

LAUNCH AND RECOVERY SYSTEM FOR AN AUTONOMOUS UNDERWATER VEHICLE

Field of Invention

[001] The present invention relates to launching and recovering of an autonomous underwater vehicle (AUV) from a surface vessel.

Background

[002] Self-propelled autonomous underwater vehicles (AUVs) are well known as robots which travel underwater without being controlled by an operator, as against the non-autonomous remotely operated underwater vehicles (ROVs) that are controlled from a surface vessel by an operator/pilot via an umbilical cord or via wireless control.

[003] The applications of the AUVs are wide. Typically the AUVs are provided with detectors, sensors, cameras and the like depending on the application. The oil and gas industry uses AUVs to make detailed maps of the seafloor before they start building subsea infrastructure. Scientists use AUVs to study lakes, oceans and ocean floors. Usage of AUVs for underwater investigations, military applications, detection of smuggling and the like are also well known. The AUVs are popular as they are not tethered by cables or cords to the surface vessel. Any cables or cords used have been found to restrict movements of the AUV; besides, the cables/cords introduce problems in handling, for eg. they tend to entangle with parts of the launch and recovery apparatus or with obstructions in the water such as plants and rocks, etc.

[004] Several types of launch and recovery systems for the AUV are known in the art. Typically a launch and recovery apparatus is lowered into the water from the surface vessel by a cable during launching of the AUV into the water and pulling up to the surface vessel by the cable during recovering of the AUV. The design and operation of the launch and recovery apparatus has been a challenge in terms of the efficiency of launching and recovering the AUV while maintaining a simple structure with simple operation.

[0005] US Patent No. 7,798,086, issued to Diehl BGT Defence GmbH & Co. KG, describes a launch and recovery apparatus in the form of a telescopic tube with an insertion/extraction device disposed at a moveable end. When not in use, the telescopic tube is retracted into a torpedo tube; during launch or recovery, the insertion/extraction device is extended out of the torpedo tube and opens out in the form of a funnel. Using an arm to launch and recover the AUV has been described in US Patent No. 6,779,475, issued to the US Navy. US Patent No. 7,028,627, issued to ECA, describes a grab comprising two arms to grab the submersible vehicle during launch and recovery.

[0006] Floating-cage type of launch and recovery apparatuses are also known in the art for launch and recovery of AUV. US patent publication 2010/0018449, by Luccioni, et al, discloses a compact cage with puller means to pull the AUV into the cage during recovery. International patent publication WO 00/71415, by Studio 3 Ingegneria SRL, describes a closable cage-like frame with means for acquiring data and transmitting energy to and from the AUV and means for centering, aligning and temporary locking of the AUV. While it is advantageous to have a compact and simple structure of the launch and recovery apparatus for storage, handling, operation and maintenance, a small opening of the cage makes the apparatus compromise in efficiency during launching and recovering.

[0007] US Patent No. 6,698,376, issued to Societe ECA, describes a submersible cage for launching and recovering an AUV. The cage comprises a lower chassis and an upper chassis with a flexible connection like a blind for adjusting a vertical distance between the two chassis. Moving the lower and upper chassis apart enlarges the vertical dimension of the cage opening for receiving the AUV. Moving the lower and upper chassis closer helps support the AUV on the lower chassis and holds it in place against the upper chassis.

[0008] The flexible blind connection as used in US Patent No. 6,698,376 advantageously increases the capture cross-section of the cage while receiving the AUV. However, the cage with the flexible blind connection is likely to get swayed or disturbed by water currents, thereby making the process of receiving the AUV difficult.

[0009] The present invention provides a launch and recovery system (LARS) and a method for launching and recovering of an AUV.

Summary

[0010] According to an embodiment of the present invention, a launch and recovery system (LARS) is provided for launching an autonomous underwater vehicle (AUV) into the water and recovering back the AUV from the water after completing a task or mission.

