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Device and system for performing measurements under ice-covered water

CROSS-REFERENCE(S) TO RELATED APPLICATION(S)

[1] This application is an original provisional patent application.

FIELD OF THE DISCLOSURE

[2] This application relates to exploration in a fluid environment. More specifically, this application relates to underwater and under ice exploration, with some embodiments of the disclosure equipped to discover and map under ice oil spills.

GOVERNMENT SUPPORT CLAUSE

[3] This invention was made with Government support provided by subaward of federal funds awarded via the Arctic Domain Awareness Center (ADAC) at the University of Alaska Anchorage (UAA). Specifically, the associated research with this invention is based on work supported by the U.S. Department of Homeland Security (DHS) under Grant Award Number 2014-ST-ML002-03; the Center for Maritime Research (ADAC). In accordance with DHS Science and Technology (S&T) Office of University Programs (OUP)-UAA ADAC Cooperative Agreement, DHS S&T has certain rights in the invention which is access to intellectual property royalty free.

ACKNOWLEDGEMENT OF EFFORT

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Research Professional, UAA, Elizabeth Matthews, MS, Education and Administrative Manager, UAA, Connor Keesecker, BA, Research and Communications.

[5] Furthermore, the ADAC respectfully acknowledges the accomplishments of the Development of Propeller Driven Long Range Autonomous Underwater Vehicle (LRAUV) System for Under-Ice Mapping of Oil Spills and Environmental Hazards teams at Woods Hole Oceanographic Institution (WHOI) and Monterey Bay Aquarium Research Institute (MBARI). Including the following skilled personnel, Amy Kukulya (WHOI), Brett Hobson (MBARI), Dr. James Bellingham (WHOI), Noa Yoder (WHOI), Amanda Besaw (WHOI), Ryan Govostes (WHOI), Steven Seeberger (WHOI), Daniel Gomez-Ibanez (WHOI), Dr. Chris Reddy, (WHOI), Sean Whelan (WHOI), Brian Kieft (MBARI), Ben Raanan (MBARI).

BACKGROUND

[6] Human activities, including oil and gas, shipping, and tourism are increasing in the northern, arctic seas. As these activities increase, the possibility of an oil-spill or other contamination increases. Operation and response to any spill in artic waters is made more difficult due to the ice-covered portions of the ocean. The artic poses many unique challenging conditions, making effective response efforts much more difficult. Currently, there is no United States Coast Guard (USCG) baseline for an autonomous under water vehicle (AUV) to meet the unique demands of Arctic operations that requires a minimal logistical footprint, a small operational team, and oil detection and mapping capability.

[7] A desirable solution would be a solution that could respond, find, characterize, and map a spill in Arctic conditions, including the denied space of under-ice water (i.e., ice-covered areas). The desired solution would preferably be autonomous with little to no human presence. Ideally, humans would only be used to deploy and recovery an AUV. The AUV would then perform all of the remaining duties without a nearby human presence.

[8] Some individual aspects of the above desirable solution are available, for example the Tethys-class long range autonomous vehicle (Hobson BW, et al., *2012 IEEE/OES Autonomous Underwater Vehicles (AUV)*, 2012, pp. 1-8), AUV line capture and line recovery (Piskura J, et al., *OCEANS 2016 MTS/IEEE Monterey*, 2016, pp. 1-5), and artic acoustic communications (Freitag L, et al., *OCEANS 2015 - MTS/IEEE Washington*, 2015, pp. 1-5). However, no previous work has successfully integrated these attempts, along with additional needed solutions, into a single, practical system.

[9] Here is described an Arctic-capable long-range AUV that is helicopter portable, carries an environmental mapping payload, allowing rapid response while providing situational awareness and damage mitigation for first responders or the USCG. The portable Long Range AUV, may detect an

under-ice anomaly and oil spills with deployable arctic buoys for aided navigation, remote communication and docking.

