

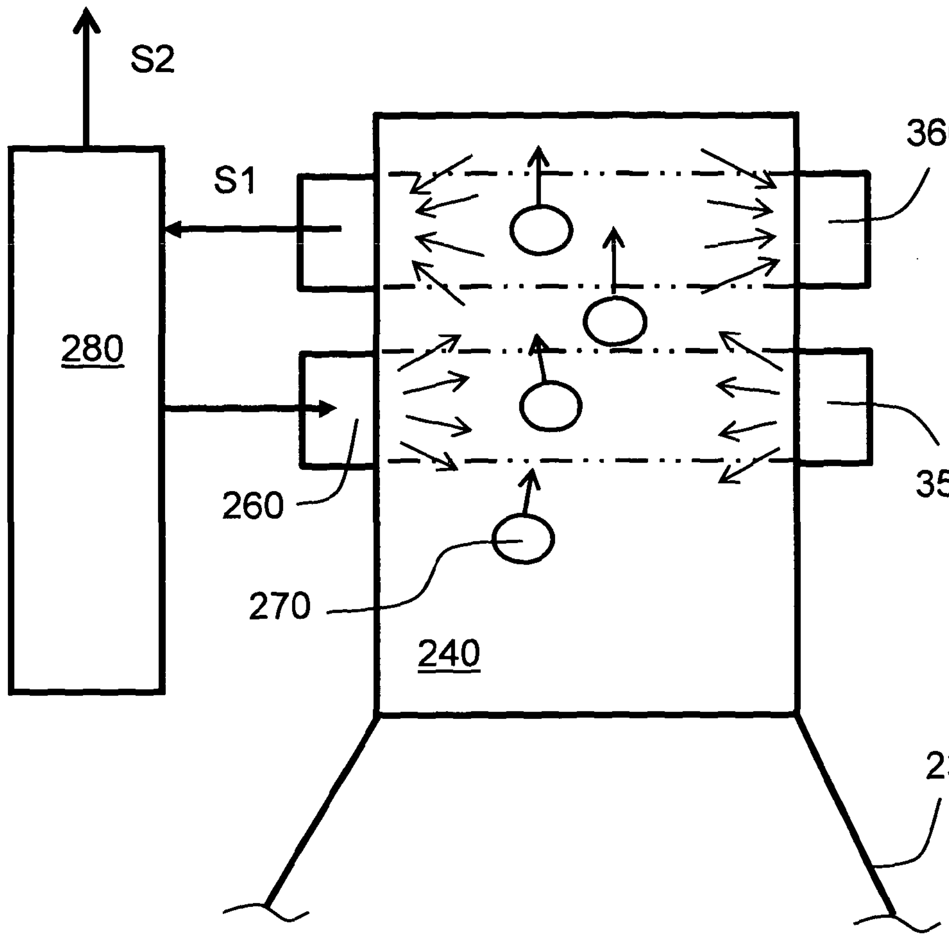

FIG. 6

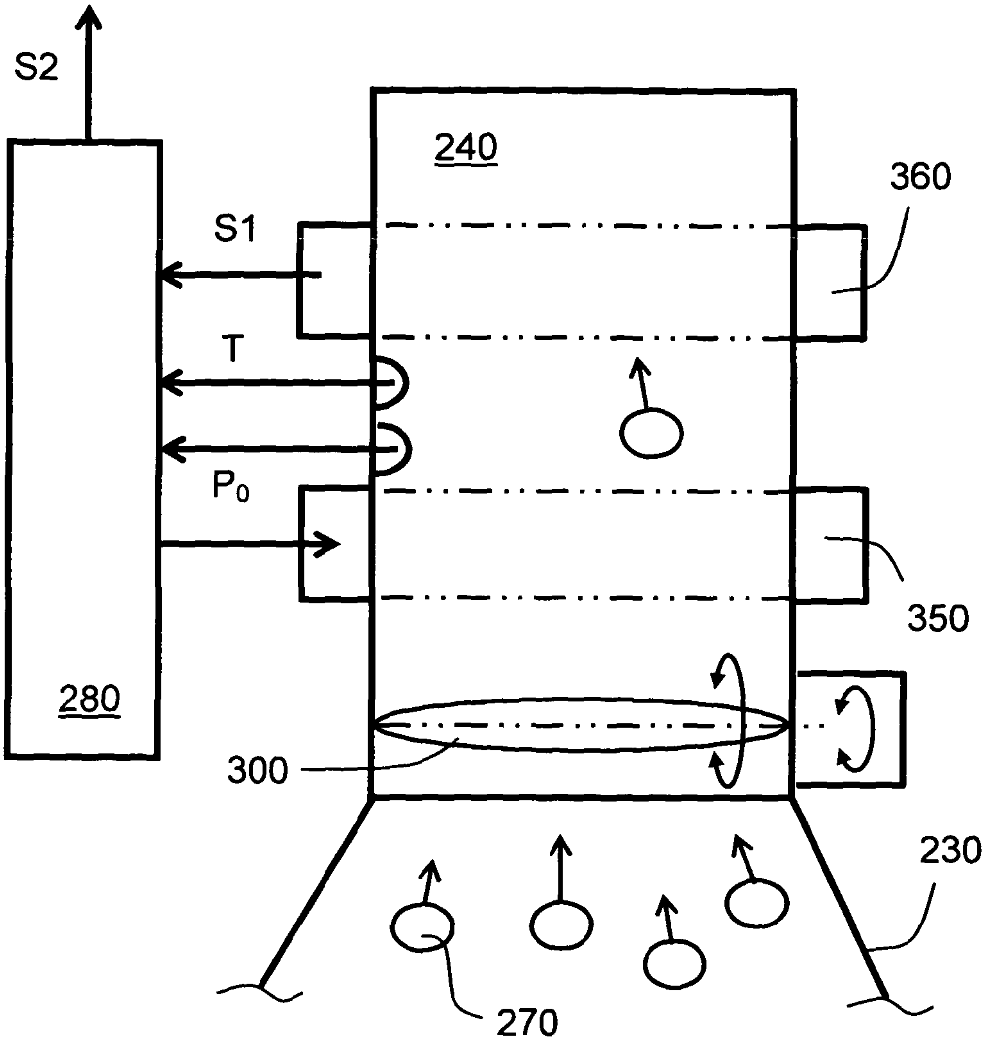

FIG. 7

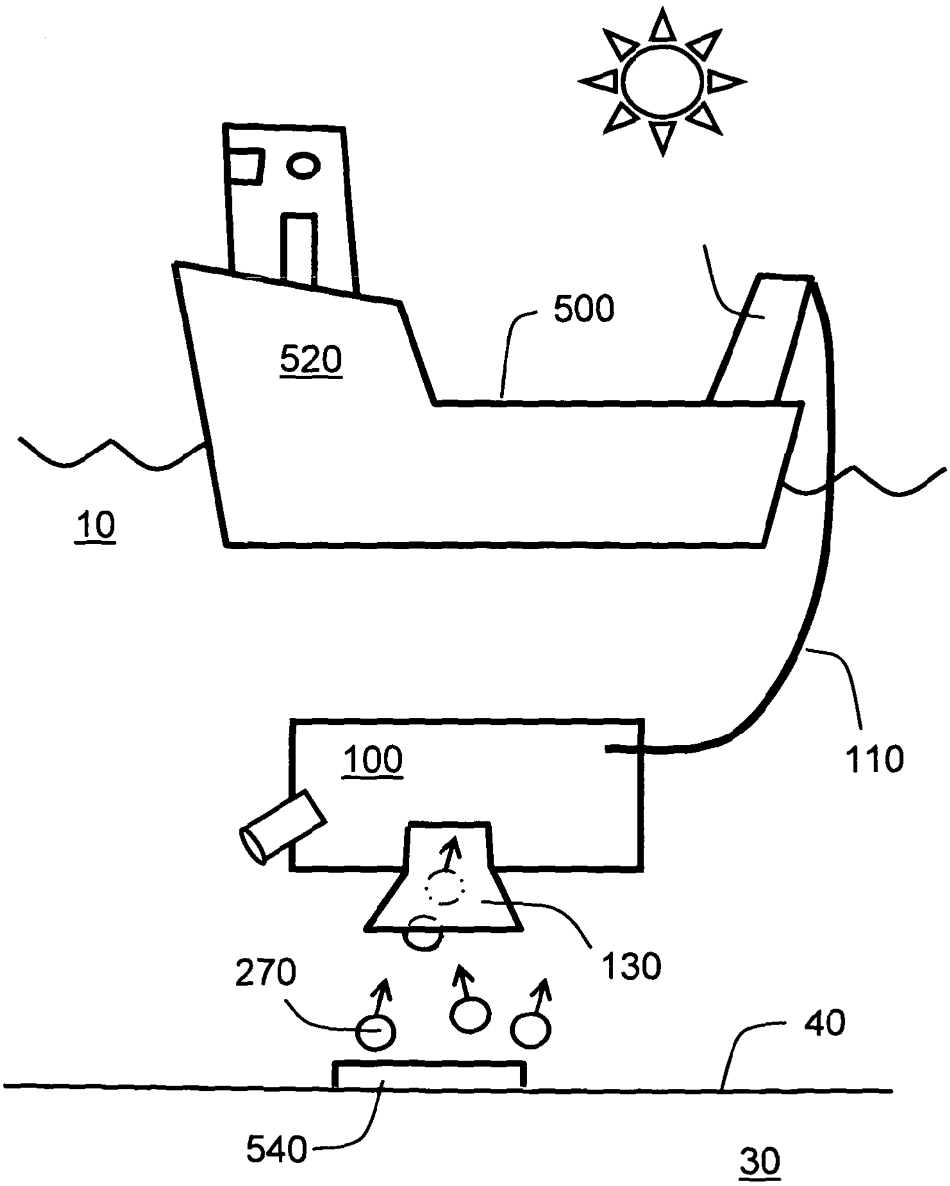

FIG. 8

UNDERWATER DETECTION APPARATUS
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Field of the invention

The present invention relates to underwater detection apparatus, for example to underwater detection apparatus for detecting a presence of bubbles arising from underwater facilities and from seabed regions. Moreover, the present invention concerns methods of using aforesaid apparatus for detecting a presence of bubbles. Furthermore, the invention relates to software products recorded on machine-readable media, wherein the software products are executable on computing hardware for implementing aforesaid methods.

Background of the invention

It is well known that bubbles occur in liquids. Moreover, it is well known that bubbles arise naturally in water-covered regions, for example in swamps and lagoons as a result of decaying organic vegetation giving rise to methane gas. It is perhaps less appreciated that bubbles are also generated naturally in ocean environments, but are not noticed in view of seemingly chaotic ocean surface wave motion. In ocean environments, the formation of bubbles can be indicative of various processes occurring below a seabed, for example geological fissures along tectonic fault lines, geological processes such as hot-water springs, and such like.

When offshore drilling for gas and/or oil is performed in an ocean environment **10** as illustrated in FIG. 1, a borehole **20** is drilled into a geological formation **30** having an upper surface forming a seabed **40**. It is customary practice to line the borehole **20** with a steel liner tube **50**. In deep-water installations, it is also conventional practice to cap the liner tube **50** at the seabed **40** with a valve arrangement **60**. The valve arrangement **60** is often referred to as being a "Christmas Tree" on account of its superficial likening to an upwardly tapered form of a coniferous tree. The geological formation **30** spatially adjacent to the borehole **20** is often porous in nature and unable to withstand high pressures which arise within the liner tube **50**, especially when an oil and/or gas reserve **70** intercepted by the borehole **20** is in its early stage of production and at high intrinsic pressure. In later stages of production from the oil and/or gas reserve, it is often necessary to inject fluids into the oil and/or gas reserve **70** at considerable pressure which causes a high internal pressure to be experienced by the liner tube **50**. The valve arrangement **60** enables flexible pipes to be attached to the liner tube **50** via the valve arrangement **60**, for example when a floating oil and/or gas production platform is employed.

As experienced in the Deep Water Horizon accident in the Gulf of Mexico in the year 2010, the liner tube **50** can leak or even fracture. Such fracture can arise from manufacturing defects in a material employed to fabricate the liner tube **50**, or can arise from the liner tube **50** being stressed beyond its design ratings (for example by excess pressure being applied to cause greater production rates from the oil and/or gas reserve **70**) during operation. When the liner tube **50** becomes