[0011] Advantageously the LARS has a cage-like capture device, which is compact, easy to store or handle. The capture device is dimensioned to capture and secure an AUV. The capture device is constructed of two rigid jaws that are pivotally joined; as there is no flexible feature where the configuration of the capture device may be swayed or disturbed by water currents.

[0012] In one embodiment, a launch and recovery system (LARS) is provided and as defined in the claims 1-13.

[0013] In another embodiment, a method of launching and recovering an autonomous underwater vehicle is provided and as defined in the claims 14-15.

Brief Description of the Drawings

[0014] This invention will be described by way of non-limiting embodiments of the present invention, with reference to the accompanying drawings, in which:

[0015] FIG. 1 illustrates a launch and recovery system (LARS) according to an embodiment of the invention, which is mounted on a surface vessel, a suspension and retrieval (SAR) apparatus, a docking apparatus and a capture device;

[0016] FIG. 2A illustrates the SAR apparatus is pivoted to an extended position and the docking apparatus is outboard from the surface vessel, whilst FIG. 2B illustrates the docking apparatus is lowered to an underwater depth for launching and recovering;

[0017] FIG. 3A illustrates the docking apparatus according to an embodiment of the present invention, whilst in FIG. 3B arrows illustrate motions of the docking apparatus provided by some thrusters;

[0018] FIGs. 4A-4B illustrate a use of winches to actuate a capture device according to an embodiment;

[0019] FIGs. 5A-5C illustrate a use of linear actuators to operate a capture device according to another embodiment;

[0020] FIGs. 6A-6D illustrate stages of launching or recovering of an AUV; and

[0021] FIG. 7 illustrates regions for permissible and non-permissible clamping onto the AUV and stereoscopic locating of the capture device with respect to the AUV.

Detailed Description

[0022] One or more specific and alternative embodiments of the present invention will now be described with reference to the attached drawings. It shall be apparent to one skilled in the art, however, that this invention may be practised without such specific details. Some of the details may not be described at length so as not to obscure the invention. For ease of reference, common reference numerals or series of numerals will be used throughout the figures when referring to the same or similar features common to the figures.

[0023] The present invention provides a launch and recovery system (LARS) 100 mounted on a surface vessel 10, a suspension and retrieval (SAR) apparatus 105, a docking apparatus 200 and a capture device 280 for launching or recovering an autonomous underwater vehicle (AUV) 30. The SAR apparatus 105 includes a frame 110 mounted onto a skid 112, a control console 114 and an electric power unit 116. The frame 110 is pivotable between a home position and an extended position. At the home position, the docking apparatus 200 and capture device 280 are inboard the surface vessel 10; at the extended position, the docking apparatus 200 and capture device 280 are moved to an outboard position that is a predetermined distance L away from the surface vessel for

launching the AUV 30 into a body of water or recovering the AUV from the water. The surface vessel 10 may be manned or unmanned. The LARS 100 may be operated manually from the control console 114 or switched to automatic control at the control console 114. Automatic control may even be carried out remotely from another location.

[0024] The AUV 30 is a self-propelling type and may be suitable for any kind of applications. The AUV is generally equipped with sensors, cameras, antennae and the like to conduct underwater inspection, underwater investigation, serve military applications, study underwater marine life, and so on.

[0025] FIG. 1 shows the skid 112 of the SAR apparatus 105 being mounted on the surface vessel 10. As shown in FIG. 1, the frame 110 is in its home position, and is pivotable to the extended position by a pair of linear actuators 120. The SAR apparatus 105 also includes a hoist winch 130 suspended from the frame 110, a hoist rope 132, and an electric umbilical cord 140 (more clearly shown in FIGs. 2A-2B) that carries electric power and electric signals between the docking system 200 and the SAR apparatus 105. Advantageously, with the hoist winch 130 being suspended from the frame 110, operation of the hoist winch 130 is independent from operation of the frame 110, and the umbilical cord 140 need only to be kept at a minimal tension by a tension reel 142 mounted near the control console 114, as seen in FIG. 2A. In another embodiment, the tension reel 142 is manually operated via a handle 144.

