DOCKING OF UNDERWATER VEHICLES

The present invention relates to docking systems for underwater vehicles and methods of docking underwater vehicles. Such systems and methods are particularly envisaged for use with autonomous underwater vehicles (AUVs).

Underwater vehicles are used for various purposes, and can take many forms and sizes to fulfil their particular function. Examples include autonomous underwater vehicles (AUVs) which can operate without continuous input from an operator, and remotely operated vehicles (ROVs) which are operated from a vessel or platform, with the ROV often linked to the host vessel or platform via a neutrally buoyant tether.

Some AUVs are adapted for surveying purposes, e.g. mapping and monitoring of subsea structures. AUVs for this purpose typically have an elongate cylindrical shape with a propeller at the rear end to propel the AUV through the water. Many commercially available AUVs with tail propellers can be classified as 'cruising' AUVs, or 'hovering' AUVs.

Cruising AUVs comprise a number of control surfaces, such as fins or rudders, provided along their surface for steering of the AUV. Cruising AUVs require continuous motion in the forward direction in order for their control surfaces to steer the AUV. Cruising AUVs are also generally bottom-heavy, so as to be ballasted in a preferred orientation under the influence of gravity and to counteract any undesired roll torque induced by the propeller. However, this may limit the pitch or diving angle attainable by the AUV. Each of these factors may limit the manoeuvrability of cruising AUVs.

Hovering AUVs, on the other hand, do not require constant forward motion to be able to steer, and can hold their position in water. Hovering AUVs employ a number of additional thrusters or propellers oriented in different directions and distributed along the body of the AUV, so as to stabilise and move the AUV in water. Sizes of hovering AUVs vary from small and light, for example with weights of a few kilograms, to very large and heavy, for example on the order of 2,000kg. However, hovering-type AUVs are typically larger than other designs of AUV for a given sensor payload. It can be impractical to use large hovering AUV systems in some circumstances due to the difficulties of transporting and manipulating the vehicle.

When underwater vehicles are not in use or require maintenance, they can return to a subsea docking station or be recovered from the water altogether.

Subsea docking stations are subsea base structures to which the underwater vehicle can dock when not in use. Subsea docking stations can be standalone structures, or part of a larger subsea construction. In some cases, the subsea docking station can additionally recharge the docked underwater vehicle. The subsea docking station can be an underwater cage or garage into which the underwater vehicle propels itself, or can be a platform or panel onto which the underwater vehicle lands. The underwater vehicle docks with the subsea docking station in a substantially horizontal orientation.

To launch and recover underwater vehicles from bodies of water, such as the sea, launch and recovery systems (LARS) are employed.

Existing LARS solutions generally require that the underwater vehicle docks with the LARS whilst the underwater vehicle is in a substantially horizontal orientation. The underwater vehicle will propel itself such that a nose end of the underwater vehicle swims into a net or cage of the LARS which captures the underwater vehicle; or such that a nose end of the underwater vehicle engages with an interface of the LARS as the underwater vehicle swims forward. Once docked with the LARS, the underwater vehicle is then winched or lifted to the surface.

The docking of an underwater vehicle with any structure whilst the underwater vehicle is suspended in water is a complex operation. This can be due to a number of factors, including the limited manoeuvrability of the underwater vehicle and any relative motion between the underwater vehicle and the structure to which the underwater vehicle is attempting to dock. For example, existing solutions for subsea docking stations may require a large unobstructed space surrounding them to facilitate the limited manoeuvrability of the underwater vehicle. The recovery of underwater vehicles can be further complicated by the LARS moving in addition to the underwater vehicle.

It is desired to provide improved docking solutions for underwater vehicles that address one or more of the above-mentioned problems.

Viewed from a first aspect of the present invention, there is provided a docking system for an underwater vehicle. The docking system comprises: a docking mechanism for docking with the underwater vehicle when in water; wherein the docking mechanism is configured to capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation and is submerged.

Existing docking solutions for underwater vehicles generally require the underwater vehicle to be in a horizontal orientation to facilitate the docking. However, requiring the underwater vehicle to be in a substantially horizontal orientation to facilitate engagement with the docking system may have a number of drawbacks.

For example, relative motion between the underwater vehicle and the docking system may increase the complexity of the docking process. When an underwater vehicle is being recovered from the water by a surface structure such as a platform or a vessel, the surface structure may be particularly influenced by the heave motion of waves (i.e. the upwards and downwards, vertical, motion of waves). This can cause the docking mechanism to be similarly influenced in the vertical direction. This could cause the docking mechanism and the underwater vehicle to move out-of-plane with one another, if the underwater vehicle is required to be in a substantially horizontal orientation during the docking process.

In another example, many underwater vehicles have a positive or negative buoyancy, causing the underwater vehicle to float or sink, respectively. This can cause an unwanted motion of the underwater vehicle in the vertical direction, which could misalign an underwater vehicle and a docking mechanism if the underwater vehicle is to remain in a substantially horizontal orientation during the docking process. To counteract this unwanted motion, underwater vehicles may need to be constantly moving to create a desired counteracting thrust from their control surfaces. However, if the underwater vehicle cannot successfully dock with the docking mechanism at a first attempt this may then require the underwater vehicle to circle back around to make another attempt at docking.

Further, underwater vehicles that have positive or negative buoyancy may experience a torque about the docking mechanism, once engaged and in a substantially horizontal orientation. This torque could cause undesired stress or damage to the docking mechanism.

In another example, docking processes that require the underwater vehicle to be in a substantially horizontal orientation often require there to be a large

unobstructed space available surrounding the docking mechanism to accommodate the approach of the underwater vehicle in the horizontal direction (both before and after the docking mechanism, should multiple docking attempts be required). This can complicate the docking process.

Providing a docking system that is configured to capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation addresses a number of these drawbacks.

By having the docking mechanism be configured to capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation, the direction in which docking occurs is made parallel to the heave motion of the waves. This may reduce the complexity of the docking process as a result, since heave motion acting on the docking system may be less likely to move the docking system and the underwater vehicle out-of-plane from one another.

Also, by having the docking mechanism be configured to capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation the direction in which docking occurs is made parallel to any buoyancy forces acting on the underwater vehicle. Accordingly, the docking process may be less affected by the buoyancy of the underwater vehicle since motion due to buoyancy will be less likely to move the underwater vehicle out-of-plane from the docking mechanism. Having the direction in which docking occurs made parallel to any buoyancy forces acting on the underwater vehicle may also mitigate any torque forces acting about the docking mechanism due to the buoyancy of the underwater vehicle.

In large bodies of water such as the sea there may be less obstructions present in a vertical direction, since obstructions may be generally present at the seabed or at sea level (e.g. other surface structures). Accordingly, the docking mechanism may be suitable for use in subsea locations where obstructions limit the horizontal space available for manoeuvring the underwater vehicle by having the docking mechanism be configured to capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation.

A vertical orientation will be understood to be one in which the major axis of the underwater vehicle is parallel to the direction of gravity, i.e. parallel to a depthwise direction. The vertical orientation is generally perpendicular to a surface of a body of water or the seabed. The major axis of an underwater vehicle may be its longitudinal axis. The major axis of the underwater vehicle may extend in, or

parallel to, a forward and a backward direction of motion of the underwater vehicle. In other words, the major axis of the vehicle is aligned with a forward direction of motion of the underwater vehicle. Accordingly, in the vertical orientation the underwater vehicle will be facing, and in some circumstances travelling substantially perpendicular to, a surface of a body of water.

The docking mechanism may be a concave member arranged to engage with one of a nose end and/or a tail end of the underwater vehicle. The docking mechanism may be arranged to at least partially surround one of a nose end and/or a tail end of the underwater vehicle.

The docking mechanism may be an elongate garage or tube-like structure comprising one or more walls arranged to surround a hull of the underwater vehicle. The garage structure may comprise an opening at one end arranged to receive the underwater vehicle when the underwater vehicle is in the substantially vertical orientation and submerged.

The docking mechanism may comprise a powered mechanism configured to secure the underwater vehicle to the docking mechanism.

The powered mechanism can be considered to be an active mechanism, i.e. a mechanism that is actively operated to facilitate securement of the underwater vehicle to the docking mechanism.

The powered mechanism may be actuated by one of an electric motor, a hydraulic mechanism or a pneumatic mechanism.

The powered mechanism may comprise a locking mechanism. The locking mechanism may comprise a locking member configured to move between an open configuration and a closed configuration. The locking member is configured to mate with a complementary portion of the underwater vehicle. The complementary portion may be located at one of a nose end or a tail end of the underwater vehicle, or along a hull of the underwater vehicle.

In the open configuration the locking member is configured to be unsecured to the underwater vehicle. In the closed configuration, the locking mechanism is configured to be secured to, or locked with, the complementary portion.