fractured, fluids from the borehole **20** leak into neighbouring regions of the geological formation **30** and is experienced often as a loss of pressure within the borehole **20**. Eventually, the fluids from a fracture in the liner tube **50** seep to the seabed **40** and appear as issuance of occasional bubbles over an expansive area of the seabed **40**. In view of optical visibility at the seabed **40** often being obscured by particulate matter, especially when there are activities which disturb sediment on the seabed **40**, these occasional bubbles are sometimes difficult to detect using conventional techniques. Crude oil is known to exsolve gas bubbles when it becomes depressurized, and such exsolved gas generated within the geological formation **30** close to the borehole **20** can potentially disturb particulate matter on the seabed **40** and thereby cause optical obscuration.

Similar considerations also pertain to underwater pipelines for oil and/or gas which, after many years of use, can develop occasional defects, for example "pin holes" from where leaks of gas can occur. It is highly desirable to detect small leaks and repair them, before they develop into major leaks causing significant environmental damage. However, in a similar situation to FIG. 1, detecting occasional leaks over an extensive area of seabed **40** in optically-obscured conditions is potentially a difficult technical problem to address.

It will be appreciated from the foregoing that there is a need for robust apparatus which is capable of operating in ocean environments **10** and detecting bubbles issuing from an extensive area of the seabed **40** in the concurrent presence of particular material which can cause aforesaid optical obscuration.

Summary of the invention

The present invention seeks to provide an improved apparatus which is operable to collect and detect in a reliable manner one or more bubbles in an aquatic environment.

According to a first aspect of the present invention, there is provided an underwater detection apparatus as defined in appended claim 1: there is provided an underwater detection apparatus for detecting a presence of one or more bubbles within an aquatic environment, characterized in that the apparatus includes a first structure including a lower peripheral edge for defining an area over which said apparatus is operable to collect the one or more bubbles, a second structure for spatially concentrating the one or more bubbles received within the area defined by the lower peripheral edge into a detection region, and a detection arrangement for detecting the one or more bubbles concentrated in operation by the bubble concentrating structure passing into the detection region and generating an output signal (S2) indicative of the one or more bubbles passing through the detection region.

The invention is of advantage in that the underwater detection apparatus is operable to collect the one or more bubbles over a potentially extensive area within the aquatic environment, and to detect the bubbles in a manner which is robust to particulate contamination within the aquatic environment.

Optionally, the apparatus is adapted to detect at least one of: one or more gas bubbles, one or more oil bubbles. "Oil" here is to be interpreted to include a broad range of fluid hydrocarbon materials.