[0026] In an alternative embodiment, the hoist winch 130 is connected to the docking apparatus 200 whilst a free end of the hoist rope 132 is attached to the frame 110.

[0027] FIGs. 2A-2B show the frame 110 is pivoted to the extended position such that the docking apparatus 200 and capture device 280 are a predetermined distance L away from the surface vessel 10. At this predetermined distance L , the docking apparatus 200, capture device 280 and AUV 30 are a clear distance away from the surface vessel 10 and accidental contact with the surface vessel caused by water swells and currents or swinging of the hoist rope 132 is prevented.

[0028] FIG. 2B shows the docking apparatus 200 and capture device 280 are lowered to a predetermined depth D, such as 5 m below the water surface. At this preferred depth, water forces from surface waves and surface disturbances in the water are lower; below this preferred depth D, underwater currents may become stronger. In addition, to minimise the water forces on the docking apparatus 200 and capture device 280, components of the docking apparatus and capture device are selected or designed with small surface areas.

[0029] FIG. 3A shows details of the docking apparatus 200 and capture device 280 according to one embodiment. As shown in FIG. 3A, the docking apparatus 200 includes the hoist rope 132 or hoist strap detachably connected to a chassis 210 of the docking apparatus 200. The chassis 210 is made from metal bars, preferably round bars, with small surface areas. Attached to the chassis and on both sides of the hoist rope 132 are two floatation devices 220a, 220b, and below the floatation devices is an electrical pod 230. Around a periphery of the chassis 210, there are six thrusters 240a-240f, with diagonally opposite pairs being arranged to operate and provide six degrees of freedom in an X-, Y- or Z-directions. By selecting a combination of the thrusters to operate in the appropriate directions and speeds, translations and rotations in the X-, Y- or Z-directions can be executed. These linear and rotation thrusts thus allow the docking apparatus 200 to translate or maneuver with six degrees of freedom (namely, surge, sway, heave, pitch, roll or yaw). FIG. 3B illustrates operation of four of the thrusters 240a, 240c, 240d, 240f to move the docking apparatus 200 in the negative X-direction. To assist in the docking of the docking apparatus 200 with the AUV, a forward camera 250a is provided at a front end on the chassis and a rear camera 250b at a rear end. These cameras 250a, 250b are also equipped with lights for illumination. In another embodiment, two pairs of hydrophones 252a, 252b are provided on the capture device 280 to communicate with antenna 32 on the AUV 30 during docking. Providing the hydrophones 252a, 250b in pairs allows stereoscopic docking, that is, precise position sensing or locating of the capture device 280 with respect to the AUV 30; this is illustrated more clearly in FIG. 7. Hydrophones 252a, 250b are advantageous when the water is turbid and visibility is too low to operate the cameras 250a, 250b. In one embodiment, as shown in FIG. 3A, each hydrophone 252a, 252b is or a pair of hydrophones 252a, 252b are operated together with a pinger 253, which wirelessly connects the hydrophones 252a, 252b to the controls inside the electrical

pod 230. In another embodiment, it is possible that each hydrophone and pinger are integrally formed as one unit.

[0030] Also as shown in FIG. 3A, a lower side of the chassis 210 is connected to the capture device 280 according to one embodiment. The capture device 280 is made up of an upper jaw 282 and a lower jaw 290 pivotably connected to the upper jaw 282. The capture device 280 is cage-like and is made from metal bars so that water forces acting on the capture device are minimal. The upper jaw 282 is a 3D taper structure, with the metal bars at a front end 282a defining a large mouth area whilst the metal bars at a rear end 282b define a semi-circular, elongate prism. The 3D taper form of the upper jaw 290 helps to guide a front end 34 of the AUV into the capture device 280, as seen more clearly in FIG. 6D. The lower jaw 290 is substantially triangular in shape and a smaller end thereof is connected to the upper jaw 282 at the rear end 282b by a pivot joint 285. Preferably, a cross bar 292 at the larger end of the lower jaw 290 that complementarily define the mouth area is curved and has a rubber sleeve to provide a cushioned contact with the AUV 30. Similarly, cross bars 293a, 293b at the smaller end (which complementarily defines the semi-circular elongate prism) are also curved and rubber cushioned. In addition, ends of the metal bars defining the mouth area on the upper jaw are also rubber cushioned 283, whilst a number of rubber pads 284 are provided inside the semi-circular elongate prism for cushioned contact with the front end 34 of the AUV 30 (which is more clearly seen in FIG. 6A).