The powered mechanism may comprise a grasping, or clamping, mechanism.

The grasping mechanism may comprise a plurality of gripping devices configured to hold the underwater vehicle.

The grasping mechanism may comprise a plurality of mechanical arms arranged to engage the underwater vehicle.

The grasping mechanism may comprise an inflatable bellows, e.g. an inflatable cushion or airbag. The bellows may be powered pneumatically, i.e. the bellows may be a pneumatic bellows. The bellows may be configured to move between an inflated configuration and a deflated configuration. In the inflated configuration, the bellows may be arranged to expand around a hull of the underwater vehicle, thereby securing the underwater vehicle to the docking mechanism. The bellows may be located on internal surfaces of the elongate garage or tube-like structure.

The powered mechanism may comprise a controllable door or hatch. The door or hatch may be movable between an opened configuration and a closed configuration. In the opened configuration, the opening of the elongate garage or tube-like structure may be arranged to receive the underwater vehicle. In the closed configuration, the door or hatch may close the opening, such that the underwater vehicle is retained in the elongate garage or tube-like structure.

The docking mechanism may comprise a passive mechanism arranged to capture the underwater vehicle.

The passive mechanism is a mechanism that is arranged to capture the underwater vehicle when the underwater vehicle and the docking mechanism come into contact with one another, such as due to motion of the underwater vehicle and/or the docking mechanism.

The passive mechanism may comprise a resiliently biased member. The resiliently biased member may be arranged to open upon application of a contact force. The resiliently biased member may be arranged to close upon engagement with the underwater vehicle.

The resiliently biased member may be a one-way door or hatch arranged to allow the underwater vehicle, or at least part of the underwater vehicle, to enter the elongate garage or tube-like structure. Once the underwater vehicle is received, the one-way door or hatch may retain the underwater vehicle therein.

The passive mechanism may comprise a female or male portion arranged to receive a complementary male or female portion located on a nose end or a tail end of the underwater vehicle. The female/male portion may be arranged to lock with the complementary male/female portion via a snap-fit engagement.

The passive and/or powered mechanism of the docking mechanism may be configured to engage a complementary passive and/or powered mechanism of the underwater vehicle.

Preferably, the docking mechanism comprises a powered or a passive mechanism, and the underwater vehicle comprises a passive mechanism. Avoiding the need to incorporate a powered mechanism into the underwater vehicle may reduce the weight and the complexity of the underwater vehicle.

The docking mechanism may comprise a docking interface configured to engage with one of a nose end or a tail end of the underwater vehicle.

The docking interface may comprise a powered mechanism, such as the locking mechanism, described above. The docking interface may additionally or alternatively comprise a passive mechanism, as described above.

The docking interface may comprise a communications interface operable to provide data communications between the underwater vehicle and a surface structure when the underwater vehicle is engaged with the docking interface.

The communications interface may be a wireless communications interface.

The communications interface may provide a contactless electrical connection for providing contactless electrical communication for bidirectional transfer of data between the underwater vehicle and the docking mechanism. For example, the communications interface may be an inductive communications interface arranged to facilitate communications by induction.

The communications interface may be arranged to communicate with the underwater vehicle by a wireless data transmissions protocol, such as WiFi, Bluetooth™, or radio data transmission.

The docking interface may comprise a power interface operable to provide electrical power to the underwater vehicle when the underwater vehicle is engaged with the docking interface. The power interface may provide a contactless electrical connection for providing contactless electrical communication for bidirectional transfer of data between the underwater vehicle and the docking mechanism. For example, the power interface may be an inductive power interface. Alternatively, the power interface may be a conductive power interface.

Contactless electrical connections may be structurally simple and to facilitate easy docking/launching of the underwater vehicle from the docking mechanism. Contactless electrical connections may also facilitate waterproofing of any electronic components of the underwater vehicle and the docking mechanism.

The communications interface and the power interface may be provided as part of an integral interface. The integral interface may use a common contactless electrical connection or conductive electrical connection to facilitate the transfer of data and/or power between the underwater vehicle and the docking mechanism.

The docking mechanism may comprise a communication device arranged to aid the underwater vehicle in locating the docking mechanism prior to the underwater vehicle docking with the docking mechanism.

The communication device may be an acoustic transmitter or transceiver.

The communication device may be an optical communication device. The optical communication device may be an optical marker. The optical marker may be an ARTag such as ArUco.

Viewed from a second aspect of the present invention, there is provided a launch and recovery system (LARS) for an underwater vehicle. The LARS comprises: a docking system according to the first aspect; and a lifting mechanism configured to move the docking mechanism between an underwater position and a surfaced position.

The LARS of the second aspect comprises a docking system according to the first aspect. Thus, the above-description of the docking system of the first aspect, including but not limited to all technical advantages and optional features, is equally applicable to the LARS of the second aspect.

The docking mechanism may comprise a remotely operated vehicle, ROV.

The ROV may be operable to traverse underwater and move to the underwater vehicle, e.g. to capture the underwater vehicle.

The LARS may comprise a tether operable to provide wired communications between the ROV and a controller.

The tether may be a neutrally buoyant tether. Alternatively, the tether may be a negatively buoyant tether. The negatively buoyant tether may sink when in water.

The lifting mechanism may be arranged to move the docking system in and out of the water via a moon pool. Alternatively, the lifting mechanism may be suspended out from the surface structure and over a body of water.

The lifting mechanism may comprise a cable winch system. The cable winch system may comprise a winch and a winch cable. The cable winch system may comprise a crane, a tether handling system, or a pulley arranged to position

the winch cable. The docking mechanism may be fixed to a free end of the winch cable.

The winch cable may be integrated with the tether. Accordingly, the winch cable may be arranged to move the docking mechanism between the underwater position and the surfaced position; and to provide wired communications between the ROV and the controller.

The lifting mechanism may comprise a mechanical arm or lift configured to be moved into and out of the water. The docking mechanism may be fixed to a free end of the mechanical arm or lift.

Viewed from a third aspect of the present invention, there is provided a subsea docking station for an underwater vehicle. The subsea docking station comprises: a subsea base structure configured to be anchored to the seabed; and a docking system according to the first aspect, wherein the docking system is mounted to the base structure.

The subsea docking station of the third aspect comprises a docking system according to the first aspect. Thus, the above-description of the docking system of the first aspect, including but not limited to all technical advantages and optional features, is equally applicable to the subsea docking station of the third aspect.

The subsea base structure may be a subsea platform

The subsea base structure may be a subsea garage.

The subsea base structure may be an aquaculture cage, a subsea facility, or a foundational structure of an offshore topside structure.

The subsea base structure may be arranged to be anchored to the seabed via a plurality of legs. Additionally or alternatively, the subsea base structure may be arranged to be anchored to the seabed by cables, a gravity base foundation, or piles.

Viewed from a fourth aspect of the present invention, there is provided a subsea docking system for an underwater vehicle. The subsea docking system comprises: a positively buoyant portion comprising a docking system according to the first aspect; wherein the positively buoyant portion is arranged to be releasably secured to the seabed; and wherein the positively buoyant portion is configured to ascend to sea level when docked with the underwater vehicle and not secured to the seabed.

The subsea docking system of the fourth aspect comprises a docking system according to the first aspect. Thus, the above-description of the docking

system of the first aspect, including but not limited to all technical advantages and optional features, is equally applicable to the subsea docking system of the fourth aspect.

The positively buoyant portion may be of use in situations where delayed recovery of the underwater vehicle is desired. For example, at the end of its mission the underwater vehicle may dock with the positively buoyant portion. When a surface structure is ready for recovery of the underwater vehicle, the positively buoyant portion can be released from the seabed, such that the underwater vehicle ascends to sea level for recovery. Providing a docking system that facilitates non-immediate recovery may improve mission logistics for the underwater vehicles.

Further, the use of a positively buoyant portion may make recovery of an underwater vehicle easier due to the positively buoyant portion passively raising the underwater vehicle to the surface for recover. Even if the underwater vehicle is itself positively buoyant, the additional positive buoyancy of the positively buoyant portion may facilitate a faster and more stable rise to the surface, and better maintain the underwater vehicle at the surface when exposed to wave action.

It will be appreciated that the term 'buoyant' is used in the context of a marine environment. As such, the buoyancy of an object will be defined relative to seawater (i.e. a fluid having a density of approximately 1025 kg/m^3). This does not preclude such an object from also being buoyant in a freshwater environment, where the buoyancy of an object will be defined relative to freshwater (i.e. a fluid having a density of approximately 1000 kg/m^3).

The positively buoyant portion may contain a positively buoyant component. The positively buoyant component may be a buoyant material. The buoyant material may be a buoyancy foam, such as Divinycell ® HCP or a syntactic foam. The buoyant material could alternatively be any other positively buoyant material. In other embodiments, the positively buoyant material could be a positively buoyant fluid such as oil or air.