Optionally, in the underwater detection apparatus, the second structure is implemented as a substantially frusto-conical structure for spatially defining a volume in which the one or more bubbles are concentrated in operation.

Optionally, in the underwater detection apparatus, the detection arrangement includes one or more sensors for passively detecting sounds generated by the one or more bubbles passing in operation through the detection region to generate a detected signal (S1), and a signal processing arrangement for processing the detected signal (S1) to generate the output signal (S2) indicative of a presence and/or a lack of presence of the one or more bubbles within the detection region.

Optionally, in the underwater detection apparatus, the detection arrangement includes a signal source for interrogating in operation the detection region using interrogating radiation, and one or more sensors for detecting one or more bubbles present in the detection area by way of transmitted portions and/or reflected portions of the interrogating radiation. More optionally, in the underwater detection apparatus, the signal source and the one or more sensors of the detection arrangement are housed within a mutually common unit. More optionally, the signal source for generating the interrogating radiation is adjustable in frequency and/or amplitude to stimulate non-linear resonance in the one or more bubbles, and the output signal (S2) indicative of the one or more bubbles present in the detection region is generated by the detection arrangement from harmonic signal components generated as a consequence of exciting the non-linear resonance in the one or more bubbles.

Optionally, the detection arrangement includes a signal processing unit for measuring a time-of-flight of the interrogating radiation through the detection region and/or an acoustic impedance of the detection region for determining a presence of one or more bubbles rising up within the detection region.

Optionally, the apparatus further includes an arrangement for periodically interrupting in operation a supply of collected bubbles from the bubble concentrating structure to the detection region for enabling the apparatus to differentiate between signals from the detection arrangement indicative of bubbles being present in the detection region, and indicative of bubbles being absent from the detection region. More optionally, in the underwater detection apparatus, the arrangement for periodically interrupting in operation the supply of collected bubbles from the bubble concentrating structure to the detection region includes at least one of:

(i) an actuated valve spatially located in operation below the detection arrangement; and

(ii) an actuated bubble collection arrangement which is operable to release periodically one or more collected bubbles therefrom into the detection region.

Optionally, in the underwater detection apparatus, the detection region further includes in respect thereof a temperature sensor and a pressure sensor for enabling the signal processing arrangement to determine sizes of the one or more bubbles from their measured non-linear resonant frequencies.

Optionally, the apparatus is adapted to be mounted upon a remotely operated vehicle (ROV) for operation.

Optionally, in the underwater detection apparatus, the detection region is provided with a gas analyzer arrangement for analyzing a chemical composition of the one or more bubbles passing in operation through the detection region.

Optionally, in the underwater detection apparatus, the signal processing arrangement is operable to excite the detection arrangement at a frequency in a range of 1 kHz to 10 MHz, more preferable in a range of 10 kHz to 5 MHz, and most preferably in a range of 100 kHz to 1 MHz.

According to a second aspect of the invention, there is provided a method of employing an underwater detection apparatus for detecting a presence of one or more bubbles within an aquatic environment, characterized in that the method includes:

(a) using a first structure including a lower peripheral edge to define an area for the apparatus for collecting the one or more bubbles;

(b) using a second structure for spatially concentrating the one or more bubbles received within the area defined by the lower peripheral edge into a detection region; and

(c) using a detection arrangement for detecting the one or more bubbles concentrated in operation by the second structure into the detection region and generating an output signal (S2) indicative of the one or more bubbles passing through the detection region.

Optionally, the method includes implementing the second structure as a substantially frusto-conical structure for spatially defining a volume in which the one or more bubbles are concentrated in operation.

Optionally, the method includes employing one or more sensors in the detection arrangement for passively detecting sounds generated by the one or more bubbles passing in operation through the detection region to generate a detected signal (S1), and employing a signal processing arrangement for processing the detected signal (S1) to generate the output signal indicative of a presence and/or a lack of presence of the one or more bubbles within the detection region.

Optionally, the method includes employing a signal source of the detection arrangement for interrogating in operation the detection region using interrogating radiation, and employing one or more sensors for detecting one or more bubbles present in the detection area by way of transmitted portions and/or reflected portions of the interrogating radiation. More optionally, the method includes adjusting in frequency and/or amplitude the signal source for generating the interrogating radiation to stimulate non-linear resonance in the one or more bubbles, and generating the output signal indicative of the one or more bubbles present in the detection region from harmonic signal components generated as a consequence of exciting the non-linear resonance in the one or more bubbles.

Optionally, the method further includes using an arrangement for periodically interrupting in operation a supply of collected bubbles from the bubble concentrating structure to the detection region for enabling the apparatus to differentiate between signals from the detection arrangement indicative of bubbles being present in the detection region, and indicative of bubbles being absent from the detection region. More optionally, the method includes implementing the arrangement for periodically interrupting in operation the supply of collected bubbles from the bubble concentrating structure to the detection region to include at least one of:

(i) an actuated valve spatially located in operation below the detection arrangement; and

(ii) an actuated bubble collection arrangement which is operable to release periodically one or more collected bubbles therefrom into the detection region.

Optionally, the method includes utilizing in respect of the detection region a temperature sensor and a pressure sensor for enabling the signal processing arrangement to determine sizes of the one or more bubbles from their measured non-linear resonant frequencies.

Optionally, the method includes implementing the apparatus for mounting upon a remotely operated vehicle (ROV) for operation.

Optionally, the method includes providing the detection region with a gas analyzer arrangement for analyzing a chemical composition of the one or more bubbles passing in operation through the detection region.

Optionally, the method includes operating the signal processing arrangement to excite the detection arrangement at a frequency in a range of 1 kHz to 10 MHz, more preferable in a range of 10 kHz to 5 MHz, and most preferably in a range of 100 kHz to 1 MHz.

According to a third aspect of the invention, there is provided a software product recorded on a machine-readable data storage medium, characterized in that the software product is executable on computing hardware for implementing a method pursuant to the second aspect of the invention.

It will be appreciated that features of the invention are susceptible to being combined in various combination without departing from the scope of the invention as defined by the appended claims.

Description of the diagrams

Embodiments of the present invention will now be described, by way of example only, with reference to the following diagrams wherein:

FIG. 1 is an illustration of an aquatic environment in which embodiments of the present invention are adapted to operate;

FIG. 2 is an illustration of an example of an apparatus pursuant to the present invention;

FIG. 3 is an illustration of a sensor arrangement for use in the apparatus of FIG. 2;

FIG. 4 is an illustration of an alternative sensor arrangement for use in the apparatus of FIG. 2;

FIG. 5 is an illustration of a neck region of the apparatus of FIG. 2;

FIG. 6 is an illustration of an optional configuration for a sensor arrangement, wherein one or more acoustic transducers are operable to emit acoustic radiation into the neck region through which fluids flow, for example potentially including one or more bubbles therein;

FIG. 7 is an illustration of an annular arrangement of transducers employed for the sensor arrangement of the apparatus in FIG. 2; and

FIG. 8 is an illustration of the apparatus of FIG. 2 together with an aquatic vessel for transporting the apparatus to a location for use.

In the accompanying diagrams, an underlined number is employed to represent an item over which the underlined number is positioned or an item to which the underlined number is adjacent. A non-underlined number relates to an item identified by a line linking the non-underlined number to the item. When a number is non-underlined and accompanied by an associated arrow, the non-underlined number is used to identify a general item at which the arrow is pointing.