SUMMARY

[10] In what follows, a brief description of the invention of the disclosure are explained in more, in which:

[11] A modified and adapted Tethys propeller driven long range autonomous underwater vehicle and corresponding communication buoys purpose built to operate as a system to accomplish characterization and communication of a marine oil spills in ice-laden regions to responding officials and spill management agencies.

BRIEF DSCRPTION OF THE DRAWINGS

[12] In what follows, preferred embodiments of the disclosure are explained in more detail with reference to the drawings, in which:

[13] FIG. 1 is a block diagram of the buoy and vehicle according to one embodiment of the present disclosure.

[14] FIGS. 2A and 2B illustrate, in two flow charts, two methods of use of the system described herein.

[15] FIGS. 3A and 3B are two views of the buoy according to one embodiment.

[16] FIG. 4 illustrates a system according to one embodiment.

[17] FIGS. 5A-5C illustrate the docking mechanism according to one embodiment; FIG. 5A showing a vehicle having whiskers and a latch; FIG. 5B graphically illustrating the distance between vehicle and buoy as determined by the vehicle on several unsuccessful docking attempts and a successful docking (distance = 0); and FIG. 5C is a screen capture of video from a front-facing camera of the buoy's docking acceptor.

[18] FIGS. 6A and 6B illustrate two possible configurations of vehicle according to the present disclosure.

[19] FIG. 7A is a graphical user interface providing information and command options for a user at a command center for controlling system according to one embodiment. FIG. 7B is a graphical user interface displaying real-time vehicle location for a user at a command center.

[20] FIGS. 8A and 8B two views of one representative pattern of one possible survey pattern for a vehicle to conduct while searching for anomalies, according to one embodiment. FIG. 7A is depicts low

level (<6 to < 9×10^4 concentration) sensor readings in dark lines, while FIG. 7B is the same survey pattern 204 where high levels (>9 to ~11×10^4 concentration) sensor readings are in dark lines (i.e., inverted from FIG. 7A).

[21] FIG. 9 is a representation of one vehicle deployment at an ice-covered location. Deployment mechanism is located at site labeled Dock B. On one occasion a vehicle was located, represented by label 'vehicle actual location' and location fixes (labeled fix 1, fix 2, and fix 4) and associated uncertainty circles. Ice-covered water is marked by cross-hatched lines; land is marked by solid white areas.

[22] The figures and illustrations used herein are not necessarily to scale and some features may be exaggerated or minimized in order to illustrate the details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present invention.

DETAILED DESCRIPTION

Overview

[23] The present disclosure describes a system and method of use thereof illustrated in FIG. 1, having at least an underwater vehicle and a gateway communications buoy. The underwater vehicle, is referred herein as simply "vehicle" and the gateway communications buoy is referred herein as simply "buoy". In one embodiment, the vehicle operates underwater to find, characterize, and map an underwater anomaly. The buoy provides navigation, homing, communications, and docking abilities for the vehicle, enabling the vehicle to operate, communicate, be recovered, and for data relay. Typically, the system includes a transportation mechanism to deliver the vehicle and buoy to a response area, a deployment mechanism to deploy vehicle and buoy into the water, and a recovery mechanism to recover the vehicle and buoys.

[24] In some embodiments, a method of operation is provided. One such method embodiment is depicted in FIG. 2, where a helicopter (a transportation mechanism) flies to a spill area and deploys an AUV (a vehicle) and a buoy into the water. The helicopter is then free to leave the spill area, while the AUV initiates communications and navigation links to the buoy and begins surveying (one of many possible behaviors) the area for the anomaly of interest. The buoy provides a communications link to a command center (in FIG. 2 an Iridium satellite link) and may accept and forward new commands (i.e. behaviors) from the command center to the vehicle. The vehicle executes predetermined behaviors and collects relevant data from its sensors. Once the vehicle finishes performing its behaviors, it returns to

and docks with the buoy's docking mechanism. The system is then ready for collection, either by the transportation mechanism or another recovery mechanism; for example, a crewed surface ship.

