

MODULAR AUTONOMOUS UNDERWATER VEHICLE

5 The present invention relates to a modular autonomous underwater vehicle for performing subsea operations, and to a method of assembling the modular autonomous underwater vehicle.

Autonomous underwater vehicles (AUVs) are used for various purposes, and can take many forms and sizes to fulfil their particular function.

10 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 and a rudder or fin for steering the forward motion. They usually require speed in the forward direction in order to be controllable. Some known survey AUVs comprise modules arranged in series. In the laboratory or factory where the AUV is constructed, the modules can be configured in different ways to enable the AUV to be adapted for its particular use and circumstances. The assembled AUV is then transported to the body of water in which it is to be launched, usually with the assistance of a crane or winch system.

20 Other known AUVs include hovering-type AUVs which do not require constant forward motion, and can hold their position in water. Size of such AUVs vary from small light weight of a few kilograms to very large, for example on the order of 2,000kg. It can be impractical to use large AUV systems in some circumstances due to the difficulties of transporting and manipulating the vehicle.

It is therefore desired to provide an AUV which is versatile and easy to transport and operate and have the capabilities of larger AUV systems.

25 According to a first aspect, the present invention provides an autonomous underwater vehicle for performing subsea operations, comprising two or more sections which are configured to be connected and disconnected from one another, wherein at least two of the sections are elongate and connectable in parallel with each other to form a rigid hull, wherein each section has a mass that is less than 80kg, and wherein each section is individually pressure-rated and can be submerged in water whilst not connected to another of the sections.

30 By providing a modular arrangement in which multiple individual sections are connected together to form the assembled AUV, with each section being relatively lightweight, the AUV is more convenient to transport to its launching location. Each section can be carried individually and assembled in situ, rather

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than needing to transport and manipulate the relatively heavy, bulky assembled AUV.

Moreover, since the AUV is intended to be launched in water to perform subsea operations, the launch site of the vehicle is likely to be a wet environment such as on a boat, a dockside or a platform. By providing a modular AUV in which each section is pressure-rated for being individually submerged in water (e.g., each section is watertight), the present AUV can advantageously be assembled on-site (i.e., at or near the intended launch location) without concerns of water ingress into the interior part of each section of the vehicle. The sections may be connected to each other to form the AUV before being submerged in the water.

Therefore, the individual sections can be manufactured in a dry environment such as a laboratory or factory, where internal components of the vehicle that are sensitive to water (e.g. electrical components) are kept dry. Then, the finished sections can be transported to the vehicle launch site easily, due to the low weight of each section. When the sections arrive at the launch site, which is typically a wet environment, they can be connected together to form the assembled AUV without concern of water damage to the internal components of the vehicle. Finally, the AUV can be launched into the water to perform subsea operations.

During the operation of the AUV, it may be desired to replace one or more components of the AUV, e.g. if a battery unit becomes low on power or if a data storage device becomes full. The present invention facilitates such component replacement because it is possible to exchange and replace sections on-site. For instance, the AUV may be removed from the water, a section comprising a battery module can be disconnected from the vehicle, a new section with a fully charged battery module can be connected in its place, and the vehicle can be re-launched. The battery in the removed section may then optionally be recharged. Since the sections are watertight, such replacement can be conducted in the wet on-site location without exposing the sensitive internal electrical components to water.

The assembled AUV includes a rigid hull formed at least by the two or more elongate sections when they are connected in parallel, i.e. side-by-side (rather than end-to-end) with their longitudinal axes oriented in the same direction but not along the same axis. Arranging the sections in parallel as opposed to conventional serial arrangements has the benefit of limiting the overall length of the vehicle and improving handling while still providing the ability to have exchangeable sections. Moreover, a rigid hull provides a stable body for the AUV. The two or more

sections may be arranged in parallel within a single plane, but other parallel arrangements are also possible.

The present invention therefore provides an AUV which is stable and robust whilst also being versatile, easy to transport and construct, and which provides flexibility in use by facilitating easy replacement of sections.