Description of embodiments of the invention

Ultrasonic bubble detection is known and provides benefits of detecting bubbles even when particular matter is concurrently present which can cause optical obscuration. A bubble in a liquid will, in general, includes a mixture of permanent gas and vapour, and will be approximately stable over timescales where dissolution and buoyancy may be neglected if a partial pressure of a gas component of the bubble counterbalances constricting pressures due to surface tension and a pressure in liquid surrounding the bubble. An applied acoustic field, namely applied ultrasonic radiation, is capable of driving the bubble into non-linear oscillation, which at small amplitudes approximates to a motion of a single-degree-of-freedom oscillator.

The bubble is thus capable of oscillating and exhibits a natural frequency of resonance υ_0 as defined by Equation 1 (Eq. 1):

$$\upsilon_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi R_0}\sqrt{\frac{3\kappa p_0}{\rho}\left(1+\frac{2\sigma}{p_0 R_0}\right)-\frac{2\sigma}{\rho R_0}} \qquad \text{Eq. 1}$$

wherein

ρ = a density of sea water in which the bubble is present;

p_0 = a static pressure within the bubble;

σ = a surface tension of the sea water;

κ = a polytropic index; and

R_0 = a radius of the bubble.

Earlier studies of bubbles have shown that bubble resonant signatures can be employed to characterized bubbles by exciting them into oscillatory resonant motion. When the motion of the bubble corresponds to a non-linear oscillator, for example as achievable using high intensities of acoustic interrogation, it is found that the bubble is capable of causing frequency multiplication; for example, the bubble is interrogated by acoustic radiation at its resonant frequency υ_0 as defined by Equation 1 (Eq. 1) at an amplitude which causes non-linear oscillation of the bubble, causing the bubble to emit radiation having a second harmonic component at a frequency $2\upsilon_0$. Moreover, earlier studies have also shown that interrogating bubbles in the aquatic environment **10** employing signals having acoustic frequencies up to 200 kHz provides measurable results, although higher frequencies have also been employed, for example over a frequency range of 100 kHz to 1 MHz. Water itself may be regarded as an incompressible medium and hence unable to exhibit such resonances; similarly solid particulate matter present in the water is not capable of exhibiting such non-linear resonance.

The present invention concerns an underwater detection apparatus for detecting one or more bubbles arising from an extensive area of seabed **40**, or from an extensive area of submerged structure, for example a sea-bed gas pipeline or electrical power cable. The apparatus is indicated generally by **100** in FIG. 2 and includes a main body **110**, an umbilical connection **120** to an aquatic surface, and a sensor arrangement **130**. The apparatus **100** is capable of being manoeuvred in the aquatic environment **10**, for example ocean environment, by way of fluid thrusters, propellers and/or actuated vanes. Beneficially, the sensor arrangement **130** includes one or more cameras for inspecting in operation a spatial vicinity of the apparatus **100** when in operation, for example to assist with manoeuvring the apparatus **100** when in operation.

The sensor arrangement **130** also includes a sensor arrangement **200** as illustrated in FIG. 3. The sensor arrangement **200** includes a first structure **210** for collecting one or more bubbles, for example implemented as a substantially frusto-conical funnel-shaped structure, including a lower peripheral edge **220**, a second structure **230** implemented in a generally upwardly-tapered form for spatially concentrating one or more bubbles received in a bubble collecting area defined by the lower peripheral edge **220**, and a neck region **240** for receiving the one or more bubbles concentrated together in the second structure **230**; the neck region **240** is also known as a "detection region". Beneficially, the neck region **240** has an effective transverse cross-sectional area which is smaller than a bubble-collecting area defined by the lower peripheral edge **220**. The neck region **240** includes a transducer arrangement **250** for detecting in operation the one or more bubbles collected within the bubble-concentrating region **230** and rising into the neck region **240** by way of their intrinsic buoyancy and/or by assistance of force fluid flow provided by a turbine or similar. Optionally, the second structure **230** is implemented in a substantially frusto-conical manner as aforementioned, although other forms of the region **230** are feasible to employ when implementing the present invention, for example asymmetrical upwardly-tapered structures of curved and/or rectilinear form.

As illustrated in FIG. 4, the transducer arrangement **250** optionally includes at least one acoustic sensor which, in simplest form, is implemented as an aquaphone **260** for listening for movement of one or more collected bubbles **270** through the neck region **240** and generating a corresponding sensor signal S1. The apparatus **100** includes a signal processing unit **280** for processing the signal S1 to generate an output signal S2 indicative of the one or more collected bubbles **270**. Optionally, the signal processing unit **280** is operable to filter the signal S1 in respect of signal frequency, and then perform an amplitude and frequency analysis of signal components present in the filtered signal S1 to generate the output signal S2, for example by performing a Fourier spectrum analysis and/or a comparison analysis to predetermined signal templates. Beneficially, neural network analysis of the filtered signal S1 is employed to identify a presence of the one or more bubbles **270**. Optionally, the signal processing unit **280** is implemented using computing hardware operable to execute one or more software products stored on machine-readable data storage media; the software products are optionally operable to employ digital recursive filters whose frequency ranges are dynamically modifiable to search for aforesaid components in the signal S1 in various frequency ranges, for example 10 Hz to 100 Hz, 100 Hz to 1 kHz and so forth. In other words, the transducer arrangement **250** in such case is employed for listening passively for bubbling sounds occurring within the neck region **240**, and then to analyze the bubbling sounds, namely the signal S1, to confirm with high reliability whether or not one or more bubbles **270** are responsible for generating the bubbling sounds.

As illustrated in FIG. 5, the neck region **240** is beneficially provided with a valve **300** spatially below the transducer arrangement **250**, for example below the aquaphone **260**. Optionally, the valve **300** is implemented as an actuated butterfly valve, although other types of actuated valves may optionally be employed, for example:

(i) linearly-actuated needle valves and slider valves; and/or

(ii) one or more fluidly-inflatable bodies for obstructing flow of the bubbles when in a fluidly-inflated state, and for allowing in a fluidly deflated state movement of the bubbles **270** into the neck region **240**.

The purpose of the valve **300** is to collect one or more bubbles **270** which are then subsequently periodically released for detection using the transducer arrangement **250**; alternative arrangements giving rise to such collection of bubbles for periodic release for detection purposes at the transducer arrangement **250** are also within the scope of the present invention, for example by employing one or more actuated bubble-collection cavities which are operable in a first state to collect bubbles received within the area defined by the lower peripheral edge **220**, and are operable in a second state to release the collected bubbles for detection via the transducer arrangement **250**. The bubble-collection cavities are implemented, for example, using one or more hollow components with associated one or more access apertures which are rotated to switch between the aforesaid first and second states.

In operation, the valve **300** is periodically closed to collect one or more bubbles **270** beneath the valve **300**, and then opened to allow the one or more bubbles **270** to progress past the transducer arrangement **250**, for example past the aquaphone **260**, to generate a clearly discernible bubbling sound in the signal S1 which is periodically processed by the signal processing unit **280** to generate the output signal S2. Optionally, opening and closing of the butterfly valve **300** is under control from the signal processing unit **280**. When one or more bubbles **270** are not present, opening and closing the valve **300** has little effect of the signal S1; conversely, when one or more bubbles **270** are present, opening the valve **300** periodically causes a corresponding surge of one or more bubbles **270** when present which is clearly discernible as one or more discernible signal components in the signal S1. Opening and closing of the valve **300** pertains *mutatis mutandis* to alternative implementations of the valve **300** as elucidated in the foregoing.