[0031] FIG. 4A shows the above docking apparatus 200, the cage-like capture device 280, and a pair of electric winches 300 attached on the upper jaw 282, with one electric winch 300 on each side of the upper jaw 282 near the mouth area. The electric winch 300 is sealed for submersible operation under water. Each electric winch 300 has a spool for a wire cable 310, with a free end of the wire cable being terminated at an associated side of the lower jaw 290. In use, the electric winches 300 are operated to wind up the wire cables 310, thereby causing the lower jaw 290 to rotate about the pivot joint 285 and cooperate with the upper jaw 282 to locate and secure the AUV inside the capture device 280. When the electric winches 300 are operated to freewheel, for example by releasing internal brakes inside the electric winches, the weight of the lower jaw 290 urges the capture device 280 to open and then to allow release of the capture device 280 from the AUV 30.

[0032] FIG. 4B shows a docking apparatus 200a according to another embodiment. The docking apparatus 200a includes the cage-like capture device 280 and a pair of linear actuators 300a to open or close the capture device, with an addition of a net 294 disposed across the lower jaw 290. The net 294 may be useful to provide an area-distributed support on a lower surface of the AUV and avoid concentrated linear loadings at the cross-bars 292, 293a, 293b.

[0033] FIGs. 5A-5C show the above the cage-like capture device 280 with a pair of linear actuators 300a for opening and closing the cage-like capture device 280; in FIGs. 5A-5C, the docking apparatus 200a is not shown. The linear actuators 300a are sealed and are suitable for submersible operation under water. One end of the linear actuator 300a is pivotally connected to the upper jaw 282 whilst the other end is connected to the lower jaw 290. By extending and retracting the linear actuators 300a, the cage-like capture device 280 is operable to open and close, thereby allowing the capture device 280 to engage with the AUV 30 for retrieval or allowing the capture device 280 to disengage from the AUV 30 during launch. In one embodiment, the linear actuator 300a is electric driven; in another embodiment, the linear actuator 300a is fluid driven.

[0034] In FIG. 5A, the net 294 is formed across the lower jaw 290, as is seen in FIGs. 3A and 4B. In FIG. 5C, the cage-like capture device 280 has side nets 296 disposed laterally at two sides. The side nets 296 connect the lower jaw 290 to the upper jaw 282, and may help to guide the front end 34 of the AUV 30 into the capture device 280 or to prevent the AUV 30 from being advertently swept laterally out of the capture device 280 during docking.

[0035] In use, the floatation devices 220a, 220b are selected so that the docking apparatus 200 and capture device 280 are substantially neutrally buoyant or slightly positive buoyant when submerged in water. Preferably, at least two floatation devices 220a, 220b are used to provide a stable upright balance. Like the chassis 210 and capture device 280, lateral surface areas of the floatation devices are also kept low to minimize water forces caused by waves and swells; this consideration may call for the use of more than two floatation devices. In another embodiment as shown in FIG. 4B, a larger volume of the electric pod 230 is selected to provide the required buoyancy to the docking device 200a and capture

device 280, so as to dispense away with the floatation devices. Being neutrally or slightly buoyant in water, the entire docking device 200, 200a together with the capture device 280 can be maneuvered relatively easily and quickly by the thrusters 240a-240f; in addition, in any case of malfunction, the entire docking device 200, 200a and capture device 280 will eventually float to the water surface for retrieval.