[25] In some embodiments of the disclosure, the vehicle is used to detect, find, characterize, map, survey, or measure at least one anomaly. An anomaly includes but is not limited to any naturally occurring or manmade object, group of objects, organism, pattern or phenomena that is located above the surface of the water, at the water bottom, underground, submerged in water, and submerged in water that is covered by a layer of ice. The anomaly has sufficiently different composition or properties from the surrounding air, water, or ice environment such that it can be detected or measured using at least one sensor or sensor array. On its longest dimension, the anomaly can be less than 1 cm, 10 cm, 1 m, 10 m, 100 m, 500 m, 1 km, 5 km, 10 km, 50 km, 100 km, 500 km, 1000 km, or 5000 km. Water containing the anomaly can be fresh water, sea water, or brackish water. Non-limiting examples of anomalies are oil, methane bubbles in the water column, water contaminants, underground reservoirs, harmful algal blooms (HABs), shelf break anomalies, whales, organisms or features on the ocean floor, objects submerged in rivers or lakes, surface oil platforms, undersea oil equipment, and undersea cables. Shelf breaks are the submerged offshore edge of a shallow continental shelf, where the seafloor transitions to continental slope. A shelf break is characterized by markedly increased slope gradients toward the deep ocean bottom. The shelf break may be as shallow as 20 meters (65 feet) and as deep as 550 meters; the worldwide average depth is 133 meters. Shelf break anomalies are any identifiable feature associated with a shelf break.

[26] Detailed embodiments of the present disclosure are disclosed herein. It is to be understood that the disclosed embodiments are merely exemplary of the disclosure that may be embodied in various and alternative forms. Although the design and use of various embodiments are discussed below, it should be appreciated that the present disclosure provides many concepts that may be embodied in a wide variety of contexts and use cases. The specific aspects and embodiments discussed herein are merely illustrative of ways to make and use the disclosure and do not limit the scope of the disclosure. Upon reading this disclosure, many alternative embodiments of the present disclosure will be apparent to persons of ordinary skill in the art.

Vehicle

[27] The present disclosure provides for at least one vehicle capable of submersion or traveling under water, typically under ice-covered water. It is within the scope of this disclosure for an embodiment to have more than one vehicle; however vehicle will be referred in the singular form for

simplicity. The vehicle is configured to be delivered to a response area to survey and map the area autonomously. Typically, a buoy is deployed within or near the response area, enabling communications between vehicle and a remote command center. Furthermore, the vehicle preferably is capable of ice-relative acoustic navigation (while remaining underneath an ice-covered surface), in addition to communications and navigation with the buoy. The vehicle may either be delivered to the response area by a transportation mechanism or may travel independently to the response area.

[28] In some embodiments, the vehicle performs a survey behavior underwater. In some embodiments, the vehicle remains underwater for the majority of the survey. In some embodiments, the vehicle remains underwater for the entirety of the survey. In some embodiments, the vehicle remains under ice-covered water for the majority of the survey. In some embodiments, the vehicle remains under ice-covered water for the entirety of the survey.

[29] While it is within the scope of the present disclosure for the vehicle to be any suitable solution known in the art, the preferred vehicle is long range, self-propelled, and easily transported, deployed, and recovered. In the currently preferred embodiment, the vehicle is a Tethys Long Range AUV (LRAUV). The LRAUV is described in Hobson BW, et al., "Tethys-class long range AUVs - extending the endurance of propeller-driven cruising AUVs from days to weeks" *2012 IEEE/OES Autonomous Underwater Vehicles (AUV)*, 2012, pp. 1-8 which is incorporated by reference in its entirety herein. The LRAUV is a long range, 300-meter depth rated, 2.7-meter-long, 0.3 m diameter, 110 kg dry weight AUV. The LRAUV is propeller driven vehicle with a speed of 0.5 to about 1.2 m/s. A buoyancy engine enables neutral buoyancy and drift mode. The LRAUV is designed to be low-drag and low-power (as in requiring little power), with a 15-day mission duration using 6 kWh rechargeable batteries. Optional expendable batteries having 11 kWh may also be added. A shifting mass is often included, using the batteries' mass to move back and forth in the vehicle's interior, aiding the buoyancy engine in low-power movement.