Optionally, the sensor arrangement **200** is implemented in an active manner, wherein fluid flowing through the neck region **240** is interrogated using acoustic radiation and corresponding transmitted and/or reflected acoustic signals detected and subsequently processed in the signal processing unit **280**; in other words, the transducer arrangement **250** is beneficially implemented to be able to function in an active interrogatory manner for detecting one or more bubbles **270** present in the neck region **240**. Optionally, active optical interrogation is employed. In FIG. 6, there is shown an optional configuration for the sensor arrangement **200** wherein one or more acoustic transducers **350** emit acoustic radiation into the neck region **240** through which fluids flow, for example potentially including one or more bubbles **270**. The one or more acoustic transducers **350** are coupled to the aforesaid signal processing unit **280** which also includes a signal source arrangement **380** for exciting the one or more transducers **350**. Beneficially, the one or more transducers **350** are implemented as one or more piezoelectric devices and/or one or more electromagnetic devices. Optionally, the one or more acoustic transducers **350** are housed in a mutually common housing to the aquaphone **260**.

Moreover, there are also included one or more receiving sensors **360** for receiving reflected and/or transmitted radiation from fluid present within the neck region **240**. Optionally, an annular arrangement of transducers is employed for implementing one or more of the transducers **350**, **360**, for example as illustrated in FIG. 7 wherein the one or more transducers **350** are operable to be excited individually or in groups, and the one or more sensors **360** are employed to receive signals individually or in groups. For example, a plurality of sensors **360** are employed to generate a corresponding plurality of signals S1 which are mutually subtracted to remove environmental noise common to the sensors **360** and to isolate differential acoustic signals therefrom which are strongly influenced by the one or more bubbles **270** present within the neck region **240**. Such a manner of operation is capable of being used for detecting transversely non-uniform distributions of bubbles **270** within the neck region **240**. The one or more acoustic sensors **360** generating the signal S1 are coupled to the signal processing unit **280** which performs signal analysis to generate the output signal S2 indicative of the presence of one or more bubbles **270** within the neck region **240**.

In respect of FIG. 6, optionally also in respect of FIG. 7, the signal processing unit **280** is operable to excite the one or more transducers **350** at a range of frequencies and/or at a range of intensities, and simultaneously receive the signal S1 from the one or more sensors **360**. The range of frequencies beneficially lies within a range of 1 kHz to 10 MHz, more preferable in a range of 10 kHz to 5 MHz, and most preferably in a range of 100 kHz to 1 MHz. Moreover, the range of frequencies is employed for obtaining information regarding radii R_0 of the one or more bubbles **270** present in the neck region **240**; the signal processing unit **280** is operable to apply Equation 1 (Eq. 1) from the foregoing to compute the radii R_0. Optionally, the neck region **240** is furnished with additional sensors for determining various parameters in Equation 1 (Eq. 1), for example the static water pressure p_0 pertaining in respect of the neck region **240**, and a temperature T in respect of the neck region **240** from which a density ρ of the water in the neck region **240** can be computed by the signal processing unit **280**; optionally, the additional sensors are spatially located locally to the neck region **240**. The range of intensities is employed for driving the one or more bubbles **270** when present in the neck region **240** into progressive degrees of non-linear resonance, for example for generating second order and higher harmonics of the acoustic radiation generated by the one or more transducers **350** and detectable by the one or more sensors **360** for generating the signal S1. Optionally, the valve **300** is included spatially beneath the one or more transducers and sensors **350**, **360** for periodically interrupting the flow of fluid through the neck region **240**, for example for periodically interrupting the one or more bubbles **270**, wherein a lack of the one or more bubbles **270** in the neck region **240** as a result of the valve **300** preventing them rising into a spatial vicinity of the one or more transducers and sensors **350**, **360** results in a lack of harmonic components present in the signal S1 as the acoustic radiation emitted from the one or more transducers **350** is varied in intensity.

Operation of the apparatus **100** will now be described with reference to FIG. 2 to FIG. 8. As illustrated in FIG. 8, the apparatus **100** is transported on a deck **500** of a ship **520** to an aquatic location **530** whereat one or more bubbles **270** within the aquatic environment **10** are to be investigated there. Such one or more bubbles **270** potentially arise from one or more of: the geological formation **30** at the location **530**, the seabed **40** at the location **530**; the geological formation **30**; apparatus **540** included on the seabed **40**, for example a pipeline and/or an electrical cable and/or a sunken aquatic vessel. For example, the present invention is useful when an electrically-screened underwater cable develops an insulation fault which is not detectable by way of electromagnetic radiation detection on account of an outer electromagnetic Earthed shield of the cable being intact, but which is detectable by way of failing internal cable insulation giving rise to heating and charring of plastics material insulation causing one or more bubbles of gas to be generated.

When the ship **520** arrives at the location **530**, the apparatus **100** is lifted into the aquatic environment **10**, for example using a crane mounted onto the deck **500**. The apparatus **10** moves around within the aquatic environment **10** whilst searching for the one or more bubbles **270** by way of the first structure **210** collecting one or more upwardly-mobile bubbles **270** and guiding them via the second structure **230** to the neck region **240** and thereby to the transducer arrangement **250** for detection as described in the foregoing. The apparatus **100** is conveniently implemented as a remotely operated vehicle (ROV), for example in a manner of a miniature submarine or similar. The apparatus **100** is beneficially operable to manoeuvre itself via remote control from the ship **520** and/or to manoeuvre itself autonomously by way of local control implemented within the apparatus **100**, for example via a computer arrangement operable to execute software for guiding the apparatus **100** to search systematically for one or more bubbles **270** within a defined spatial region within an aquatic environment **10**. *Optionally, the computer arrangement is operable to guide* the apparatus **100** to implement a general search for bubbles in a first mode of operation, and to perform a thorough search within a given region in a second mode of operation in an event that one or more bubbles **270** are detected in the first mode of operation. Such a manner of functioning of the apparatus **100** potentially enables large areas of the seabed **40** to be mapped out when searching for features and/or structures giving rise to one or more bubbles **270**. For example, in the first mode, gas bubbles **270** are detected, whereas a more detailed analysis including chemical analysis of the collected bubbles **270** is performed in the second mode.

Optionally, the neck region **240** has a horizontal cross-sectional area which is less than 50% of a bubble-collecting area defined by the lower peripheral edge **220**, more optionally less than 25% of the bubble-collecting area of the lower peripheral edge **220**, and most optionally less than 10% of the bubble-collecting area of the lower peripheral edge **220**. Optionally, as aforementioned, the second structure **230** is implemented as a substantially frusto-conical upwardly-tapered structure, a generally upwardly-tapered structure, an asymmetrical upwardly-tapered structure, an upwardly-tapered structure whose spatial extent can be dynamically altered in operation, or any combination of such optionally implementations.

Optionally, the apparatus **100** includes an arrangement for collecting the one or more bubbles **270** after they have passed through the neck region **240** for subsequent analysis for determine their chemical nature, for example methane, breakdown gaseous products from overheated electrical plastics material insulation, air bubbles from a sunken damaged submarine and so forth. Optionally, analysis of the one or more collected bubbles **270** is performed when the apparatus **100** returns to its corresponding ship **520** and associated deck **500**. Alternatively, the apparatus **100** includes one or more gas analyzers spatially integrated therewith for analyzing a chemical composition of the one or more collected bubbles **270** from the detection region **240**, for example in real-time; such one or more gas analyzers beneficially include at least one of infra-red optical sensors, electrochemical sensors, combustion sensors (for example Pellistors), semiconductor gas sensors, acoustic gas sensors.