Since each section has a mass that is less than 80kg, each section may be able to be carried by up to two people. This is particularly useful as it reduces or removes the need for complicated and expensive crane systems for transporting and moving the vehicle, at least until the sections are connected together. Each section may have a mass that is less than 70kg, or less than 60kg, or less than 50kg. Typically, each section will have a mass of greater than 10kg, or greater than 20kg, or greater than 30kg.

The term "pressure rated" means that a section can be submerged to a particular depth (or pressure) within water without water ingress occurring. The depth may range from tens of meters to thousands of meters. The pressure rating may be at least 10 meters, or at least 100 meters. A typical pressure rating, e.g. for a portable section of 50-80 kgs, may be at least 500 meters, or at least 1000 meters.

A hull of each of the sections may be made of a metal, such as aluminium, or titanium. In other embodiments, a hull of each of the sections may be made of a composite material, but such materials are likely to be pressure rated only for depths of up to about 100 meters. The AUV may be understood as being 'modular' by virtue of the plurality of sections (i.e., modules) that are connectable together to form the AUV. The AUV may therefore be referred to as a modular AUV.

One or more or each section may be rigid, i.e. it cannot bend or flex in normal use. This provides strength and resilience to the sections individually and to the assembled AUV (in particular the rigid hull) once the sections are connected together.

The rigid hull may be formed by all the sections which are rigidly connected together (as opposed to sections that are connected by flexible joints, as discussed further below.)

One or more of the elongate sections may have a length-to-width ratio of at least 5 to 1, or at least 6 to 1, or at least 7 to 1, or at least 8 to 1, or at least 9 to 1, or at least 10 to 1. Each section may have a substantially cylindrical shape. This provides a streamlined shape for efficient movement through water.

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A length of the autonomous underwater vehicle may be less than 3 meters, or less than 2.5 meters.

5 A length of each of the sections may be less than 3 meters, or less than 2.5 meters, or less than 2.2 meters, or less than 2 meters, or less than 1.5 meters. A length of each of the sections of the AUV may be greater than 30 cm. An AUV may comprise of at least two, or at least three sections. In one example a section may be about 100 cm long, have a radius of about 10 cm, being neutrally buoyant in water, have a weight (in air) of approx. 31 kg.

10 The assembled AUV, in particular the rigid hull, may comprise two sections connected in parallel, or three sections connected in parallel, or four sections connected in parallel, or more.

15 Where three or more parallel sections are provided, the AUV may comprise at least one central section and two side sections which are located either side of the central section. The side sections may be directly connectable to the central section. The side sections may be the two radially outermost sections. All sections located between the outermost side sections may be referred to as central sections. For example, where four parallel sections are provided, there may be two central sections connectable together and two side sections connectable to respective ones of the central sections.

20 The connection between adjacent parallel sections of the rigid hull may be a rigid connection, i.e. a connection which does not permit relative movement such as flexural movement, rotation, translation, etc. This provides stability to the AUV body which helps the vehicle to resist movements e.g. due to water currents. It also eases handling on a deck or shore as the AUV can be stable in itself and not roll over or rock radially.

25 A connection interface between two adjacent sections may comprise a mechanical connection to physically connect the two sections together and a contactless electrical connection to enable contactless electrical communication between the two sections. Thus, the connection interface can be structurally simple to facilitate easy removal and replacement of sections, without requiring the complicated disconnection and reconnection of electrical components.

30 The electrical connection can be of inductive type for transfer of power and data. High frequency data transfer (e.g. at least one gigahertz) may also be used to obtain high-speed data link connections between the sections.

The connection interface between two of the sections may make the vehicle stiff in a direction perpendicular to the lengthwise direction of the sections.

The connection method may allow for connecting the sections without opening any of the pressurised sections.

5 One or more sections may be connected in series, i.e. end-to-end. The connection between adjacent sections connected in series may be a flexible connection to allow relative flexural movement of the sections. This contrasts with the rigid connection between parallel sections. For example, the AUV may comprise a joint module for connecting the two sections together in series, wherein
10 the joint module is configured to allow for a flexural motion of the AUV. Thus, one or more sections may be able to flex relative to the rigid hull of the AUV. Such sections could be used to perform operations, e.g. it may operate as an 'arm' of the AUV which can manipulate a tool. The rigid hull may provide a stable base for the arm(s).