[30] In some embodiments, the vehicle is equipped with at least one sensor or sensor array. Sensors include, but are not limited to, active or passive sensors used to probe, measure, or categorize signals from properties, compositions, or other measurable features of an anomaly. Sensors may be attached to, towed by, or contained within the vehicle. In one embodiment, an LRAUV may be equipped with sensor such as conductivity, temperature, and depth (CTD), dissolved oxygen, fluorescence, backscatter and hydrocarbon detection, and PAR (Photosynthetically Active Radiation) sensors, as well as with a Doppler velocity log (DVL), Up-Down ADCP, sonar, communications, navigation (e.g., a USBL array), sonar (e.g., a multibeam sonar sensor), inertial measurement unit (INS), and the presently disclosed docker. Communications include any of satellite communications (e.g., Iridium), WiFi, cellular, argos

communications, VHF, underwater optical communications, and underwater acoustic communications. Underwater communications may include long range, underwater acoustic communications as described in Freitag L, et al., "Long range acoustic communications and navigation in the Arctic" *OCEANS 2015 - MTS/IEEE Washington*, 2015, pp. 1-5, incorporated by reference in its entirety herein. An LRAUV enables vehicle to be a propeller-driven AUV that can drift, hover and accurately navigate to a specified area. The buoyancy engine and mas shifter enable the vehicle to dive when stuck under-ice. In some embodiments, the Up-Down ADCP is an 600kHz RDI Pathfinders ADCP available from Teledyne Instruments, enabling measurement of water velocities and relative terrain navigation; the PAR sensor is from Licor, for example a LI-190R sensor, enabling measurement of photosynthetic artificial radiation, which is important for biological measurements in conjunction with the Ecopuck. A SeaOwl Ecopuck provides dissolved and droplet signals, a Seabird CTD provides conductivity, temperature and density measurement as well as dissolved oxygen measurements. Underwater optical or acoustic communications enables the vehicle to communicate to the gateway buoy without needing to surface, and also enables the vehicle to navigate to the source of the communications.

[31] In a preferred embodiment, the vehicle has an upward looking acoustic ice surface topography sonar. This sonar assists, along with buoy navigation, in ice-relative navigation. The vehicle's software further analyzes the sonar data to identify zones or areas of possible anomalies (e.g., oil accumulation). Detection of an anomaly area may trigger a new behavior for the vehicle. For example, a detected anomaly area may trigger a behavior instructing the vehicle to move to a location approximately below the detected area and a hover or zero-speed position holding mode. An acoustic echo may be produced and analyzed by the vehicle's software to determine if an anomaly exists; for example, to determine if oil is sandwiched between the seawater and sea ice. Upon anomaly detection, additional behaviors may be executed; for example, to continue a pre-planned survey, collecting one or more samples, ending the overall mission and docking with a buoy, communicating the anomaly detection, and the like.

[32] The vehicle can operate autonomously, can be controlled by human operators, or a combination thereof. Vehicle control is preferably conducted via remote communications. In one embodiment, an internet-accessible dashboard is provided for secure control by a user via a control device. The control device may be any suitable solution as known in the art, including by not limited to a computer, an ipad, and a cell phone. Information is relayed to and from the vehicle by the communications mechanism to a second communicator. In some embodiments, the second communicator is the gateway buoy. In under-ice environments, the communications are acoustic underwater communications. The buoy then relays the vehicle's communications to the command center. In some situations, the vehicle may safely surface

in the fluid body (e.g., the ocean) and communicate with the second communicator by another communications solution on the vehicle, for example, directly to the command center by cellular, VHF, or WiFi, if within range.