[0036] FIGs. 6A-6C show the sequences of releasing the AUV 30 from the capture device 280. In a similar manner, FIGs. 6C to 6A can also be used to illustrate the sequences of capturing the AUV into the capture device 280 with the aid of the docking apparatus 200. As seen in FIG. 6A, a depth sensor 255 is mounted on the chassis 210. The depth sensor 255 is used to monitor the depth D of submersion of the capture device 280. In addition, a velocity sensor 257 is mounted on a lower side of the lower jaw 290. In use, the velocity sensor 257 captures movements of the capture device 280 and stores each velocity in a respective log using Doppler effect. Outputs of the velocity sensor 257 can be operated (for eg. by time integration) to determine distances of movement of the capture device 280 from the AUV 30, such as distances U , V and M shown in FIGs. 6B-6C. Alternatively, the depth sensor 255 and velocity sensor 257 can be mounted on any part on the capture device 280 or the docking apparatus 200. During launching, the lower jaw 290 is operated to open by pivoting about the pivot 285 by freewheeling the electric winches 300 or extending the linear actuators 300a. In FIG. 6B, the docking apparatus 200 is then moved diagonally to the right and upwardly, ie. at distances U and V in the respective X - and Y -directions so the front end 34 of the AUV 30 is still inside the open capture device 280; these movements are monitored with the help of the cameras 250a, 250b and/or hydrophones 252a, 252b. As seen in FIG. 6C, the dashed lines show the ultrasonic lines of communication between the hydrophones 252a, 252b and the antenna 32. Once the docking apparatus 200 is moved to a clear distance M from the AUV 30, the lower jaw 290 is operated to close the capture device 280 and the hoist winch 130 is then operated to retrieve the capture device 280 and the docking apparatus 200. Separation of the capture device from the AUV can also be achieved by operating a propulsion system of the AUV in cooperation with operation of some of the thrusters 240a-240f on the docking apparatus. Reversing the above relative movements of the AUV and capture device as shown in FIGs. 6C to 6A allow the capture device 280 to engage with the AUV 30 during capturing.

[0037] In the event of an unexpected surge in the water forces during launching or capturing, the 3D taper form of the upper jaw 282 makes contact with the head 34 or front side of the AUV so that chances of mechanical contact of the capture device 280 with other parts of the AUV 30 are minimized. The 3D taper form of the upper jaw 282 also ensures that the mechanical contacts between the upper jaw and AUV are tangential and gliding, as shown in FIG. 6D.

[0038] In one embodiment, the external dimension of the AUV 30 may be about 20 cm in diameter, 200 cm in length and has a weight of about 60 kg. When submerged in water, the AUV is slightly positively buoyant and weighs only a few hundred grams; this allows the AUV to float to the surface in the event of lost communication with the surface vessel 10. However, depending on the application of the AUV, the LARS 100, the frame, the skid and the capture device 280 are dimensioned to fit the AUV. FIG. 7 shows areas of the AUV that are suitable for mechanical clamping or support and delicate areas that are susceptible to mechanical damage where clamping are not permitted.

[0039] While specific embodiments have been described and illustrated, it is understood that many changes, modifications, variations and combinations thereof could be made to the present invention without departing from the scope of the present invention. For example, a sealed hydraulic power unit may be provided adjacent to the electric pod 230 to supply hydraulic fluid to operate the linear actuators 300a. In addition, the electric pod 230 may contain a battery and a wireless transceiver for wireless communication between the docking apparatus 200 and the surface vessel 10 so as to dispense with the use of the umbilical cord 140.