15 One or more of the sections themselves may be modular. That is, a given section may comprise one or more modules, each module being configured for performing a specific function. The modules can be configured within the respective section as desired. In this way the configuration of the AUV may be adapted for a particular purpose. For example, to accommodate greater power
20 requirements, the number of sections that contain battery modules may be increased, or multiple battery modules may be located within a particular section. The modules of a particular section may be referred to as sub-modules to differentiate from the sections themselves which can be considered 'modules' of the assembled AUV. An AUV which comprises sections that themselves comprise sub-
25 modules may be referred to as having a 'super-modularity'.

 One or more sections may comprise one or more thruster modules. The thruster module(s) may be configured to provide motion control of the AUV in water. Multiple thruster modules may be provided in a given section, e.g. at both ends of an elongate section.

30 The one or more thruster modules may apply thrust to the AUV and may be arranged for propulsion of the entire AUV in translation. The one or more thruster modules may be for generating a propulsive force in a direction along the length of the AUV, e.g. aligned with a longitudinal axis of the AUV. The one or more thruster modules may be for generating a propulsive force in a direction at an angle to the

length of the AUV, i.e. in a lateral and/or vertical direction compared to the length of the AUV.

5 A combination of thrust directions may be used to rotate the AUV, e.g. in a pitch, yaw, and/or roll movement. For example, the AUV may be controlled to pitch downwards by applying a downward thrust at the fore end of the AUV and/or an upward thrust at the aft end of the AUV.

10 When two or more sections are connected via a joint module that permits relative flexural movement of the adjoining sections, the one or more thruster modules may apply thrust to the AUV to control the flexural motion of the joint module. Thus, the thruster module(s) may be for controlling the movement of an arm section, e.g. to control a tool or other component.

15 The thruster module(s) may also advantageously allow for the AUV to keep a constant position and/or orientation in the water, in addition to providing thrust for propulsion. Thus, the thrust device(s) may be arranged to provide thrust to give a hovering type capability to the AUV. An advantage of the AUV being able to hover in water is that high-definition images, e.g. of a subsea structure, can be collected for underwater photogrammetry and photo-mosaicking. This imaging may be used in conjunction with a navigation system to provide an accurate representation of the subsea structure.

20 The motion control provided by the thruster module(s) may therefore include propulsion, rotation, pitch and/or hovering of the autonomous underwater vehicle in water.

25 The thrust device(s) may include propellers, impellers, tunnel thrusters, rotatable (azimuth) thrusters, screws (single, twin, contra rotating, controllable-pitch, nozzle style etc.), rudders, fins and/or water jets. Control surfaces like rudders, fins and guide vanes can be provided and may be used as thrust devices to passively or actively to contribute to direction control. This can be whilst the AUV is being propelled by a separate thrust device, and also in a situation where the AUV is being towed. The control surfaces may be part of the thrust device(s).

30 A thruster module may, for example, include tunnel thrusters using propellers, or water jet thrusters. One specific example uses a thruster module with thrusters oriented in two perpendicular directions, which may be two directions that are generally orthogonal to the longitudinal extent of the AUV. This allows thrust to be applied in any lateral direction, such as an up-and-down direction, or a side-ways direction. There may be multiple thruster modules along the length of the

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AUV. This allows thrust to be applied to different parts of the AUV in different directions, which means that all kinds of movements can be achieved, such as a translation movement of the AUV, or a rotation without translation, or combinations of the two.

5 At least one of the sections may comprise a battery module configured to provide electrical power to electrical component(s) of the AUV. For example, the battery module(s) may be for electrically powering one or more thruster modules, sensors, navigation systems, cameras, etc. The battery module may comprise one or more batteries which are preferably rechargeable. As mentioned previously, the
10 present AUV advantageously facilitates easily replacement of a depleted battery since the section containing the depleted battery can simply be disconnected from the AUV and another section with a fully powered battery can be connected in its place. The depleted battery can then be recharged (or replaced) while the AUV is re-launched in the water.