[33] The vehicle is most preferably customizable with different sensors or components. In the currently preferred embodiment, the vehicle accepts a number of different sensors, each being modular to enable that vehicle with several sensing capabilities. In some embodiments, a range of sensors are included on a single vehicle to make that vehicle multi-purpose for different anomalies. For example, one vehicle may have sensors to detect oil, harmful algal blooms (HABs), shelf breaks, organism detection (e.g., whales), offshore energy production monitoring, and the like. Unrelated sensors for a given mission in this multi-purpose vehicle would then be turned off to extend mission time. In other embodiments, multiple vehicles may be provided, each vehicle having sensors specialized in detecting a specific anomaly and a command center could activate the appropriate vehicle, or a sub-set of the plurality of vehicles in response to an event.

[34] In some embodiments, the vehicle is equipped with a propulsion mechanism. The propulsion mechanism may be any suitable solution as known in the art. In one embodiment, the propulsion mechanism may be a motor and propeller system. In one embodiment, the propulsion mechanism is a buoyancy engine, using a pump to repeatedly change buoyancy. In one embodiment, the propulsion mechanism is a mass-shifter, using an adjustable mass within or connected to the vehicle to change the buoyancy of the vehicle. In some embodiments, the propulsion mechanism is a combination of solutions described herein.

Vehicle Docking mechanism.

[35] The present disclosure provides for a solution enabling the vehicle to dock to buoy while remaining underwater; this docking solution on the vehicle is referred herein as the docking mechanism or as simply the “docker”. In one preferred embodiment, the docker includes a custom nose payload having a latch, and at least two whiskers. In some embodiments the whiskers are fixed in place, in a catching state, forming an approximately V-shape away from the vehicle, forward and to either side of the vehicle’s nose. The vehicle homes in the buoy and the buoy’s docking acceptor during the docking behavior, and the vehicle is configured to determine the distance between itself and the buoy. The outstretched whiskers give the vehicle a larger surface area to contact the docking acceptor. If the vehicle fails to contact the docking acceptor, the determined distance between vehicle and docking acceptor increases, triggering a new docking behavior in that the vehicle will turn to navigate back

towards the buoy again and attempt a second docking. Repeated misses are possible, and the resulting distance determinations are illustrated in FIG. 5B. Once contact is made between docker and docking acceptor, the latch enables the vehicle to securely attach to the docking acceptor and remained docked until a new behavior is commanded (e.g., an undocking behavior or a recovery behavior).

[36] In one preferred embodiment, the whiskers articulate, as illustrated in FIG. 5A. Here, the whiskers have at least two states, a catching state and a storage state. In the storage state, the whiskers fit at least partially within spaces built into the side of the vehicle nose such that when not docking, the vehicle presents a streamlined profile without the whiskers significantly protruding from the vehicle's exterior. The articulating whiskers may then be commanded to move or pivot into an open, catching state. When in the catching state, the articulating whiskers function like the fixed whiskers described above. In some embodiments, the docker further has a forward-facing video camera enabling imaging of the docking behavior. In some embodiments, the docker may comprise elements known in the art, as described in Piskura J, et al., "Development of a robust Line Capture, Line Recovery (LCLR) technology for autonomous docking of AUVs" *OCEANS 2016 MTS/IEEE Monterey*, 2016, pp. 1-5, incorporated by reference in its entirety herein.