The apparatus **100** is beneficially adapted to measure oil bubbles present in water and rising up into the neck region **240**, for example arising from leaks from underwater oil pipelines and from leaking underwater oil valves, for example associated with "Christmas Tree" underwater well heads. Such oil bubbles exhibit highly viscously damped behaviour devoid of resonance effects as a function of ultrasonic radiation interrogating intensity. However, such oil bubbles have a density which is often less than saline water, resulting in them moving into the neck region **240**. The transducer arrangement **250** is beneficially optionally provided with an acoustic transmitter transducer and a corresponding receiver transducer for measuring an acoustic impedance of the neck region **240** a function of time. As oil bubbles enter and rise through the neck region **240** in operation, coupling efficiency of acoustic energy propagating from the transmitter transducer to the receiver transducer is modulated. For example, if the transmitter transducer is excited using a signal of constant amplitude and frequency, a corresponding output signal from the receiver transducer varies as oil bubbles enter into the neck region **240**. By measuring temporal variations in the output signal from the receiver transducer, for example in the signal processing unit **280** by recursive filtering, Fast Fourier Transform (FFT) or similar, spectral signatures for gas bubbles and oil bubbles are susceptible to being indentified. Optionally, the valve **300** is used in a closed state to collect gas and oil bubbles therebelow, and then switched to an open state to allow the gas bubbles to rise first, followed by the oil bubbles later. Temporal characteristics of acoustic coupling between the transmitter transducer and the receiver transducer as firstly gas bubbles and thereafter oil bubbles rise in the neck region **240** is able to provide valuable information regarding leaks and other processes occurring underwater. In addition, or alternatively, time of flight of pulses of acoustic radiation to propagate from the transmitter transducer to the receiver transducer to determine a density of the neck region **240**. Temporal variations in the time of flight are monitored by the signal processing unit **280** to identify and nature of bubbles, either gas or oil, propagating through the neck region **240**.

Modifications to embodiments of the invention described in the foregoing are possible without departing from the scope of the invention as defined by the accompanying claims. Expressions such as “including”, “comprising”, “incorporating”, “consisting of”, “have”, “is” used to describe and claim the present invention are intended to be construed in a non-exclusive manner, namely allowing for items, components or elements not explicitly described also to be present. Reference to the singular is also to be construed to relate to the plural. Numerals included within parentheses in the accompanying claims are intended to assist understanding of the claims and should not be construed in any way to limit subject matter claimed by these claims.

CLAIMS

1. An underwater detection apparatus (100) for detecting a presence of one or more bubbles (270) within an aquatic environment (10), characterized in that the apparatus (100) includes a first structure (210) including a lower peripheral edge (220) for defining an area over which said apparatus (100) is operable to collect the one or more bubbles (270), a second structure (230) for spatially concentrating the one or more bubbles (270) received within the area defined by the lower peripheral edge (220) into a detection region (240), and a detection arrangement (240, 250) for detecting the one or more bubbles (270) concentrated in operation by the bubble concentrating structure (210) passing into the detection region (240) and generating an output signal (S2) indicative of the one or more bubbles (270) passing through the detection region (240).

2. An underwater detection apparatus (100) as claimed in claim 1, characterized in that the apparatus (100) is adapted to detect at least one of: one or more gas bubbles (270), one or more oil bubbles (270).

3. An underwater detection apparatus (100) as claimed in claim 1 or 2, characterized in that the second structure (230) is implemented as a substantially frusto-conical structure for spatially defining a volume in which the one or more bubbles (270) are concentrated in operation.

4. An underwater detection apparatus (100) as claimed in claim 1, 2 or 3, characterized in that the detection arrangement (240, 250) includes one or more sensors (260, 300) for passively detecting sounds generated by said one or more bubbles (270) passing in operation through the detection region (240) to generate a detected signal (S1), and a signal processing arrangement (280) for processing the detected signal (S1) to generate said output signal (S2) indicative of a presence and/or a lack of presence of the one or more bubbles (270) within the detection region (240).

5. An underwater detection apparatus (100) as claimed in any one of the preceding claims, characterized in that said detection arrangement (240, 250) includes a signal source (380) for interrogating in operation the detection region (240) using interrogating radiation, and one or more sensors for detecting one or more bubbles (270) present in the detection area (240) by way of transmitted portions and/or reflected portions of the interrogating radiation.

6. An underwater detection apparatus (100) as claimed in claim 5, characterized in that said signal source (380) and said one or more sensors of said detection arrangement (24, 250) are housed within a mutually common unit.

7. An underwater detection apparatus (100) as claimed in claim 5, characterized in that the detection arrangement (240, 250, 280) includes a signal processing unit (280) for measuring a time-of-flight of the interrogating radiation through the detection region (240) and/or an acoustic impedance of the detection region (240) for determining a presence of one or more bubbles (270) rising up within the detection region (240).

8. An underwater detection apparatus (100) as claimed in claim 5, characterized in that the signal source for generating the interrogating radiation is adjustable in frequency and/or amplitude to stimulate non-linear resonance in said one or more bubbles (270), and said output signal (S2) indicative of the one or more bubbles (270) being present in the detection region (240) is generated by the detection arrangement (240, 250) from harmonic signal components generated as a consequence of exciting said non-linear resonance in the one or more bubbles (270).

9. An underwater detection apparatus (100) as claimed in any one of the preceding claims, characterized in that said apparatus (100) further includes an arrangement (300) for periodically interrupting in operation a supply of collected bubbles (270) from the bubble concentrating structure (210) to the detection region (240) for enabling said apparatus (100) to differentiate between signals from the detection arrangement (240, 250) indicative of bubbles (270) being present in the detection region (240), and indicative of bubbles (270) being absent from the detection region (240).

10. An underwater detection apparatus (100) as claimed in claim 9, characterized in that said arrangement for periodically interrupting in operation the supply of collected bubbles (270) from the first structure (210) to the detection region (240) includes at least one of:

(i) an actuated valve (300) spatially located in operation below said detection arrangement (240, 250); and

(ii) an actuated bubble collection arrangement which is operable to release periodically one or more collected bubbles (270) therefrom into the detection region (240).

11. An underwater detection apparatus (100) as claimed in any one of the preceding claims, characterized in that said detection region (240) further includes in respect thereof a temperature sensor and a pressure sensor for enabling the signal processing arrangement (280) to determine sizes of the one or more bubbles (270) from their measured non-linear resonant frequencies.

12. An underwater detection apparatus (100) as claimed in any one of the preceding claims, characterized in that said apparatus (100) is adapted to be mounted upon a remotely operated vehicle (ROV) for operation.

13. An underwater detection apparatus (100) as claimed in any one of the preceding claims, characterized in that the detection region (240) is provided with a gas analyzer arrangement for analyzing a composition of the one or more bubbles (270) passing in operation through the detection region (240).

14. An underwater detection apparatus (100) as claimed in any one of the preceding claims, characterized in that the signal processing arrangement (280) is operable to excite the detection arrangement (240, 250) at a frequency in a range of 1 kHz to 10 MHz, more preferable in a range of 10 kHz to 5 MHz, and most preferably in a range of 100 kHz to 1 MHz.