The positively buoyant portion may be configured to be releasably secured to the seabed via an anchor portion.

The anchor portion may be a subsea base structure anchored to the seabed.

The subsea docking system may comprise a negatively buoyant portion configured to rest on the seabed; wherein the positively buoyant portion is

configured to be releasably secured to the seabed via the negatively buoyant portion.

The subsea docking system may be a portable subsea docking system.

The portable subsea docking system may be regarded as portable insofar as it is configured to be deployed from sea level. For example, the negatively buoyant portion is arranged to sink the positively buoyant portion to the seabed when released in the water.

The negatively buoyant portion may weigh more than the underwater vehicle.

The negatively buoyant portion may weigh less than 200 kg; less than 180 kg; less than 160 kg; less than 140 kg; less than 120 kg; or less than 100 kg. The negatively buoyant portion may thus be suitable to be physically moved into the water by two, three or four human operators, aiding its portability.

In other embodiments, the negatively buoyant portion may weigh more than 200 kg; more than 500 kg; more than 1000 kg; more than 1500 kg; or more than 2000 kg.

The positively buoyant portion may be releasably secured to the seabed via a tether.

The tether may be arranged to secure the positively buoyant portion directly to the seabed (i.e. one end of the tether may be anchored to the seabed). Alternatively, the tether may be arranged to secure the positively buoyant portion to an anchor portion or the negatively buoyant portion.

The positively buoyant portion may comprise a control device; wherein the control device is configured to control a release mechanism releasably securing the positively buoyant portion to the seabed.

The release mechanism may be configured to sever the tether or a cable securing the positively buoyant portion to the seabed.

The release mechanism may be a latching mechanism comprising a latching member, wherein the latching member is operable to disengage from a complementary retaining member anchored to the seabed, thereby releasing the positively buoyant portion from the seabed.

The control device may be configured to control the release mechanism releasably securing the positively buoyant portion to the seabed at a predetermined time, or after a predetermined period has elapsed.

The positively buoyant portion may comprise a receiver. The control device may be configured to control the release mechanism releasably securing the positively buoyant portion to the seabed in response to the receiver receiving a release signal.

The release signal may be an acoustic signal. The receiver may be an acoustic receiver.

The release signal may be an electronic communication signal. The receiver may be an inductive receiver arranged to receive the electronic communication signal from the underwater vehicle.

The positively buoyant portion may comprise a transmitter. The transmitter may be configured to transmit an acoustic signal when the underwater vehicle is not docked to the docking mechanism. The acoustic signal is suitable for aiding the underwater vehicle in locating the docking mechanism.

Viewed from a fifth aspect of the present invention, there is provided a subsea exploration system. The subsea exploration system comprises: an underwater vehicle; and at least one of: a docking system according to the first aspect; a LARS according to the second aspect; a subsea docking station according to the third aspect; and a subsea docking system according to the fourth aspect.

The subsea exploration system of the fifth aspect comprises at least one of: a docking system according to the first aspect; a LARS according to the second aspect; a subsea docking station according to the third aspect; and a subsea docking system according to the fourth aspect. Thus, the above-description of the docking system according to the first aspect; the LARS according to the second aspect; the subsea docking station according to the third aspect; and the subsea docking system, including but not limited to all technical advantages and optional features, may be equally applicable to the subsea exploration system of the fifth aspect.

The underwater vehicle generally comprises: a hull comprising a nose end and a tail end; and a propulsion mechanism configured to propel the underwater vehicle; and a steering mechanism; wherein the steering mechanism is arranged to enable the propulsion mechanism to rotate in at least one of a pitch and a yaw direction, relative to the hull; and wherein the propulsion mechanism comprises a pair of counter-rotating propellers, the rotational speed of each propeller being independently controllable.

By using a pair of counter-rotating propellers, roll torques generated by each propeller may cancel out when the propellers are operated at the same rotational speed. Accordingly, the use of a pair of counter-rotating propellers can improve the roll control of the underwater vehicle by mitigating against the generation of undesirable roll torque during propulsion of the underwater vehicle. The use of a pair of counter-rotating propellers may also negate the need for additional control surfaces associated with mitigating undesirable roll torques induced by a propeller. Further, where it is desirable to adjust a rotational orientation of the underwater vehicle about its roll axis, the rotational speeds can be asymmetrically controlled since their respective speeds are independently controllable, providing further roll control for the underwater vehicle.

Using the steering mechanism to provide pitch and yaw control to the propulsion mechanism may also provide greater and more responsive control for the underwater vehicle. For example, actuating the steering mechanism such that the propulsion mechanism is greatly offset to the longitudinal axis of the hull provides a tighter turning circle for the underwater vehicle in water, thereby improving its manoeuvrability.

Since the underwater vehicle does not require control surfaces to induce steering due to the presence of the steering mechanism, and further since no control surfaces are required to counteract roll torques introduced by the propellers, the AUV need not experience drag forces associated with the presence of control surfaces. The underwater vehicle may therefore have an improved hydrodynamic profile, reducing drag it may experience and further improving the manoeuvrability of the underwater vehicle as a result.

A longitudinal axis of the hull generally extends between the nose end and the tail end, i.e. in a forward-aft direction of the underwater vehicle. Generally, in use, the nose end defines a forward-facing end of the underwater vehicle during forward propulsion of the underwater vehicle.

The underwater vehicle may roll about the longitudinal axis. That is, the roll axis of the underwater vehicle and the longitudinal axis of the underwater vehicle are generally identical.

The underwater vehicle may also comprise a port side and a starboard side. The hull may comprise a transverse axis extending between the port side and the starboard side, i.e. in a left-right direction of the underwater vehicle. The underwater vehicle may pitch about the transverse axis. That is, the pitch axis of

the underwater vehicle and the transverse axis of the underwater vehicle are generally identical.

The underwater vehicle may also comprise a top side and a bottom side. The hull may comprise a vertical axis extending between the top side and the bottom side, i.e. in an up-down direction of the underwater vehicle. The underwater vehicle may yaw about the vertical axis. That is, the yaw axis of the underwater vehicle and the vertical axis are generally identical.

The propulsion mechanism may comprise two or more pairs of counter-rotating propellers, the rotational speed of each propeller being independently controllable.

The propulsion mechanism may be located at one of the nose end or the tail end of the hull. The steering mechanism may connect the propulsion mechanism to the hull.

The steering mechanism may comprise an active joint configured to rotate the propulsion mechanism. The active joint may be any one of: a cardan joint; a motorised ball joint; a pneumatic actuator; an electric actuator; or a hydraulic actuator.

The underwater vehicle may comprise a docking member configured to secure the underwater vehicle to the docking mechanism. The docking member is preferably located at one of the nose end or the tail end of the underwater vehicle.

The docking member may comprise a powered mechanism configured to secure the underwater vehicle to the docking mechanism.

The powered mechanism may be actuated by one of an electric motor, a hydraulic mechanism or a pneumatic mechanism.

The powered mechanism may comprise a locking mechanism. The locking mechanism may comprise a locking member configured to move between an open configuration and a closed configuration. The locking member is configured to mate with a complementary portion of the docking mechanism. The complementary portion may be located at the docking interface of the docking mechanism.

In the open configuration the locking member is configured to be unsecured to the docking mechanism. In the closed configuration, the locking mechanism is configured to be secured to, or locked with, the complementary portion.

The docking member may comprise a passive mechanism arranged to capture, or be captured by, the docking mechanism.

The passive mechanism may comprise a resiliently biased member. The resiliently biased member may be arranged to open upon application of a contact force. The resiliently biased member may be arranged to close upon engagement with the docking mechanism.

The passive mechanism may comprise a female or male portion arranged to receive a complementary male or female portion located at a docking interface of the docking mechanism. The female/male portion may be arranged to lock with the complementary male/female portion via a snap-fit engagement.

The passive and/or powered mechanism of the docking member may be configured to engage a complementary passive and/or powered mechanism of the docking mechanism.

Preferably, the docking member comprises a passive mechanism and not a powered mechanism. Avoiding the need to incorporate a powered mechanism into the underwater vehicle may reduce the weight and the complexity of the underwater vehicle.

The underwater vehicle may comprise a controller.

The controller may comprise a processor and a memory, and may be in wired or wireless communication with one or more components of the underwater vehicle. The memory may store computer-readable instructions which, when executed by the processor, causes the underwater vehicle to perform one or more operations.

The controller may be in communication with the powered mechanism of the docking mechanism, the controller being configured to operate the powered mechanism.

The controller may be in communication with the propulsion mechanism, the controller being configured to control roll of the underwater vehicle using the pair of counter-rotating propellers.