15 The AUV may comprise one or more operational module, such sensors; cameras of one or more different types, echo sounders, gas sniffers, etc.

 The electrical component may comprise a sonar module. The sonar module may be for navigation, ranging, communication, etc. For example, the sonar module may be for locating underwater hazards, searching for and mapping objects
20 on the seafloor such as shipwrecks, pipelines or other subsea structures, and/or mapping the seafloor itself.

 The electrical component may comprise a navigation module. The navigation module may be for enabling the AUV to autonomously navigate for performing the subsea operation without on-going human/operator input.

25 The electrical component may comprise a camera module. The camera module may be for capturing still images and/or video footage, e.g. of a subsea structure. Multiple still images can be stitched together to form a detailed high-definition map of a subsea structure. This stitching may be enhanced using a high-end navigation system. The optional hovering capability of the present AUV also
30 enhances the AUV's ability to capture high definition still images since the AUV can hold itself in place in the water.

 The electrical component may comprise a satellite module. The satellite module may be for navigation, e.g. using GPS to track the AUV's location, and/or for communications, etc.

The AUV may comprise an accessory, or a connection point for an accessory, attached to the AUV. The accessory may be any type of accessory required for subsea operations, including all types of underwater mapping, monitoring and IMR accessories, for example inspection accessories such as a camera or other sensor, or manipulator tools such as a gripper tool. The AUV may be configured to manoeuvre itself to a target site, and carry out station keeping or hovering (also called dynamic positioning). The AUV may be configured to use the accessory to perform a required operation.

Any one or more of the above modules or accessories may be integrated with one another, and/or may be provided internal or external of a pressure rated housing of the respective section of the AUV.

The accessory or connection point may be attached at any convenient point on the AUV and as noted above it may be any type of accessory, including an inspection accessory, manipulator tools, and other types of IMR accessories. Thus, the accessory or connection point may be at the front end of the AUV; it may be at a mid-point; or it may be at the stern end of the AUV. There may be multiple accessories or connection points. Where a connection point is present there may be an accessory mounted to it in releasable fashion. Advantageously the connection point can be arranged for connection of alternative types of accessories, which can hence allow a single AUV to be fitted with different accessories for different subsea operations.

In some preferred examples the AUV has the accessory or the connection point for a tool at a front section, or at the front end of a section, so that the accessory is located at the front end of the AUV. An accessory mounted at the front end can have the greatest range of movement and visibility of the water ahead of the AUV, e.g. for navigating around obstacles.

The AUV may comprise a data storage module. The data storage module may be located in a side section of the autonomous underwater vehicle. As with the battery modules discussed above, it may be advantageous for the data storage module to be located on a side section, since a side section can be more easily removed and replaced compared to a central section.

The data storage module may be configured to permit access to stored data without compromising the pressure rating of the respective section. For example, the data storage module may comprise a data transfer port and/or a removable data storage medium, which may be accessible from an exterior of the AUV without

compromising the pressure rating. The data storage module may comprise a wireless data transmission interface, such as WiFi, Bluetooth™, cellular or radio data transmission.

5 Additionally, or alternatively, the data storage module, or indeed the respective section comprising the data storage module, may be removable from the AUV. For example, when the data storage module becomes full, the AUV can be retrieved, the data storage module or the section comprising the data storage module can be removed, the data storage module can be replaced or a new section comprising a new data storage module can be connected to the AUV, and the AUV
10 can be re-launched.

In embodiments in which parallel central and side sections are provided, one or more of the side sections may comprise a first battery module and a thruster module powered by the battery module. The central section may comprise a second battery module and an electrical component powered by the second battery
15 module. The electrical component may comprise a sonar module, a navigation module, a camera module, and/or a satellite module, as discussed previously.