CLAIMS:

1. A launch and recovery system (LARS) for launching an autonomous underwater vehicle (AUV) into a body of water and recovering back the AUV from the water, the LARS comprising:
 - a suspension and retrieval (SAR) apparatus mountable on a surface vessel;
 - a docking apparatus suspended from the SAR apparatus; and
 - a capture device connected to the docking apparatus for engaging and securing the AUV, wherein the capture device is a cage-like structure made up of an upper jaw having a 3D taper form, defining a large front end transitioning to a semi-circular elongate prismatic rear end, and a lower jaw pivotally joined to the upper jaw at the semi-circular elongate prismatic rear end by a pivot joint;so that opening of the capture device provides a large exit area for non-contact with the AUV and operating the docking apparatus to move the capture device clear from the AUV during launch, or opening the capture device to provide a large entrance area for a front end of the AUV to enter therein, operating the docking apparatus to substantially locate the AUV inside the capture device and closing the lower jaw to secure the AUV inside the capture device during recovery.
2. The LARS according to claim 1, further comprising a hoist winch suspended on the SAR apparatus and a free end of an associated rope is terminated on a chassis of the docking apparatus.
3. The LARS according to claim 1 or 2, wherein the SAR apparatus is pivotable between a home position inboard the surface vessel and an extended position outboard of the surface vessel.
4. The LARS according to any one of claims 1-3, further comprising a plurality of rubber pads disposed in spaced orientation around an inside of the semi-circular elongate prismatic rear end of the capture device to fit the front end of the AUV.
5. The LARS according to any one of claims 1-4, further comprising cross bars disposed across the lower jaw at both the front end and rear end, with the cross bars having rubber sleeves to provide cushioned contact with the AUV.

6. The LARS according to any one of claims 1-5, wherein the taper form of the upper jaw is arranged to make tangential or gliding contact with the front end of the AUV.
7. The LARS according to any one of claims 1-6, further comprising a pair of electric winches disposed on the upper jaw whilst associated wire cables are terminated at the lower jaw, so that the pair of winches are operable to close the lower jaw against the upper jaw for securing the AUV inside the capture device.
8. The LARS according to any one of claims 1-6, further comprising a pair of linear actuators linking the lower jaw to the upper jaw, so that the linear actuators are operable to open and close the capture device during engagement or release of the AUV.
9. The LARS according to any one of the preceding claims, further comprising:
two or more floatation devices to provide substantially neutral or slight buoyancy when the capture device is submerged in water.
10. The LARS according to any one of claims 1-9, further comprising a camera disposed at the front end of the capture device and another camera disposed at the rear end, with the cameras being equipped with lights for illumination.
11. The LARS according to any one of claims 1-10, further comprising a pair of hydrophones disposed at the front end of the upper jaw to provide stereoscopic locating of the AUV.
12. The LARS according to claim 11, further comprising a pair of hydrophones disposed at the front end of the lower jaw.
13. The LARS according to any one of the preceding claims, further comprising a depth sensor so that launch and recovery of the AUV is operable at a predetermined depth.
14. Method for launching/recovering an autonomous underwater vehicle (AUV) from the water employing a launch and recovery system (LARS) having a cage-like

capture device that is dimensioned to substantially accommodate the AUV, with the cage-like capture device having an upper jaw with a 3D taper form defining a large front end transitioning to a semi-circular elongate prismatic rear end, and a lower jaw pivotally joined to the upper jaw at the semi-circular elongate prismatic rear end, the method comprising:

- operating a suspension and retrieval (SAR) apparatus between an inboard position and an outboard position on a surface vessel;

- suspending and launching/recovering the LARS when the SAR apparatus is at the outboard position; and

- during launching of the AUV, increasing the mouth area at the front end by pivoting the lower jaw away from the upper jaw; translating the capture device a clear distance away from the AUV; closing the capture device; and retrieving the capture device from the water; or

- during recovering of the AUV, increasing the mouth area at the front end by pivoting the lower jaw away from the upper jaw; translating the capture device so that the AUV is substantially inside the capture device; and closing the lower jaw against the upper jaw to locate and secure the AUV inside the capture device.

15. The method according to claim 14, wherein suspending and launching/recovering the LARS is implemented by operating a hoist winch located on a pivoted frame of the SAR.