The controller may be in communication with the steering mechanism, the controller being configured to control at least one of the pitch and the yaw of the underwater vehicle (e.g. relative to the hull) using the steering mechanism.

The controller may be configured to independently control the rotational speed of each propeller so as to control a roll of the underwater vehicle during substantially vertical ascent and/or descent of the underwater vehicle.

The controller may be in communication with the propulsion mechanism and the steering mechanism; the controller being configured to: control roll of the

underwater vehicle by independently controlling the rotational speed of each propeller of the pair of counter-rotating propellers; and control at least one of the pitch and the yaw of the underwater vehicle relative to the hull using the steering mechanism.

Using the steering mechanism to provide pitch and yaw control to the propulsion mechanism may also provide greater and more responsive control for the underwater vehicle.

The controller may be configured to control the steering mechanism and the propulsion mechanism such that the underwater vehicle is oriented in a substantially vertical orientation when descending to or ascending from a seabed.

The underwater vehicle may be considered to be in a substantially vertical orientation when the forward-aft direction of the underwater vehicle is substantially aligned with the direction of gravity. The substantially vertical orientation is therefore substantially perpendicular to sea level (i.e. the surface of the sea on a global scale).

The underwater vehicle can be operated to arrive at the substantially vertical orientation using the propulsion mechanism and the steering mechanism.

The underwater vehicle may have a mass of between 40 kg and 80 kg. The underwater vehicle may have a mass of less than 200 kg; less than 180 kg; less than 160 kg; less than 140 g; less than 120 kg; or less than 100 kg.

The underwater vehicle may have a length of less than 3 metres, or of less than 2.5 metres.

The underwater vehicle may have a diameter of about 20 cm and a dry weight of about 31.5 kg/m. Such an underwater vehicle may be substantially neutrally buoyant in water.

The underwater vehicle may thus be suitable to be physically moved into the water by two, three or four human operators, aiding its portability.

In other embodiments, the underwater vehicle may have a mass of greater than 200 kg; greater than 500 kg; greater than 1000 kg; greater than 1500 kg; or greater than 2000 kg.

In other embodiments, the underwater vehicle may have a length of greater than 3 metres; or greater than 4 metres; or greater than 5 metres.

The underwater vehicle may have a diameter of between 20 cm to 50 cm. The underwater vehicle may have a diameter of less than 1 m; less than 1.5 m; or less than 2 m.

The underwater vehicle is preferably neutrally buoyant. This may ensure energy-efficient cruising of the vehicle when submerged. In other embodiments, the underwater vehicle is positively buoyant. This may ensure that the underwater vehicle does not sink to the seabed in the event of a systems failure. In other embodiments, the underwater vehicle can be negatively buoyant.

In preferred embodiments, the underwater vehicle is an autonomous underwater vehicle (AUV). In other embodiments, however, the underwater vehicle could be a remotely operated vehicle (ROV).

Where the subsea exploration system comprises the LARS, the subsea exploration system may additionally comprise a surface vessel; wherein the LARS is mounted to the surface vessel.

The surface vessel may be a boat, helicopter or amphibious vehicle.

Where the subsea exploration system comprises the LARS, the subsea exploration system may comprise a platform; wherein the LARS is mounted to the platform.

The platform may be a topside structure such as a floating platform or a fixed platform.

Viewed from a sixth aspect of the present invention, there is provided a method of docking an underwater vehicle. The method comprises: positioning the underwater vehicle in a substantially vertical orientation; and moving at least one of a docking mechanism and the underwater vehicle such that the docking mechanism captures the underwater vehicle when the underwater vehicle is in the substantially vertical orientation and is submerged.

Existing docking solutions for underwater vehicles generally require the underwater vehicle to be in a horizontal orientation to facilitate the docking. However, requiring the underwater vehicle to be in a substantially horizontal orientation to facilitate engagement with the docking system may have a number of drawbacks.

For example, relative motion between the underwater vehicle and the docking system may increase the complexity of the docking process. When an underwater vehicle is being recovered from the water by a surface structure such as a platform or a vessel, the surface structure may be particularly influenced by the heave motion of waves (i.e. the upwards and downwards, vertical, motion of waves). This can cause the docking mechanism to be similarly influenced in the vertical direction. This could cause the docking mechanism and the underwater

vehicle to move out-of-plane with one another, if the underwater vehicle is required to be in a substantially horizontal orientation during the docking process.

In another example, many underwater vehicles have a positive or negative buoyancy, causing the underwater vehicle to float or sink, respectively. This can cause an unwanted motion of the underwater vehicle in the vertical direction, which could misalign an underwater vehicle and a docking mechanism if the underwater vehicle is to remain in a substantially horizontal orientation during the docking process. To counteract this unwanted motion, underwater vehicles may need to be constantly moving to create a desired counteracting thrust from their control surfaces. However, if the underwater vehicle cannot successfully dock with the docking mechanism at a first attempt this may then require the underwater vehicle to circle back around to make another attempt at docking.

Further, underwater vehicles that have positive or negative buoyancy may experience a torque about the docking mechanism, once engaged and in a substantially horizontal orientation. This torque could cause undesired stress or damage to the docking mechanism.

In another example, docking processes that require the underwater vehicle to be in a substantially horizontal orientation often require there to be a large unobstructed space available surrounding the docking mechanism to accommodate the approach of the underwater vehicle in the horizontal direction (both before and after the docking mechanism, should multiple docking attempts be required). This can complicate the docking process.

Having the docking mechanism capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation addresses a number of these drawbacks.

By having the docking mechanism capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation, the direction in which docking occurs is made parallel to the heave motion of the waves. This may reduce the complexity of the docking process as a result, since heave motion acting on the docking system may be less likely to move the docking system and the underwater vehicle out-of-plane from one another.

Also, by having the docking mechanism capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation the direction in which docking occurs is made parallel to any buoyancy forces acting on the underwater vehicle. Accordingly, the docking process may be less affected by the

buoyancy of the underwater vehicle since motion due to buoyancy will be less likely to move the underwater vehicle out-of-plane from the docking mechanism. Having the direction in which docking occurs made parallel to any buoyancy forces acting on the underwater vehicle may also mitigate any torque forces acting about the docking mechanism due to the buoyancy of the underwater vehicle.

In large bodies of water such as the sea there may be less obstructions present in a vertical direction, since obstructions may be generally present at the seabed or at sea level (e.g. other surface structures). Accordingly, the method of docking the underwater vehicle may be suitable for use in subsea locations where obstructions limit the horizontal space available for manoeuvring the underwater vehicle by having the docking mechanism be configured to capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation.

The method of the sixth aspect may have one or more or all features corresponding to those of the docking system of the first aspect and/or the subsea exploration system of the fifth aspect. Thus, the above-description of the docking system of the first aspect and/or the fifth aspect, including but not limited to all technical advantages and alternative embodiments, may be equally applicable to the method of the sixth aspect.

The method may comprise using a docking system according to the first aspect.

The method may comprise using an underwater vehicle as described in the fifth aspect.

The method may comprise using the subsea exploration system of the fifth aspect, wherein the subsea exploration system comprises the docking system of the first aspect.

Capturing the underwater vehicle may comprise: a docking interface of the docking mechanism engaging with one of a nose end or a tail end of the underwater vehicle.

Capturing the underwater vehicle may be performed using a powered mechanism and/or a passive mechanism.

The method may comprise actuating the powered mechanism.

The method may comprise: ascending or diving with the underwater vehicle in a substantially vertical orientation.

The step of ascending with the underwater vehicle may be performed as part of moving the underwater vehicle such that the docking mechanism captures the underwater vehicle.

The method may comprise using a communication device to aid the underwater vehicle in locating the docking mechanism prior to the underwater vehicle docking with the docking mechanism. The method may comprise emitting an acoustic signal and/or an optical signal. The optical signal may be generated by an optical marker.

Moving the docking mechanism may comprise lowering the docking mechanism into the water. The docking mechanism may be lowered into the water using a lifting mechanism. Moving the docking mechanism may additionally or alternatively comprising operating the ROV.

Viewed from a seventh aspect of the present invention, there is provided a method of manoeuvring an underwater vehicle out of a body of water. The method comprises: docking an underwater vehicle using a method according to the sixth aspect; and lifting the docking mechanism out of the water whilst the underwater vehicle remains captured.

The method of the seventh aspect comprises the method of the sixth aspect. Thus, the above-description of the method of the sixth aspect, including but not limited to all technical advantages and optional features, is equally applicable to the method of the seventh aspect.

The method of the seventh aspect may have one or more or all features corresponding to those of the LARS of the second aspect. Thus, the above-description of the LARS of the second aspect, including but not limited to all technical advantages and alternative embodiments, may be equally applicable to the method of the seventh aspect.

The method may comprise using a LARS according to the second aspect.

The method may comprise lowering the docking mechanism into the water.