15. A method of employing an underwater detection apparatus (100) for detecting a presence of one or more bubbles (270) within an aquatic environment (10), characterized in that said method includes:

(a) using a first structure (210) including a lower peripheral edge (220) to define an area for said apparatus (100) for collecting the one or more bubbles (270);

(b) using a second structure (230) for spatially concentrating the one or more bubbles (270) received within the area defined by the lower peripheral edge (220) into a detection region (240); and

(c) using a detection arrangement (240, 250) for detecting the one or more bubbles (270) concentrated in operation by the second structure (210) into the detection region (240) and generating an output signal (S2) indicative of the one or more bubbles (270) passing through the detection region (240).

16. A method as claimed in claim 15, characterized in that said method includes employing said signal processing arrangement (280) to detect at least one of: one or more gas bubbles (270), one or more oil bubbles (270).

17. A method as claimed in claim 15 or 16, characterized in that said method includes implementing said second structure (230) as a substantially frusto-conical structure for spatially defining a volume in which the one or more bubbles (270) are concentrated in operation.

18. A method as claimed in claim 15, 16 or 17, characterized in that said method includes employing one or more sensors (300) in the detection arrangement (240, 250) for passively detecting sounds generated by said one or more bubbles (270) passing in operation through the detection region (240) to generate a detected signal (S1), and employing a signal processing arrangement (280) for processing the detected signal (S1) to generate said output signal (S2) indicative of a presence and/or a lack of presence of the one or more bubbles (270) within the detection region (240).

19. A method as claimed in claim 15, 16, 17 or 18, characterized in that said method includes employing a signal source (380) of said detection arrangement (240, 250) for interrogating in operation the detection region (240) using

corresponding interrogating radiation, and employing one or more sensors for detecting one or more bubbles (270) present in the detection area (240) by way of transmitted portions and/or reflected portions of the interrogating radiation.

20. A method as claimed in claim 19, characterized in that said method includes employing a signal processing unit (280) in the detection arrangement (240, 250, 280) for measuring a time-of-flight of the interrogating radiation through the detection region (240) and/or an acoustic impedance of the detection region (240) for determining a presence of one or more bubbles (270) rising up within the detection region (240).

21. A method as claimed in claim 19, characterized in that said method includes adjusting in frequency and/or amplitude the signal source for generating the interrogating radiation to stimulate non-linear resonance in said one or more bubbles (270), and determining from said signal (S1) indicative of the one or more bubbles (270) present in the detection region (240) harmonic signal components generated as a consequence of exciting said non-linear resonance in the one or more bubbles (270) for generating the output signal (S2) for providing the output signal (S2).

22. A method as claimed in any one of claims 15 to 21, characterized in that said method further includes using an arrangement (300) for periodically interrupting in operation a supply of collected bubbles (270) from the bubble concentrating structure (210) to the detection region (240) for enabling said apparatus (100) to differentiate between signals from the detection arrangement (240, 250) indicative of bubbles (270) being present in the detection region (240), and indicative of bubbles (270) being absent from the detection region (240).

23. A method as claimed in claim 22, characterized in that the method includes implementing the arrangement for periodically interrupting in operation the supply of collected bubbles (270) from the second structure (210) to the detection region (240) to include at least one of:

(i) an actuated valve (300) spatially located in operation below said detection arrangement (240, 250); and

(ii) an actuated bubble collection arrangement which is operable to release periodically one or more collected bubbles (270) therefrom into the detection region (240).

24. A method as claimed in any one of claims 15 to 23, characterized in that said method includes utilizing in respect of the detection region (240) a temperature sensor and a pressure sensor for enabling the signal processing arrangement (280) to determine sizes of the one or more bubbles (270) from their measured non-linear resonant frequencies.

25. A method as claimed in any one of claims 15 to 24, characterized in that said method includes implementing said apparatus (100) for mounting upon a remotely operated vehicle (ROV) for operation.

26. A method as claimed in any one of claims 15 to 25, characterized in that the method includes providing said detection region (240) with a gas analyzer arrangement for analyzing a composition of the one or more bubbles (270) passing in operation through the detection region (240).

27. A method as claimed in any one of claims 15 to 26, characterized in that said method includes operating the signal processing arrangement (280) to excite the detection arrangement (240, 250) at a frequency in a range of 1 kHz to 10 MHz, more preferable in a range of 10 kHz to 5 MHz, and most preferably in a range of 100 kHz to 1 MHz.

28. A software product recorded on a machine-readable data storage medium, characterized in that said software product is executable on computing hardware (280) for implementing a method as claimed in any of claims 15 to 27.

Amendments to the claims have been filed as follows.

CLAIMS

1. An underwater detection apparatus (100) for detecting a presence of one or more bubbles (270) within an aquatic environment (10), said apparatus (100) includes a first structure (210) including a lower peripheral edge (220) for defining an area over which said apparatus (100) is operable to collect the one or more bubbles (270), a second structure (230) for spatially concentrating the one or more bubbles (270) received within the area defined by the lower peripheral edge (220) into a detection region (240), and a detection arrangement (240, 250) for detecting the one or more bubbles (270) concentrated in operation by the bubble concentrating structure (210) passing into the detection region (240) and generating an output signal (S2) indicative of the one or more bubbles (270) passing through the detection region (240), wherein said detection arrangement (240, 250) includes a signal source (380) for interrogating in operation the detection region (240) using interrogating radiation, and the detection arrangement (240, 250, 280) includes a signal processing unit (280) for measuring a time-of-flight of the interrogating radiation through the detection region (240) and/or an acoustic impedance of the detection region (240) for determining a presence of one or more bubbles (270) rising up within the detection region (240).

2. An underwater detection apparatus (100) as claimed in claim 1, wherein the apparatus (100) is adapted to detect at least one of: one or more gas bubbles (270), one or more oil bubbles (270).

3. An underwater detection apparatus (100) as claimed in claim 1 or 2, wherein the second structure (230) is implemented as a substantially frusto-conical structure for spatially defining a volume in which the one or more bubbles (270) are concentrated in operation.

4. An underwater detection apparatus (100) as claimed in claim 1, 2 or 3, wherein the detection arrangement (240, 250) includes one or more sensors (260, 300) for passively detecting sounds generated by said one or more bubbles (270) passing in operation through the detection region (240) to generate a detected signal (S1), and a signal processing arrangement (280) for processing the detected signal

(S1) to generate said output signal (S2) indicative of a presence and/or a lack of presence of the one or more bubbles (270) within the detection region (240).

5. An underwater detection apparatus (100) as claimed in claim 1, wherein said detection arrangement (240, 250) includes one or more sensors for detecting one or more bubbles (270) present in the detection area (240) by way of transmitted portions and/or reflected portions of the interrogating radiation.

6. An underwater detection apparatus (100) as claimed in claim 1, wherein said signal source (380) and said one or more sensors of said detection arrangement (24, 250) are housed within a mutually common unit.

7. An underwater detection apparatus (100) as claimed in claim 1, wherein the signal source for generating the interrogating radiation is adjustable in frequency and/or amplitude to stimulate non-linear resonance in said one or more bubbles (270), and said output signal (S2) indicative of the one or more bubbles (270) being present in the detection region (240) is generated by the detection arrangement (240, 250) from harmonic signal components generated as a consequence of exciting said non-linear resonance in the one or more bubbles (270).

8. An underwater detection apparatus (100) as claimed in any one of the preceding claims, wherein said apparatus (100) further includes an arrangement (300) for periodically interrupting in operation a supply of collected bubbles (270) from the bubble concentrating structure (210) to the detection region (240) for enabling said apparatus (100) to differentiate between signals from the detection arrangement (240, 250) indicative of bubbles (270) being present in the detection region (240), and indicative of bubbles (270) being absent from the detection region (240).