Gateway buoy

[37] The present disclosure provides for a communications solution referred herein simply as the buoy, illustrated in at least FIGS. 1, 3A-3B, and 4. The buoy provides at least communications, navigation, and docking acceptor mechanisms for the vehicle. Preferably, the buoy is within or proximate to the response area. Buoy communications include underwater and in-air communications components. Typically, underwater communications relay information between buoy and vehicle, while in-air communications relay information between buoy and command center. A typical communications relay includes (1) establishing a underwater communications link between vehicle and buoy, (2) communications (e.g., via RF Antenna) from buoy to shore antenna, (3) shore antenna to internet, and (4) internet to user (e.g., via browser dashboard). Position and navigation components on the buoy enable the vehicle to move about the response area in desirable patterns and to desirable locations, as well as return to the buoy without returning to the surface to obtain absolute location information (e.g., GPS coordinates). In some embodiments, a single buoy provides navigation information with a ultrashort baseline (USBL) component. In other embodiments, more than one buoy is provided, each buoying providing a node in a long baseline (LBL) array.

[38] In some embodiments, the buoy provides a docking acceptor, enabling underwater docking of vehicle to buoy. This docking ability provides easy recovery of vehicle after a mission and, in some embodiments, recharging of vehicle's batteries and data transfer. A Buoy may have more than one docking acceptor and may dock with more than one vehicle. Buoy may also include an ice anchor, a bottom anchor, and a power generator (e.g., solar panels, wind or water turbine). In one embodiment, buoy is activatable by communication link from the command center; for example, the buoy is in a low-power state until a command is sent through in-air communications (e.g. Iridium), commanding buoy to enter a fully active (and higher power consuming) state.

[39] In the currently preferred embodiment, buoys are provided in one of a high frequency (HF) configuration or a low frequency (LF) configuration. In HF configuration embodiments, the buoy uses communications at approximately 25 kHz frequency with shorter ranges than LF configurations. The exact ranges are impacted by environmental factors, but for HF configurations average out to about 3 km. In LF configuration embodiments, buoy has an acoustic range of between 5 km and exceeding 10 km. In some embodiments, a buoy may be both HF and LF. In these embodiments, some buoy components are HF, for example, a DUSBL is HF, used for homing and docking, and some buoy components are LF, for example the underwater communications mechanism. Typically, the buoy would then switch between HF and LF configurations to use each component or set of components.

[40] Buoy components are illustrated in FIGS. 3A-3B. Buoy most often has a radome, a structural weatherproof enclosure that minimally attenuates electromagnetic signals transmitted or received by components located within the radome. In one embodiment, the radome encloses an ANTCOM antenna, an antenna stalk, and a core handle. In some embodiments, the one or more antennas may be extendable. In one of these embodiments, the one or more antennas may be extended or otherwise deployed through ice, either manually or autonomously. The main buoy housing is referred to as the endcap, and often has SubConn connectors, a viewport, switch spindle and depressor, an endcap distribution board, the main chassis components, a power source (e.g., electrochemical battery packs), the underwater communications mechanism (in FIG. 3A, a micromodem electronics stack), and at least one in-air communications mechanism (e.g., an Iridium 9523 interface with associated module). The end cap exterior housing (also referred as the hull), has a hull handle, floatation foam, hull coupling bars and hose to buoy coupler with cable chase.

[41] In one embodiment, underneath the buoy is a HSLS artic hose with SubConn connectors, termination, hose, v-clamps and hose adaptor bale that connects to the docking mechanism via a yale grip having SubConn connectors, a load bearing transducer cable, impulse connectors. Attached to the

yale grip, in one embodiment illustrated in FIG. 3A, is a transduce cage having transducer mounts and a geospectrum M21 transducer.

[42] The buoy most often includes satellite communications (e.g., Iridium), radio frequency communications, WiFi, cellular, visual identification flasher, USBL, LBL, other communications solutions, underwater docking target, and expendable batteries.

[43] In some embodiments, system has only a single buoy. In some embodiments, more than one buoy is provided. Additional buoys enable LBL positioning and navigation, as well as enable other behaviors including navigating the vehicle from one buoy to another.