Viewed from an eighth aspect of the invention, there is provided a method of docking an underwater vehicle to a subsea docking station. The method comprises: docking an underwater vehicle using the method according to the sixth aspect; wherein the docking mechanism is mounted to a subsea docking station.

The method of the eighth aspect comprises the method of the sixth aspect. Thus, the above-description of the method of the sixth aspect, including but not

limited to all technical advantages and optional features, is equally applicable to the method of the eighth aspect.

The method of the eighth aspect may have one or more or all features corresponding to those of the subsea docking station of the third aspect. Thus, the above-description of the subsea docking station of the third aspect, including but not limited to all technical advantages and alternative embodiments, may be equally applicable to the method of the eighth aspect.

The method may comprise using a subsea docking station according to the third aspect.

Viewed from a ninth aspect of the invention, there is provided a method of using a subsea docking system according to the fourth aspect. The method comprises: docking an underwater vehicle to the positively buoyant portion using the method according to the sixth aspect.

The method of the ninth aspect comprises the method of the sixth aspect. Thus, the above-description of the method of the sixth aspect, including but not limited to all technical advantages and optional features, is equally applicable to the method of the ninth aspect.

The method of the ninth aspect comprises using the subsea docking system according to the fourth aspect. Thus, the above-description of the subsea docking system of the fourth aspect, including but not limited to all technical advantages and alternative embodiments, may be equally applicable to the method of the ninth aspect.

The method may comprise releasing the positively buoyant portion from the seabed when the underwater vehicle is docked to the positively buoyant portion, such that the positively buoyant portion and the underwater vehicle ascend to sea level.

The positively buoyant portion may be configured to be releasably secured to the seabed via a negatively buoyant portion, and the method may comprise: lowering the negatively buoyant portion into a body of water when secured to the positively buoyant portion, such that the positively buoyant portion sinks to a seabed.

The method may comprise undocking the underwater vehicle from the docking mechanism in response to receiving an acoustic signal from a surface structure.

The method may comprise transmitting, by the positively buoyant portion, an acoustic signal.

The method may comprise the underwater vehicle navigating to and/or positioning itself relative to, the underwater vehicle in response to the acoustic signal.

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

Figures 1A-C illustrate an underwater vehicle being recovered by a launch and recovery system;

Figures 2A and 2B illustrate a first exemplary arrangement for actively docking an underwater vehicle to a docking mechanism;

Figures 3A and 3B illustrate a second exemplary arrangement for actively docking an underwater vehicle to a docking mechanism;

Figures 4A and 4B illustrate a first exemplary arrangement for passively docking an underwater vehicle to a docking mechanism;

Figure 5 shows a subsea docking station;

Figure 6 illustrates an underwater vehicle being used in combination with a portable subsea docking system;

Figure 7 shows an autonomous underwater vehicle, AUV, from a side view; and

Figure 8 shows the AUV of figure 7 in a perspective view.

Embodiments described herein relate to docking systems for underwater vehicle. The docking systems described herein comprise a docking mechanism for docking with the underwater vehicle when in water, wherein the docking mechanism is configured to capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation and is submerged. The docking systems are described in the context of certain preferred embodiments, including a launch and recovery system, a subsea docking station, and a portable subsea docking system. The structural, functional and operational features common to the docking systems will be apparent from the following description of the docking systems in the context of these certain preferred embodiments.

Figures 1A-C illustrate various stages of an underwater vehicle 100, which in the present embodiment is an autonomous underwater vehicle, AUV, 100, being recovered by a launch and recovery system, LARS, 200 according to one embodiment.

The LARS 200 comprises a docking mechanism 201 having a docking interface 201a. The docking mechanism 201 is connected to a surface vessel 205 via a lifting mechanism. In the present embodiment, the lifting mechanism is a cable winch system comprising a winch and a winch cable 202. The surface vessel 205 is a boat located at sea level 1, although in other embodiments other surface structures can be used to support the docking mechanism 201. In other embodiments, the lifting mechanism may be a mechanical arm configured to be moved into and out of the water.

The AUV 100 is recovered from the water 3 by docking with the docking mechanism 201. The docking mechanism 201 captures the AUV 100 with the AUV 100 in a substantially vertical orientation and underwater in the sea 3. It will be appreciated that the AUV 100 is in the substantially vertical orientation when its longitudinal axis, or its forward direction of motion, is substantially parallel to the depthwise direction or perpendicular to sea level 1.

As shown in figure 1A, in a first stage of the recovery process the docking mechanism 201 is lowered into the water 3 from the boat 205, via the winch cable 202. The docking mechanism 201 reaches an underwater position at which the docking mechanism 201 is submerged. Also, the AUV 100 orients itself in a substantially vertical orientation, i.e. so that a longitudinal axis of the AUV 100 is perpendicular to sea level 1. This results in a nose end of the AUV 100 facing towards the docking mechanism 201.

In a second stage of the recovery process, as shown in figure 1B, the AUV 100 then engages the docking mechanism 201 whilst the AUV 100 is in the substantially vertical orientation. In the present embodiment, the AUV 100 engages the docking mechanism 201 by propelling itself in an upward direct D, and into engagement with the docking interface 201a. In other embodiments, engagement may occur as a result of the docking mechanism 201 being lowered towards the AUV 100, or through a combination of both the AUV 100 and the docking mechanism 201 moving towards one another.

Once the docking mechanism 201 has captured the AUV 100, the AUV 100 is lifted out of the water 3 by the winch cable 202. The winch cable 202 moves the docking mechanism 201, and in turn the docked AUV 100, to a surface position at which both the docking mechanism 201 and the AUV 100 are above the surface of the body of water 3.

In the present embodiment, the winch cable 201 is passed through a moon pool of the boat 205 and thus manoeuvres the docking mechanism 201 and the AUV 100 into and out of the water 3 via the moon pool. In other embodiments, the winch cable 202 could be positioned over a side of the boat 205 via a crane, tether handling system, or other similar apparatus.

The AUV 100 can be launched by the LARS 200 in a reverse operation. For example, the AUV 100 is firstly lowered into the water 3 via the winch cable 202. The AUV 100 may remain in a substantially vertical orientation as it is being submerged. Once the AUV 100 is submerged in the water, the AUV 100 disengages from the docking mechanism 201. The AUV 100 can then propel itself away from the docking mechanism 201 to begin or resume a subsea operation.

The docking interface 201a comprises a communications interface that, when engaged with the AUV 100, provides data communications between the AUV 100 and the vessel 205. The docking interface 201a also comprises a power interface that, when engaged with the AUV 100, provides electrical power to the AUV 100. In the present embodiment, the communications interface and the power interface are provided by an inductive type for transfer of power and data. In other embodiments, the communications interface can be provided by an acoustic transceiver for the transmission and receipt of signals.

The winch cable 202 provides a wired communication path between the vessel 205 and the docking mechanism 201. The wired communication path is used to power the docking mechanism 201 and to control the docking mechanism 201. Further, when the AUV 100 is docked with the docking mechanism 201, the wired communication path is used to relay data communications between the vessel 205 and the AUV 100.

In some embodiments, the docking mechanism 201 is a remotely operated vehicle, ROV, docking mechanism 201. The winch cable 202 serves as a tether, providing wired communications between the vessel 205 and the docking mechanism 201, as well as a mechanism to lift the ROV docking mechanism 201 in and out of the water 3. The ROV docking mechanism 201 is actively positioned through remote control of the ROV docking mechanism 201, and moves to the AUV 100 to capture the AUV 100. The winch cable 202 can be neutrally buoyant, positively buoyant, or negatively buoyant as desired.

In the present embodiment, the docking mechanism 201 comprises a powered mechanism configured to secure the AUV 100 to the docking mechanism

201. The powered mechanism is a mechanism that is used to actively capture, or engage with, the AUV 100. In the present embodiment the powered mechanism is actuated by an electric motor, but in other embodiments the powered mechanism could alternatively be actuated by a hydraulic or pneumatic mechanism.

The powered mechanism of the present embodiment is illustrated in closer detail in figures 2A and 2B. The powered mechanism comprises a locking mechanism 210 that is configured to interlock with a corresponding portion located at the nose end of the AUV 100. The locking mechanism 210 comprises a plurality of finger portions 211 that are configured to engage respective receiving portions 212 located at the nose end of the AUV 100. The finger portions 211 are configured to be actuated, by an electric motor, between an open configuration in which the finger portions 211 do not engage the receiving portions 212, and a closed configuration in which the finger portions 211 engage the receiving portions 212.