There are various advantages of having the thrusters and batteries isolated in the side section(s) of the AUV in this way. The noisy high-power thrusters and batteries are separated from the more sensitive instrumentation in the central
20 section. This greatly reduces the electrical noise and interference on the sensitive instrumentation. Moreover, by locating the thrusters and batteries on side sections, they are easily replaceable on deck to quickly ready the vehicle for another dive after completing a mission.

By the reference to an AUV for performing subsea operations, it is meant
25 that the AUV is suitable for at least one particular subsea operation. For example, the AUV may include the necessary equipment for performing a particular subsea operation, such as via one or more accessories provided on the AUV. For example, for the purposes of inspecting subsea pipelines, the AUV may include one or more cameras and/or light sources. Additionally, or alternatively, the AUV may
30 include manipulator tools such as a gripper tool.

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

Figure 1 shows a top view of an AUV according to a first embodiment of the present invention;

Figure 2 shows a perspective view of the AUV of Figure 1 in an assembled state;

Figure 3 shows a perspective view of the AUV of Figure 1 in a disassembled state;

5 Figure 4 shows a top view of an AUV according to a second embodiment of the present invention;

Figure 5 shows a perspective view of the AUV of Figure 4;

Figure 6 shows a top view of an AUV according to a third embodiment of the present invention;

10 Figure 7 shows a perspective view of the AUV of Figure 6;

Figure 8 shows a top view of an AUV according to a fourth embodiment of the present invention;

Figure 9 shows a perspective view of the AUV of Figure 8;

Figure 10 shows a platform for docking of the AUV of Figure 8; and

15 Figure 11 shows the AUV of Figure 1 performing a subsea operation.

With reference to Figures 1, 2 and 3, an AUV 100 for performing subsea operations is shown. The AUV 100 comprises three elongate sections 2, 4 rigidly connected in parallel with each other. The three elongate sections 2, 4 include a central section 2 and two side sections 4 located on either side of the central section 2.

20 Adjacent pairs of the three sections 2, 4 are connected by respective connection portions 6. Each connection portion 6 has a length of around 70% of the length of the respective side sections 4. Thus, the connection between adjacent sections 2, 4 is strong and rigid, such that the three sections 2, 4 connected together form a rigid hull 22.

30 The hull 22 of the assembled AUV 100 has a relatively small height and long length compared to its width. Each individual section 2, 4 has a substantially cylindrical shape, as shown best in Figure 3. This provides a streamlined shape to the assembled AUV 100, enabling it to move through water more efficiently compared to the large, bulky conventional hovering-type AUVs.

Each side section 4 comprises two thruster modules 8 located at respective ends of the side section 4. Each thruster module 8 comprises two thrusters 10.

35 The first thruster 10a is oriented to generate vertical thrust to provide up-down thrust control. Thus, the first thrusters 10a can be operated to cause the AUV 100 to hover in the water.

The second thruster 10b is oriented to generate horizontal thrust at an angle of 45 degrees with respect to the forward-rearward direction of the AUV 100. In the illustrated example, two of the second thrusters 10b are oriented perpendicular to the other two of the second thrusters 10b. Thus, by selective activation of the
5 second thrusters 10b, they can provide forward-rearward, left-right and rotational thrust control.

The thruster modules 8 can therefore be used to manoeuvre the AUV 100 in water by providing thrust in a combination of directions.

Each side section 4 also comprises two battery modules 12 for powering
10 the thrusters 10 and other electrical components of the AUV 100. The thruster modules 8 and battery modules 12 of each side section 4 are connected in series along the length of the side section 4.

It will be appreciated that the above example is merely one possible configuration of thrusters. The thrusters may be arranged in various possible
15 configurations. In some embodiments, one or more of the thruster modules may be connected to a steerable joint, such that it can be angled to provide rapid pitch and yaw movements.

The central section 2 comprises a sonar and camera module 14, a navigation module 16, a satellite module 18, and a tail module 20. The sonar and
20 camera module 14 is located at a front end of the central section 2 to provide visibility as the AUV 100 moves through the water. The navigation module 16 and satellite module 18 are located in a middle region of the central section 2, and the tail module 20 is located at a rear end of the central section 2.