Deployment

[44] The present disclosure provides for a transportation mechanism, a deployment mechanism and a recovery mechanism. In the currently preferred embodiment, the system of the vehicle and buoy is readily deployable without requiring special handling equipment. The transportation mechanism may include, but is not limited to, ships, aircraft (fixed or rotary wing), zodiacs, piloted, remotely-operated, or autonomous vehicles operating on land, in air or underwater, or manual deployment by human operators from land, air, water surface, underwater, beach, pier, or other manmade or natural structure. The transportation mechanism may be used to deploy at least one vehicle, or at least one buoy, or at least one vehicle and at least one buoy. The transportation mechanism incorporates a deployment mechanism such as a hoist, crane, boom, towline, fixture, or the like. Operating on ice usually requires a simple deployment mechanism comprising a gantry placed over an access hole, with associated rudimentary block and tackle for ease of getting the system to and from the ice. Other deployment mechanisms may be incorporated into the transportation mechanism; for example, a pulley and lift bail system secured to a helicopter via a releasable hook solution.

[45] The recovery mechanism in one currently preferred embodiment includes the buoy and the buoy's docking acceptor. Once the vehicle completes the commanded behaviors and sends the desired data back to the command center, it docks to the docking acceptor. The docking occurs underwater and often under ice. The vehicle may remain at the docking acceptor until the system is recovered. A human-assisted recovery team may then recover the system at their leisure and in good conditions. In some cases, a vessel or rotary wing aircraft is brought to the buoy's vicinity, the buoy is cut out of the ice, and a deployment mechanism (e.g. a gantry) is used to extract the vehicle.

Behaviors

[46] The present disclosure provides for a number of software behaviors for a vehicle to perform as determined by a user. Behaviors enable the vehicle to be deployed, perform a mission, and enable recovery. Behaviors include, but are not limited to, docking, undocking, preventing surfacing, new sensor configurations, refinement of plume tracking for anomaly mapping, find ice-hole, circle if lost, multi-buoy navigation, multi-buoy dock, and multi-buoy leapfrog. Additional behaviors may be included for different embodiments; for example, in one embodiment, a behavior for finding an oil spill source is included. This behavior may include using the vehicle's onboard sensors to detect oil and to follow an increasing maximum of sensed oil concentration. In another embodiment or use, the behavior of mapping the extent of an anomaly (e.g., an oil plume) may be executed. Here the behavior may have instructions for the vehicle to perform a defined survey (e.g., mow the lawn) while sensing for the anomaly (e.g., oil concentration). In some embodiments, a detect and report behavior is used to detect an anomaly and prioritizes informing first responders at the command center of the anomaly detection. In many embodiments, relaying of information through the buoy in real or close to real time is important, and vehicles may have informing behaviors to prioritize information transfer, most often by means of the buoy.

[47] Use cases. Several possible use cases are now presented, but it should be understood that this list is not limiting. The disclosed system and method may be used for detecting a hot spot of contamination underwater or under-ice and mapping out the contaminated area. Finding the extent of the contamination; for example, where oil (a contaminate) is and is not; locating the source of contamination. Operating for 15 days and reporting data back over the horizon; collecting baseline data and reacting to anomalies. Parking the vehicle underwater attached to a cable or ⅜ inch line (i.e., the docking acceptor) until needed again (and, in some cases, further staying in a low power or sleep mode while docked). Detecting marine mammals, mapping the underside of the ice and seafloor and therefore the system is multi-mission capable. Additionally, many other environmental anomalies can be detected by the system besides the often-given example of oil. The system can be configured to 'listen' for events; for example, whales, weather, and the like, as well as detect and respond to these events. Other applications include detection of harmful algae blooms, gas bubbles, methane leaks, pipeline mapping, hydrographic surveys, and the like. The disclosed system (both vehicle and buoy) has a small footprint and is designed to be rapid response and helicopter portable. No other capability exists for under-ice rapid response helicopter portable in the form of an AUV and buoy system.