Figure 2A shows the locking mechanism 210 prior to engagement with the AUV 100. The AUV 100 and the docking mechanism 201 are moved into proximity with each other, with the AUV 100 in the substantially vertical orientation. The locking mechanism 210 is in the open configuration, such that the docking mechanism 201 can capture the AUV 100. The locking mechanism 210 is then moved to the closed configuration, resulting in the finger portions 211 of the locking mechanism 210 engaging with the corresponding receiving portions 212 of the AUV 100. The AUV 100 is secured to the docking mechanism 201, as a result.

In the present embodiment, the receiving portions 212 are recessed portions formed in the nose of the AUV 100. In other embodiments, the receiving portions 212 can be protrusions defining an opening for receiving corresponding finger portions 211, such as lashing rings protruding from the AUV 100.

In other embodiments, the locking mechanism 210 can secure the docking mechanism 201 to the AUV 100 using a twist lock mechanism. The locking mechanism 210 can comprise a first portion configured to mate with a second portion located on the AUV 100 by a twisting motion of the first portion. Other suitable arrangements for the locking mechanism 210 are contemplated.

A powered mechanism according to another embodiment is illustrated in closer detail in figures 3A and 3B. The docking mechanism 201 is provided in the form of a garage or tube comprising side walls and an opening 201c at one end. The garage or tube is arranged to at least partially surround the hull of the AUV

100. The opening 201c is arranged to receive the AUV 100 in the substantially vertical orientation.

The docking mechanism 201 also comprises the powered mechanism, which is in the form of a bellows mechanism 220. As illustrated, the bellows mechanism 220 is in the form of an inflatable cushion, or airbag, mechanism. The bellows mechanism 220 is configured to capture the AUV 100 by engaging with the hull of the AUV 100. The docking mechanism 201 comprises at least two bellows 221 (e.g. inflatable cushions or airbags) located on internal side surfaces of the docking mechanism 201 and arranged to evenly surround the hull of the AUV 100 when the AUV 100 is positioned in the docking mechanism 201. For the two bellows 221, this is achieved by positioning the bellows 221 opposite one another.

The bellows 221 are movable between a deflated position in which the bellows 221 do not engage with the AUV 100 (as shown in figure 3A), and an inflated position in which the bellows are arranged to engage the AUV 100 (as shown in figure 3B). The docking mechanism 201 is secured to the AUV 100 when the bellows mechanism 220 is in the inflated position.

In other embodiments, the docking mechanism 201 comprises a passive mechanism configured to secure the AUV 100 to the docking mechanism 201. The passive mechanism is a mechanism that captures, or engages with, the AUV 100 due to motion of the AUV 100 and/or the docking mechanism 201.

Figures 4A and 4B illustrate a passive mechanism in closer detail. The passive mechanism is an interlocking mechanism 230, wherein a recessed portion 231 is arranged to receive a complementary protruding portion 232. As illustrated the recessed portion 231 is provided on the docking mechanism 201 and the protruding portion 232 at the nose end of the AUV 100, but in other embodiments protruding portion could be provided as part of the docking mechanism 201 and the recessed portion 231 could be provided on the nose end of the AUV 100. Upon motion of the AUV 100 or the docking mechanism 201, the protruding portion 232 and the recessed portion 231 engage one another, and the resulting contact force causes a snap-fit engagement.

Figure 5 shows a subsea docking station 300, according to another embodiment. The subsea docking station 300 comprises a subsea base structure 305 anchored to the seabed 5, and a docking mechanism 301 having a docking interface 301a. The docking mechanism 301 is structurally and functionally similar

to the docking mechanism 201 discussed previously, and therefore like features will not be repeated.

The subsea base structure 305 is a platform in the present embodiment, and in other embodiments could be a cage-like structure or tube-like structure with an open upper end. The subsea base structure 305 is provided as a standalone structure in the embodiment illustrated in figure 6. In other embodiments, however, it can be part of, or in combination with, a wider construction such as an aquaculture cage, a subsea facility, or at a foundational structure of an offshore topside structure such as a rig, platform or wind turbine.

The subsea base structure 305 is anchored to the seabed 5 via a plurality of legs 306, although in other embodiments alternative means for anchoring the subsea base structure 305 to the seabed 3, such as using cables, a gravity base foundation, or piles.

In the present embodiment, the docking mechanism 301 is mounted to the subsea base structure 305 such that it is exposed from above. The docking mechanism 301 is configured to engage the AUV 100 when the AUV 100 is in a substantially vertical orientation. The AUV 100 propels itself downward and into engagement with the docking interface 301a, to dock itself to the subsea docking station 300.

The subsea docking station 300 comprises a number of features to help the AUV 100 navigate to the subsea docking station 300 and correctly orient itself for engagement with the docking mechanism 301a.

The subsea docking station 300 comprises an acoustic communications module 307 that can establish a remote communication link with the AUV 100 before it is docked, and can be used by the AUV 100 for locating the docking mechanism 301.

The subsea docking station 300 also comprises an optical marker, for example an ARTag such as ArUco, to aid the AUV 100 in positioning itself relative to the docking mechanism 301 during the docking process, and prior to engagement with the docking interface 301a.

The AUV 100 can dock with the subsea docking station 300 if it needs to be securely stationed for a period of time, e.g. during or between subsea operations. Additionally or alternatively, the AUV 100 can dock with the subsea docking station 300 to facilitate data communications with a remote processor, or to recharge the AUV 100. The docking interface 301a can be provided with a communications

interface and a power interface as necessary, to facilitate the transfer or data and/or power between the AUV 100 and the subsea docking station 300.

Figures 6A-D illustrate the various stages of an AUV 100 being used in combination with a portable subsea docking station 400, according to another embodiment.

The portable subsea docking station 400 comprises a negatively buoyant portion 402 and a positively buoyant portion 403. The negatively buoyant portion 402 and the positively buoyant portion 403 are releasably secured to one another by a tether 404.

The positively buoyant portion 403 comprises a docking mechanism 401 having a docking interface 401a. The docking mechanism 401 is configured to engage with the AUV 100 when the AUV 100 is in a substantially vertical orientation. The docking mechanism 401 is structurally and functionally similar to the docking mechanisms 201, 301 discussed previously, and therefore like features will not be repeated.

The positively buoyant portion 403 is positively buoyant such that it will aid ascension of the AUV 100 to the surface when the positively buoyant portion 403 is engaged with the AUV 100 and not otherwise secured to the seabed 5.

In the present embodiment, the AUV 100 is designed to have close to a neutral buoyancy to enable energy-efficient cruising. For example, an AUV 100 having a diameter of 0.5m and a length of 2m will experience a buoyancy force of approximately 4000 N. Ideally, the AUV 100 will be designed to have close to neutral buoyancy to enable energy-efficient cruising, and may thus have a mass of approximately 400 kg. The buoyancy of the positively buoyant portion 403 is chosen to facilitate a fast and stable ascension of the AUV 100 to the surface. In the present embodiment, the positively buoyant portion 403 has a positive buoyancy of around 400N, although other values are contemplated in alternative embodiments.

In other embodiments, the AUV 100 is positively buoyant. For example, the ballast of the AUV 100 can be trimmed so that the AUV 100 is slightly positively buoyant. This can prevent the AUV 100 sinking to the seabed in the event of a systems failure. The buoyancy of the positively buoyant portion 403 is still chosen to facilitate a fast and stable ascension of the AUV 100 to the surface, and can still be around 400N, although other values are contemplated in alternative embodiments.

In embodiments where the AUV 100 is negatively buoyant, the buoyancy of the positively buoyant portion 403 should be greater than the buoyancy of the AUV 100 and also facilitate a fast and stable ascension of the AUV 100 to the surface. For example, if the AUV 100 experiences a negative buoyancy of around 40 N to 100 N, the buoyancy of the positively buoyant portion 403 should be increased by an equivalent value.

The positively buoyant portion 403 contains a buoyancy component that is more buoyant than seawater. In the present embodiment the buoyancy component is a buoyancy foam such as Divinycell ® HCP or a syntactic foam. In other embodiments, the buoyancy component can be an alternative buoyancy material or a buoyant fluid such as oil or air, or another suitable buoyant material, to provide the desired buoyancy.

The negatively buoyant portion 402 is negatively buoyant such that it will rest on the seabed 5 when secured to the positively buoyant portion 403. That is, the negatively buoyant portion 402 anchors the positively buoyant portion 403 to the seabed 5 when the two portions 402, 403 are secured to one another. The negatively buoyant portion 402 is a weighted structure serving as an anchor portion.

In other embodiments the positively buoyant portion 403 can be releasably secured to the seabed 5 via an alternative anchoring mechanism such as a cable or tether directly anchoring the positively buoyant portion 403 to the seabed 5, or the positively buoyant portion 403 can be releasably secured to the seabed 5 via a foundational subsea structure such as a pile or base structure fixed to the seabed 5.

The portable subsea docking station 400 can be used as follows.