Since the battery modules 12 are located in the side sections 4, the side
25 sections 4 can be easily removed from the AUV 100 once the batteries are depleted, and sections comprising fully charged batteries can be connected in their place. This process is much quicker than recharging the batteries. Thus, operational downtime of the AUV 100 is reduced. Moreover, the batteries are kept away from the sensitive instruments in the central section 2 (e.g. the navigation
30 module 16 and the satellite module 18) which reduces noise and interference from the batteries.

Figures 1 and 2 show the AUV 100 in an assembled state, in which the sections 2, 4 are connected together, ready to be launched in water for performing subsea operations. Figure 3 shows the AUV 100 in a disassembled state, in which
35 the sections 2, 4 are disconnected from one another. Each section 2, 4 has a mass

of less than 80kg, e.g. around 30-50kg, meaning that each section 2, 4 can be carried by to two people. Thus, the disassembled AUV 100 can be easily transported to the launch site, where it can be assembled for deployment.

Each of the sections 2, 4 is individually, i.e. when not assembled, pressure-rated for submersion in water, and the sections 2, 4 can be assembled without compromising the pressure-rating. This enables the sections 2, 4 to be connected and disconnected in wet environments without risk of damaging the internal electrical components of the AUV 100.

An AUV 200 according to a second embodiment is shown in Figures 4 and 5.

The AUV 200 is similar to the AUV 100, with a central section 202 and two side sections 204 connected in parallel forming a rigid hull 222. The side sections 204 are the same as the side sections 4 in AUV 100. The AUV 200 includes the addition of an arm section 224. The arm section 224 is connected to the front of the central section 202 via two joint modules 226. The arm section 224 is connected to the central section 202 in series, i.e. end-to-end.

The arm section 224 is elongate and comprises a sonar and camera module 214 at a front end thereof, which is the front-most part of the assembled AUV 200.

The joint modules 226 that connect the sections 202, 224 allow for flexion between the central section 202 and the arm section 224 in multiple angles. This allows the AUV 200 to manipulate the sonar and camera module 214 into various positions, so that it can be optimally positioned for the function it is desired to fulfil.

The central section 202 is the same as central section 2 of AUV 100 except that instead of including a sonar and camera module at a front end of the central section 202, the central section 202 is instead connected to one of the joint modules 226.

Figure 4 shows the AUV 200 in a position in which the joint modules 226 are not bent and the arm section 224 is axially aligned with the central section 202. This configuration may be particularly suitable for travelling long distances subsea, due to the streamlined shape of the AUV 200.

Figure 5 shows a configuration in which the joint modules 226 are bent, causing the axis of the arm section 224 to deviate from the axial position of Figure 4. This allows the position of the sonar and camera module 214 at the front end to be manipulated as desired.

Although not shown in the Figures, the sections 202, 204, 224 of the AUV 200 can be disconnected in a similar fashion to the AUV 100 shown in Figure 3. Thus, each section 202, 204, 224 can be disconnected from the others and then carried by up to two people, due to the lightweight and pressure-rated nature of the sections 202, 204, 224.

An AUV 300 according to a third embodiment is shown in Figures 6 and 7. The AUV 300 comprises a rigid hull 322 including four elongate sections 302, 304 connected in parallel with one another. The four parallel sections 302, 304 comprise first and second central sections 302a, 302b (collectively referred to as central sections 302) and two side sections 304.

The two side sections 304 are the same as the side sections 4, 204 of AUVs 100, 200, e.g. they each comprise two battery modules 312 and two thruster modules 308.

Adjacent hull sections 302, 304 are rigidly connected together via respective connection portions 306.

The first central section 302a comprises a navigation module 316. The second central section 302b comprises a satellite module 318. Each central section 302 comprises a tail module 320 at the rear end thereof.

The AUV 300 further comprises two arm sections 324a, 324b. The first arm section 324a is connected in series with the first central section 302a via two joint modules 326a, and the second arm section 324b is connected in series with the second central section 302b via two joint modules 326b. The first arm section 324a comprises a light module 328 at a front end thereof, and the second arm section 324b comprises a sonar and camera module 314 at a front end thereof.