9. An underwater detection apparatus (100) as claimed in claim 8, wherein said arrangement for periodically interrupting in operation the supply of collected bubbles (270) from the first structure (210) to the detection region (240) includes at least one of:

(i) an actuated valve (300) spatially located in operation below said detection arrangement (240, 250); and

(ii) an actuated bubble collection arrangement which is operable to release periodically one or more collected bubbles (270) therefrom into the detection region (240).

10. An underwater detection apparatus (100) as claimed in any one of the preceding claims, wherein said detection region (240) further includes in respect thereof a temperature sensor and a pressure sensor for enabling the signal processing arrangement (280) to determine sizes of the one or more bubbles (270) from their measured non-linear resonant frequencies.

11. An underwater detection apparatus (100) as claimed in any one of the preceding claims, wherein said apparatus (100) is adapted to be mounted upon a remotely operated vehicle (ROV) for operation.

12. An underwater detection apparatus (100) as claimed in any one of the preceding claims, wherein the detection region (240) is provided with a gas analyzer arrangement for analyzing a composition of the one or more bubbles (270) passing in operation through the detection region (240).

13. An underwater detection apparatus (100) as claimed in any one of the preceding claims, wherein the signal processing arrangement (280) is operable to excite the detection arrangement (240, 250) at a frequency in a range of 1 kHz to 10 MHz, more preferable in a range of 10 kHz to 5 MHz, and most preferably in a range of 100 kHz to 1 MHz.

14. A method of employing an underwater detection apparatus (100) for detecting a presence of one or more bubbles (270) within an aquatic environment (10), wherein said method includes:

(a) using a first structure (210) including a lower peripheral edge (220) to define an area for said apparatus (100) for collecting the one or more bubbles (270);

(b) using a second structure (230) for spatially concentrating the one or more bubbles (270) received within the area defined by the lower peripheral edge (220) into a detection region (240); and

(c) using a detection arrangement (240, 250) for detecting the one or more bubbles (270) concentrated in operation by the second structure (210) into the detection region (240) and generating an output signal (S2) indicative of the one or more bubbles (270) passing through the detection region (240), and

(d) employing a signal source (380) of said detection arrangement (240, 250) for interrogating in operation the detection region (240) using corresponding interrogating radiation, and

(e) employing a signal processing unit (280) in the detection arrangement (240, 250, 280) for measuring a time-of-flight of the interrogating radiation through the detection region (240) and/or an acoustic impedance of the detection region (240) for determining a presence of one or more bubbles (270) rising up within the detection region (240).

15. A method as claimed in claim 14, wherein said method includes employing said signal processing arrangement (280) to detect at least one of: one or more gas bubbles (270), one or more oil bubbles (270).

16. A method as claimed in claim 14 or 15, wherein said method includes implementing said second structure (230) as a substantially frusto-conical structure for spatially defining a volume in which the one or more bubbles (270) are concentrated in operation.

17. A method as claimed in claim 14, 15 or 16, wherein said method includes employing one or more sensors (300) in the detection arrangement (240, 250) for passively detecting sounds generated by said one or more bubbles (270) passing in operation through the detection region (240) to generate a detected signal (S1), and employing a signal processing arrangement (280) for processing the detected signal (S1) to generate said output signal (S2) indicative of a presence and/or a lack of presence of the one or more bubbles (270) within the detection region (240).

18. A method as claimed in claim 14, 15, 16 or 17, wherein said method includes employing one or more sensors for detecting one or more bubbles (270) present in the detection area (240) by way of transmitted portions and/or reflected portions of the interrogating radiation.

19. A method as claimed in claim 18, wherein said method includes adjusting in frequency and/or amplitude the signal source for generating the interrogating radiation to stimulate non-linear resonance in said one or more bubbles (270), and determining from said signal (S1) indicative of the one or more bubbles (270) present in the detection region (240) harmonic signal components generated as a consequence of exciting said non-linear resonance in the one or more bubbles (270) for generating the output signal (S2) for providing the output signal (S2).

20. A method as claimed in any one of claims 14 to 19, wherein said method further includes using an arrangement (300) for periodically interrupting in operation a supply of collected bubbles (270) from the bubble concentrating structure (210) to the detection region (240) for enabling said apparatus (100) to differentiate between signals from the detection arrangement (240, 250) indicative of bubbles (270) being present in the detection region (240), and indicative of bubbles (270) being absent from the detection region (240).

21. A method as claimed in claim 20, wherein the method includes implementing the arrangement for periodically interrupting in operation the supply of collected bubbles (270) from the second structure (210) to the detection region (240) to include at least one of:

(i) an actuated valve (300) spatially located in operation below said detection arrangement (240, 250); and

(ii) an actuated bubble collection arrangement which is operable to release periodically one or more collected bubbles (270) therefrom into the detection region (240).

22. A method as claimed in any one of claims 14 to 21, wherein said method includes utilizing in respect of the detection region (240) a temperature sensor and a pressure sensor for enabling the signal processing arrangement (280) to determine

sizes of the one or more bubbles (270) from their measured non-linear resonant frequencies.

23. A method as claimed in any one of claims 14 to 22, wherein said method includes implementing said apparatus (100) for mounting upon a remotely operated vehicle (ROV) for operation.

24. A method as claimed in any one of claims 14 to 23, wherein the method includes providing said detection region (240) with a gas analyzer arrangement for analyzing a composition of the one or more bubbles (270) passing in operation through the detection region (240).

25. A method as claimed in any one of claims 14 to 24, wherein said method includes operating the signal processing arrangement (280) to excite the detection arrangement (240, 250) at a frequency in a range of 1 kHz to 10 MHz, more preferable in a range of 10 kHz to 5 MHz, and most preferably in a range of 100 kHz to 1 MHz.

26. A software product recorded on a machine-readable data storage medium, wherein said software product is executable on computing hardware (280) for implementing a method as claimed in any of claims 15 to 27.

Application No: GB1113278.4 **Examiner:** Simon Colcombe

Claims searched: 1-28 **Date of search:** 4 November 2011

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X,Y	X:1-3, 5-7, 14-17, 19, 20, 27; Y: 4, 12, 18, 25, at least	GB1152404 A (AUTOMATISME CIE GLE) Figure 1 and related description
X	X:1-3, 5, 6, 15-17, 19; at least	JP2002022590 A (HONDA) EPO & WPI abstracts; Figs 1-3, in particular
X	X:1-3, 5, 6, 15-17, 19; at least	EP0519689 A2 (EXPERTEK) Figures 1-3 and related description; claim 1 for example
X	X:1-3, 5, 6, 15-17, 19; at least	DE3922314 A1 (ZIMMER) EPO & WPI abstracts and drawing
X	X:1-3, 5, 6, 15-17, 19; at least	JP01145541 A (KAYABA INDUSTRY) EPO abstract; Figure 2
X	X:1-3, 5, 6, 15-17, 19; at least	JP63122927 A (MITSUBISHI ELECTRIC) EPO abstract and Figure 1
Y	12, 25	US4658750 A (MALCOSKY) Whole document
Y	4, 18	US4462249 A (ADAMS) Abstract for example

Y	4, 18	JP59012329 A (SUMITOMO RUBBER) EPO abstract

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

E21B; G01M; G01N

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	**Subgroup**	**Valid From**
G01M	0003/06	01/01/2006
E21B	0047/10	01/01/2006
G01M	0003/24	01/01/2006
G01N	0029/02	01/01/2006