The portable subsea docking station 400 can be deployed from the surface by releasing it into the water. The negatively buoyant portion 402 causes the portable subsea docking station 400 to sink and, as shown in figure 6A, the portable subsea docking station 400 comes to rest on the seabed 3.

The portable subsea docking system 400 sinks in a substantially vertical direction, such that its position at the surface when launched will correspond to its position at the seabed 5. Accordingly, a GPS location giving the position of the portable subsea docking station 400 at the surface can be extrapolated to give the position of the portable subsea docking station 400 at the seabed 5.

In other embodiments where the positively buoyant portion 403 is releasably secured to the seabed 5 via alternative anchor portions, the alternative anchor

portions and the positively buoyant portion 403 can be delivered to the seabed 5 using conventional techniques.

The AUV 100 is docked with the docking mechanism 401, and will therefore also be deployed to the seabed 5 via the portable subsea docking station 400. The AUV 100 can remain docked to the portable subsea docking system 400 until it is ready to begin a subsea operation.

The AUV 100 can begin a mission, such as subsea mapping, either upon receipt of a first acoustic signal S1 from a transmitter at the surface, or at a scheduled time. The AUV 100 disengages from the docking mechanism 401 and performs its subsea operation, as shown in figure 6B.

In some embodiments, the AUV 100 is configured to actively disengage from the docking mechanism 401 upon receipt of the first acoustic signal S1. In other embodiments, additionally or alternatively the docking mechanism 401 is configured to actively disengage from the AUV 100 upon the positively buoyant portion 403 receiving the first acoustic signal S1.

The positively buoyant portion 403 comprises a transceiver that emits a second acoustic signal T when the AUV 100 is disengaged from the docking mechanism 401. The second acoustic signal T can aid the navigational capabilities of the AUV 100, by providing a way for the AUV 100 to determine its position relative to the portable subsea docking station 400.

After the AUV 100 has completed its subsea operation, or should otherwise return to the portable subsea docking station 400, it will navigate to the portable subsea docking station 400.

In some embodiments, the portable subsea docking station 400 may be deployed to the seabed 5 without being engaged to an AUV 100. Instead, an AUV 100 deployed into the water 3 via an alternative launch system may engage with the portable subsea docking station 400 once it completes a subsea operation.

As shown in figure 6C, the docking mechanism 401 is configured to capture the AUV 100 whilst the AUV 100 is in a substantially vertical orientation.

The AUV 100 can use the acoustic signals T emitted by the transceiver of the positively buoyant portion 403 to navigate to, and correctly position itself relative to, the docking interface 401a. The positively buoyant portion 403 can also comprise an optical marker, such as an ARTag, to aid the AUV 100 in positioning itself relative to the docking interface 401a during the docking process.

Once the AUV 100 has successfully docked to the portable subsea docking station 400, the AUV 100 can remain docked until it is ready to begin another subsea operation, or until it is ready for recovery by a surface vessel.

If the AUV 100 is to resume, or begin another, subsea operation the steps described in relation to figure 6B and 6C will repeat.

If the AUV is to be recovered from the water 3, the following steps will occur.

Firstly, the positively buoyant portion 403 receives a signal initiating the recovery process. In the embodiment illustrated in figure 6D, this signal can be a third acoustic signal S2 transmitted by a surface vessel. In other embodiments, this signal can be an acoustic signal or an electronic communication transmitted by the AUV 100, e.g. at a scheduled time such as after a set period of time has elapsed or at a predetermined time.

Secondly, upon receipt of the signal S2 initiating the recovery process, the positively buoyant portion 403 is arranged to release from the negatively buoyant portion 402. In the present embodiment, this is achieved by a control device configured to control a release mechanism in response to the transceiver receiving the third acoustic signal S2. In some embodiments the release mechanism is a locking mechanism attached to the tether 404, operable to release the positively buoyant portion 403 from the negatively buoyant portion 402. In other embodiments, the release mechanism is a cutting mechanism (present at an end of the positively buoyant portion 403) operable to sever the tether 404.

Thirdly, once no longer secured to the negatively buoyant portion 402, the positively buoyant portion 403 in combination with the AUV 100 will float to the surface. The positively buoyant portion 403 and the AUV 100 can then wait for recovery by a surface vessel. The transceiver of the positively buoyant portion 403 and the communications systems of the AUV 100 can emit signals to aid the surface vessel in locating the AUV 100, whilst awaiting recovery.

Figure 7 shows the autonomous underwater vehicle, AUV, 100 from a side view, and figure 8 shows the same AUV 100 from a perspective view, in closer detail.

The AUV 100 comprises a hull 101 formed of multiple sections and modules, extending from a nose end of the AUV 100 to a tail end of the AUV 100. Generally, in use, the nose end defines a forward-facing end of the AUV 100 during forward propulsion of the AUV 100. A longitudinal axis of the AUV 100 extends from the nose end to the tail end, i.e. in a forward-aft direction of the AUV 100.

The hull 101 is a rigid hull 101 insofar as it maintains a stiff and inflexible housing for the various components located therein. However, the rigid hull 101 can be provided with one or more articulatable, flexible sections as desired for performing various subsea operations. The hull 101 is generally cylindrical.

The hull 101 comprises a nose 102, a navigation section 103, a battery module 104 and a propulsion section 105. The nose 102 is located at the nose end of the AUV 100 and can house a payload. The navigation section 103 includes various controllers and sensors for controlling the operations and navigation of the AUV 100. The battery module 104 is configured to provide a source of electrical power for the AUV 100 which, in the present embodiment, is a 1.7 kWh battery. (batteries of differing capacity are contemplated in other embodiments). The propulsion module 105 is configured to generate a motive force to propel the AUV 100 subsea, and to control the positioning of the AUV 100.

The navigation section 103 comprises a sidescan sonar transducer 131 on each side of the hull 101 of the AUV 100. The sidescan sonar transducers 131 are for scanning structures or landscapes during subsea operations. Each sidescan sonar transducer 131 extends in a forward-aft direction of the AUV 100 and is configured to emit a conical or fan-shaped beam in a direction perpendicular to the forward-aft direction of the AUV 100. The sidescan sonar transducers 131 are diametrically opposed about the hull 101 in the present embodiment, although in other embodiments they can be positioned at different circumferential positions as desired. Other subsea surveying sensors, such as multibeam echosounders (MBESs) and cameras, may also be fitted.

The navigation section 103 also comprises a communications module 132 comprising a WiFi transceiver for communications with any nearby vessels. A strobe light for signalling is also provided as part of the communications module 132.

Additionally, the navigation section 103 comprises equipment configured to determine a position of the AUV 100. For example, the navigation section 103 may comprise a GPS sensor for monitoring a position of the AUV 100, which may form part of the communications module 132. Additionally, or alternatively, the navigation section 103 comprises a Doppler Velocity Log, DVL, 133 for estimating a velocity of the AUV 100, and hence a position of the AUV 100 during subsea operations, relative to the seabed. The navigation section 103 may also comprise a series of transponders 134 forming a high precision acoustic positioning system for

additionally monitoring the position of the AUV 100 during subsea operations. The DVL 133 and the transponders 134 are located on an underside of the hull 101. A positioning transponder similar to or the same as 134 may also be fitted at the top side of the AUV.

The navigation section 103 also comprises an interchangeable data storage module 135. The data storage module 135 is interchangeable in the field, and can therefore be changed rapidly when the AUV 100 is surfaced, which allows the AUV 100 to be rapidly redeployed, rather than recovering the AUV 100 and downloading data from the data storage module 135 by a wired connection or the like.

The AUV 100 comprises a controller comprising a processor and a memory. The controller is in communication, e.g. wired or wireless communication, with the payload located in or towards the nose 102, the various sensors and controllers of the navigation section 103, the battery of the battery section 104, and also the various components of the propulsion section 105. The controller is located in the navigation section 103 in the present embodiment, but can be provided in an alternative section or module as appropriate in other embodiments. The memory of the controller stores computer-readable instructions which, when executed by the processor of the controller, causes the AUV 100 to perform various operations.

The propulsion section 105 comprises a propulsion mechanism 152. The propulsion mechanism 152 is located at the tail end of the hull 101. In other embodiments, however, the propulsion mechanism 152 can be located at a nose end of the hull 101.

The propulsion mechanism 152 is configured to propel the AUV 100 during subsea operations. The propulsion mechanism 152 comprises a pair of counter-rotating propellers 153 and a plurality of fins 154. The counter-rotating propellers 153 each generate a motive force for propelling the AUV 100 through water, and the fins 154 improve the efficiency of the propellers 153 by stabilising the motion of the AUV 100. The rotational speed of each propeller in the pair of counter-rotating propellers 153 is independently controllable. This can provide roll control to the AUV 100 as follows.