As shown in Figure 7, the joint modules 326a, 326b allow adjoining sections to flex relative to each other. Thus, for example, the first arm section 324a and joint modules 306a can be used to manipulate the light module 328 relative to the first central section 302a to illuminate a particular object, and the second arm section 324b and the joint modules 326b can be used to manipulate the sonar and camera module 314 to image the object. The four parallel sections 302a, 302b, 304a, 304b form the rigid hull 322 which acts as a stable base for the arms 324a, 324b. A particular advantage is that the two arms 324a, 324b can move independently, meaning e.g. the object can be illuminated and imaged or otherwise interacted with from different angles.

Although not shown in the Figures, the sections 302, 304, 324a, 324b of the AUV 300 can be disconnected in a similar fashion to the AUV 100 shown in Figure 3. Thus, each section 302, 304, 324a, 324b can be disconnected from the others and then carried by up to two people.

5 An AUV 400 according to a fourth embodiment is shown in Figures 8 and 9.

The AUV 400 is similar to the AUV 100, with a central section 402 and two side sections 404 connected in parallel forming a rigid hull 422. The side sections 404 are the same as the side sections 4, 204, 304 in AUVs 100, 200, 300. The AUV 400 also includes a forward arm section 424a connected in series to the front
10 end of the central section 402 and a rear arm section 424b connected in series to the rear end of the central section 402. A joint module 426a, 426b connects each arm section 424 to the respective end of the central section 402.

A sonar and camera module 414 is located at a front end of the front arm section 424a. A thruster module 430 is located at a rear end of the rear arm section
15 424b. The thruster module 430 may be a primary thrust device for propelling the AUV 400 in a forward direction. This may be beneficial for providing large amounts of thrust for long distance travel, whereas the thruster modules 408 on the side sections 404 may be more useful for manoeuvres such as rotating the AUV 400.

As shown in Figure 9, the joint modules 426a, 426b allow the adjoining arm sections 424a, 424b to flex relative to the hull 422. Thus, for example, the front arm section 424a can be used to manipulate the sonar and camera module 414, and the rear arm section 424b can be used to manipulate the primary thrust device 430 to
20 change the direction of thrust. The rigid hull 422 formed by the three parallel sections 402, 404 provide a stable base for the arms 424a, 424b.

25 Figure 10 shows a subsea AUV docking system 500 comprising the AUV 400 and a platform 432 for docking of the AUV 400. The subsea AUV docking system 500 provides for charging of the AUV 400 and data transfer with the AUV 400, such as uploading or download of data.

By docking with the AUV 400 in a configuration in which both arm sections
30 424, 424b are flexed upwards, the bottom surface of the AUV 400 is provided by only the rigid hull 422, enabling the AUV 400 to sit on the platform surface without damaging the arm components.

Figure 11 shows the AUV 100 in use performing a subsea operation. In this example, the AUV 100 is illuminating and imaging a structure on a waterbed 434.

35 Due to its hovering capabilities, the AUV 100 can image the waterbed 434 while the

AUV 100 holds itself in position in the water, thereby enabling a camera of the AUV 100 to capture high definition images.

The above-described embodiments show exemplary configurations of the AUV of the present invention. It will be appreciated that other configurations could also be designed which fall within the scope of the claims. Indeed, an advantage of the present invention is the flexibility provided by the super-modular nature of the AUV. That is, different sections can be interchanged within the AUV; and different modules can be interchanged within each section. For example, the AUV 100 could be reconfigured into the AUV 200 by disconnecting the sonar and camera module at the front end of the central section; connecting in its place two joint modules, and connecting the sonar and camera module to the front end of the front joint module.

In each configuration, the sections are pressure-rated which enables them to be easily connected and disconnected in wet environments, such as on the platform of Figure 10, without damaging the internal electrical components of the AUV. Additionally, since each section is relatively lightweight, the disassembled sections can be carried by up to two people which facilitates transport and assembly. Moreover, once assembled, the sections connected rigidly in parallel with one another provide a rigid hull which provides strength and stability to the assembled AUV.