[48] Although specific features of the present disclosure are shown in some drawings and not in others, this is for convenience only, as each feature may be combined with any or all of the other features in accordance with the disclosure. While there have been shown, described, and pointed out fundamental novel features of the disclosure as applied to a preferred embodiment thereof, it will be understood that various omissions, substitutions, and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit and scope of the disclosure. For example, it is expressly intended that all combinations of those elements and/or steps that perform substantially the same function, in substantially the same way, to achieve the same results be within the scope of the disclosure. Substitutions of elements from one described embodiment to another are also fully intended and contemplated. It is also to be understood that the drawings are not necessarily drawn to scale, but that they are merely conceptual in nature.

[49] It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto. Other embodiments will occur to those skilled in the art and are within the following claims.

Claims

1. A method for underwater operation, comprising the steps of:

(a) providing a vehicle comprising a propulsion mechanism, a sensor, a communications mechanism and a docker; and providing a buoy comprising an underwater communications mechanism, an in-air communications mechanism, a navigation mechanism, and a docking acceptor;

(b) deploying said vehicle and said buoy to a response area;

(c) establishing a link between said buoy and said vehicle;

(d) surveying, with said vehicle, said response area; and

(e) docking said vehicle to said buoy.

2. The method of claim 1 wherein said response area is at least partially covered by ice.

3. The method of claim 2 wherein said vehicle does not surface during step (d).

4. The method of claim 1 futher comprising the step of transporting said vehicle and said buoy with a transportation mechanism.

5. The method of claim 4 wherein said transportation mechanism is a helicopter.

6. The method of claim 1 further comprising the step of (f) recovering said vehicle.

7. The method of claim 1 wherein said link is a communications link.

8. The method of claim 7 further comprising the step of (g) establishing a navigation link between said buoy and said vehicle.

9. The method of claim 1, wherein the majority of time spent in step (d) is under-ice.

10. A system for underwater operation, comprising:

a vehicle comprising:

a propulsion mechanism configured to move said vehicle;

a sensor configured to detect at least one environmental parameter;

a communications mechanism configured to send and receive signals underwater; and

a docker;

a buoy comprising:

an underwater communications mechanism configured to send and receive signals underwater;

an in-air communications mechanism configured to send and receive signals though air;

a navigation mechanism configured to emit navigation signals underwater; and

a docking acceptor configured to be located underwater and to accept said docker;

11. The system of claim 10 wherein said vehicle is configured to move in ice-covered water.

12. The system of claim 10 further comprising a transportation mechanism configured to carry said vehicle.

13. The system of claim 12 wherein said transportation mechanism is a helicopter.

14. The system of claim 10 further comprising a recovery mechanism configured to remove said vehicle from underneath water and to recover said buoy.

15. The system of claim 10 wherein said recovery mechanism is configured to remove said vehicle through ice, and said buoy from ice.

Abstract

A system and method to locate and sample oil in ice covered seas is disclosed herein. An uncrewed, autonomous underwater vehicle swims along pre-planned survey lines below the ice with an upward looking, acoustic ice surface topography sonar and uses acoustic ranging to one or more buoys (e.g., beacons) mounted to the ice so provide an ice-relative navigation. These acoustic beacons also have radio telemetry links to the internet and satellite positioning devices. Software on-board the underwater vehicle processes the sonar data to identify zones of likely oil accumulation and when an area of high likelihood of oil accumulation is identified the vehicle autonomously navigates to a location directly below the area and transitions to a zero-speed position holding mode. A second on-board algorithm processes the acoustic echo to determine if there could be oil sandwiched between the seawater and ice. If an oil signal is detected, the vehicle autonomously maneuvers to insert an oil/water sampler intake tube into the suspected oil and pulls a sample into a multi-sample canister. The sample passes through an oil detection sensor for real-time oil detection before being archived. The vehicle would be programmed to continue its pre-planned survey, possibly collecting many more samples and conclude the mission by docking below one of the acoustic/radio gateways beacons.