In prior art systems where a single propeller blade was used, the rotational motion of the propeller would cause the AUV to roll undesirably. This would be counteracted by various control surfaces, together with the use of a fixed ballast at the bottom of the AUV, to maintain a normal orientation of the AUV. In the present embodiment, the use of a pair of counter-rotating propellers 153 results in the

torques induced by each propeller cancelling out. Therefore, where the pair of counter-rotating propellers 153 are operated at the same rotational speed, no roll torque is undesirably induced. The use of a pair of counter-rotating propellers 153 can therefore improve the roll control of the AUV 100 by mitigating against the generation of undesirable roll torque during propulsion of the AUV 100.

Further, where it is desirable to induce a roll torque, e.g. to adjust a rotational orientation of the AUV 100 about its roll axis, the rotational speeds of the propellers 153 can be asymmetrically controlled. When the rotational speeds are imbalanced, the roll torque components induced by each propeller do not cancel out and accordingly the desired roll torque can be induced.

The AUV 100 also comprises a steering mechanism 155. The propulsion mechanism 152 is mounted to the hull 101 via the steering mechanism 155. The steering mechanism 155 is configured to provide directional control to the propulsion mechanism 152 relative to the hull 101, and hence to the pair of counter-rotating propellers 153. Accordingly, the steering mechanism 155 can provide pitch and yaw control for the AUV 100 by directing the motive force generated by the propulsion mechanism 152 relative to hull 101.

The steering mechanism 155 comprises a motorised joint, such as a motorised cardan joint, that is configured to provide pitch and yaw control to the propulsion mechanism 152 relative to the axis of the hull 101 of the AUV 100. The motorised joint is protected by an oil-filled bellows defining a part of the exterior surface of the AUV 100. In other embodiments, the motorised joint can instead be a motorised ball joint, or can be replaced with any other suitable active joint such as a pneumatic, electric or hydraulic actuator.

Compared to prior art AUVs that use control surfaces to provide steering, using the steering mechanism 155 to provide pitch and yaw control directly to the propulsion mechanism 152 can provide greater and more responsive control for the AUV 100. For example, actuating the steering mechanism 155 such that the propulsion mechanism 152 is greatly offset to the longitudinal axis of the hull 101 provides a tighter turning circle for the AUV 100 in water, thereby improving its manoeuvrability. Also, since the AUV 100 does not require any control surfaces to induce steering due to the presence of the steering mechanism 155, the hull 101 of the AUV 100 does not experience drag forces associated with the presence of control surfaces, thus improving its hydrodynamic profile and reducing drag.

Further, the use of control surfaces as in the prior art requires the AUV to have forward motion to induce a directional thrust. For the AUV 100 of the present embodiment, however, the AUV 100 can make a directional turn from a standstill since the steering mechanism 155 directly controls the direction of the propulsion mechanism 152 and hence the motive force it generates.

CLAIMS

1. A docking system for an underwater vehicle, comprising:

a docking mechanism for docking with the underwater vehicle when in water;

wherein the docking mechanism is configured to capture the underwater vehicle when the underwater vehicle is in a substantially vertical orientation and is submerged.

2. A docking system as claimed in claim 1, wherein the docking mechanism comprises a powered mechanism configured to secure the underwater vehicle to the docking mechanism.

3. A docking system as claimed in claim 1 or 2, wherein the docking mechanism comprises a passive mechanism arranged to capture the underwater vehicle.

4. A docking system as claimed in claim 1, 2 or 3, wherein the docking mechanism comprises a docking interface configured to engage with one of a nose end or a tail end of the underwater vehicle.

5. A docking system as claimed in claim 4, wherein the docking interface comprises a communications interface operable to provide data communications between the underwater vehicle and a surface structure when the underwater vehicle is engaged with the docking interface.

6. A docking system as claimed in claim 4 or 5, wherein the docking interface comprises a power interface operable to provide electrical power to the underwater vehicle when the underwater vehicle is engaged with the docking interface.

7. A docking system as claimed in any preceding claim, wherein the docking mechanism comprises a communication device arranged to aid the underwater vehicle in locating the docking mechanism prior to the underwater vehicle docking with the docking mechanism.

8. A launch and recovery system, LARS, for an underwater vehicle, comprising:

a docking system as claimed in any preceding claim; and

a lifting mechanism configured to move the docking mechanism between an underwater position and a surfaced position.

9. A LARS as claimed in claim 8, wherein the docking mechanism comprises a remotely operated vehicle, ROV.

10. A LARS as claimed in claim 9, comprising a tether operable to provide wired communications between the ROV and a controller.

11. A LARS as claimed in any one of claims 8, 9 or 10, wherein the lifting mechanism comprises a cable winch system.

12. A subsea docking station for an underwater vehicle, comprising:

a subsea base structure configured to be anchored to the seabed; and

a docking system as claimed in any one of claims 1 to 7;

wherein the docking system is mounted to the base structure.

13. A subsea docking system for an underwater vehicle, comprising:

a positively buoyant portion comprising a docking system as claimed in any of claims 1 to 7;

wherein the positively buoyant portion is configured to be releasably secured to the seabed; and

wherein the positively buoyant portion is configured to ascend to sea level when docked with the underwater vehicle and not secured to the seabed.

14. A subsea docking system as claimed in claim 13, comprising:

a negatively buoyant portion configured to rest on the seabed;

wherein the positively buoyant portion is configured to be releasably secured to the seabed via the negatively buoyant portion.

15. A subsea docking system as claimed in claim 13 or 14, wherein the positively buoyant portion is releasably secured to the seabed via a tether.

16. A subsea docking system as claimed in claim 13, 14 or 15, wherein the positively buoyant portion comprises a receiver and a control device;

wherein the control device is configured to control a release mechanism releasably securing the positively buoyant portion to the seabed in response to the receiver receiving a release signal.

17. A subsea exploration system, comprising:

an underwater vehicle; and

at least one of:

a LARS as claimed in any one of claims 8 to 11;

a subsea docking station as claimed in claim 12; and

a subsea docking system as claimed in any one of claims 13 to 16.

18. A subsea exploration system as claimed in claim 17, wherein the underwater vehicle comprises:

a hull comprising a nose end and a tail end; and

a propulsion mechanism configured to propel the underwater vehicle; and

a steering mechanism;

wherein the steering mechanism is arranged to enable the propulsion mechanism to rotate in at least one of a pitch and a yaw direction, relative to the hull; and

wherein the propulsion mechanism comprises a pair of counter-rotating propellers, the rotational speed of each propeller being independently controllable.

19. A subsea exploration system as claimed in claim 17 or 18, wherein the underwater vehicle is an autonomous underwater vehicle, AUV.

20. A subsea exploration system as claimed in claim 17, 18 or 19, comprising:

the LARS as claimed in any one of claims 8 to 11; and

a surface vessel;

wherein the LARS is mounted to the surface vessel.

21. A subsea exploration system as claimed in claim 17, 18 or 19, comprising:

the LARS as claimed in any one of claims 8 to 11; and

a platform;

wherein the LARS is mounted to the platform.

22. A method of docking an underwater vehicle, the method comprising:

positioning the underwater vehicle in a substantially vertical orientation; and

moving at least one of a docking mechanism and the underwater vehicle such that the docking mechanism captures the underwater vehicle when the underwater vehicle is in the substantially vertical orientation and is submerged.

23. A method as claimed in claim 22, wherein capturing the underwater vehicle comprises:

a docking interface of the docking mechanism engaging with one of a nose end or a tail end of the underwater vehicle.

24. A method as claimed in claim 22 or 23, the method comprising:

ascending or diving with the underwater vehicle in a substantially vertical orientation.

25. A method of manoeuvring an underwater vehicle out of a body of water, the method comprising:

docking an underwater vehicle using the method as claimed in claim 22, 23 or 24; and

lifting the docking mechanism out of the water whilst the underwater vehicle remains captured.

26. A method as claimed in claim 25, the method comprising:

lowering the docking mechanism into the water.

27. A method of docking an underwater vehicle to a subsea docking station, the method comprising:

docking an underwater vehicle using the method as claimed in claim 22, 23 or 24;

wherein the docking mechanism is mounted to a subsea docking station.

28. A method of using a subsea docking system as claimed in any of claims 13 to 16, the method comprising:

docking an underwater vehicle to the positively buoyant portion using the method as claimed in claim 22, 23 or 24.

29. A method as claimed in claim 28, comprising:

releasing the positively buoyant portion from the seabed when the underwater vehicle is docked to the positively buoyant portion, such that the positively buoyant portion and the underwater vehicle ascend to sea level.

30. A method as claimed in claim 28 or 29, wherein the positively buoyant portion is configured to be releasably secured to the seabed via a negatively buoyant portion, the method comprising:

lowering the negatively buoyant portion into a body of water when secured to the positively buoyant portion, such that the positively buoyant portion sinks to a seabed.