Whilst a limited number of variations are shown, it will be appreciated that any combination of subsystems may be distributed across any number of sections. For example, the AUV may include only the two side sections 4, and one or more of a sonar and camera module, a navigation module, a satellite module, and a tail module may be incorporated therein.

Additionally, the AUV is not limited to the sections being arranged in a single plane. For example, one or more sections may be connected above or below a central or side section, or at an angle thereto.

CLAIMS

1. An autonomous underwater vehicle for performing subsea operations, comprising two or more sections which are configured to be connected and disconnected from one another, wherein at least two of the sections are elongate and connectable in parallel with each other to form a rigid hull, wherein each section has a mass that is less than 80kg and wherein each section is individually pressure-rated and can individually be submerged in water whilst not connected to another of the sections.
2. An autonomous underwater vehicle as claimed in claim 1, wherein each section has a mass that is less than 70kg, or less than 60kg.
3. An autonomous underwater vehicle as claimed in claim 1 or 2, wherein at least one of the sections comprises a thruster module configured to provide motion control of the autonomous underwater vehicle in water.
4. An autonomous underwater vehicle as claimed in claim 3, wherein the motion control includes propulsion, rotation, pitch, and hovering of the autonomous underwater vehicle in water.
5. An autonomous underwater vehicle as claimed in any preceding claim, wherein at least one of the sections comprises a battery module configured to provide electrical power to an electrical component of the autonomous underwater vehicle.
6. An autonomous underwater vehicle as claimed in any preceding claim, wherein one or more of the elongate sections has a length to width ratio of at least 5 to 1.
7. An autonomous underwater vehicle as claimed in any preceding claim, wherein the at least two elongate sections comprise a central section and two side sections which are located either side of the central section.

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8. An autonomous underwater vehicle as claimed in claim 7, wherein one or more of the side sections comprise a first battery module and a thruster module powered by the battery module.
- 5 9. An autonomous underwater vehicle as claimed in claim 7 or 8, wherein the central section comprises a second battery module and an electrical module powered by the second battery module.
- 10 10. An autonomous underwater vehicle as claimed in claim 9, wherein the electrical module comprises at least one of: a sonar module, a navigation module, a camera module, and a satellite module.
- 15 11. An autonomous underwater vehicle as claimed in any preceding claim, wherein at least one section comprises a tool or a connection point for a tool.
- 20 12. An autonomous underwater vehicle as claimed in any preceding claim, wherein a connection interface between two of the sections comprises a mechanical connection to physically connect the two sections together and a contactless electrical connection for providing contactless electrical communication for bidirectional transfer of power and/or data between the two sections.
- 25 13. An autonomous underwater vehicle as claimed in any preceding claim, comprising a joint module for connecting two of the sections together in series, wherein the joint module allows for a flexural motion of the autonomous underwater vehicle.
- 30 14. An autonomous underwater vehicle as claimed in any preceding claim, comprising a data storage module, wherein the data storage module is preferably located in a side section of the autonomous underwater vehicle.
15. An autonomous underwater vehicle as claimed in any preceding claim, wherein one or more of the sections comprise multiple modules configured to be rearranged within the section.

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16. An autonomous underwater vehicle as claimed in any preceding claim,
wherein a width of the autonomous underwater vehicle is less than 1m.

5 17. An autonomous underwater vehicle as claimed in any preceding claim,
wherein a length of the autonomous underwater vehicle is less than 2.5 meters.

18. A method of assembling the autonomous underwater vehicle of any
preceding claim, comprising:
providing the two or more sections; and
10 connecting the two or more sections together to form the autonomous
underwater vehicle.

19. A method as claimed in claim 18, wherein the sections are connected
together on-site at a location proximate a body of water in which the autonomous
15 underwater vehicle is to be launched.

20. A method as claimed in claim 18 or 19, comprising carrying each section
using a maximum of two people before connecting the sections together.

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