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Asfar et al.

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(54) **UNMANNED AUTONOMOUS SUBMARINE**

(76) Inventors: **Khaled R. Asfar**, Dept. of Mechanical Engineering, Jordan University of Science & Technology, P.O. Box 3030, Irbid 22110 (JO); **Khalid A. Rashdan**, P.O. Box 851295, Amman 11185 (JO); **Yasser J. Al-Alami**, P.O. Box 9899, Amman 11191 (JO)

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Related U.S. Application Data

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(51) **Int. Cl.**
B63G 8/22 (2006.01)

(52) **U.S. Cl.** **114/312**; 114/333

(58) **Field of Classification Search** 114/125, 114/312, 333
See application file for complete search history.

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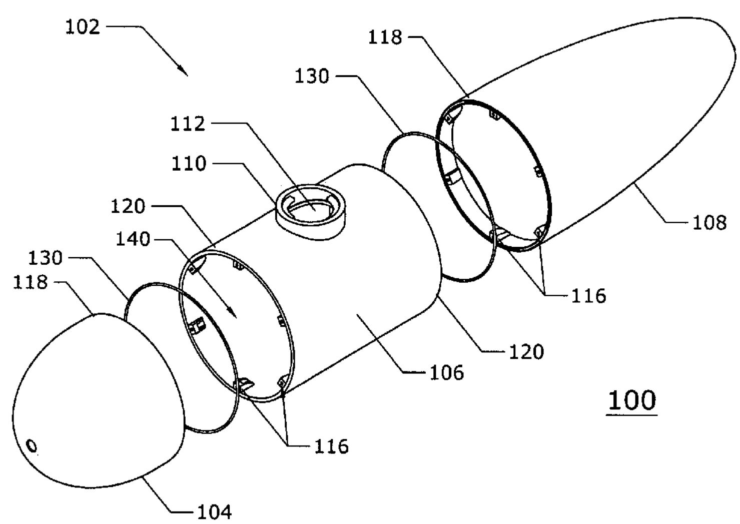
Primary Examiner—Stephen Avila
(74) *Attorney, Agent, or Firm*—Abelman, Frayne & Schwab

(57) **ABSTRACT**

An unmanned autonomous submarine which can float, dive and move in water to perform various tasks. The submarine includes a pressurized cabin which is necessary for the diving and flotation system to work properly. This also helps to increase its sealing power against water leakage into the cabin. The submarine is autonomous, that is automatic and self controlled. It is propelled by water jet propulsion. It can be programmed to dive to preset depths, move along preset trajectories, and return to the base after completing the assigned tasks. A remote control option is provided in order to perform special tasks. The submarine is equipped with several sensors that can measure depth, orientation, attitude, location and speed. It is also equipped with an underwater video camera that can send wireless video pictures from underwater to a monitor above water surface.

39 Claims, 11 Drawing Sheets



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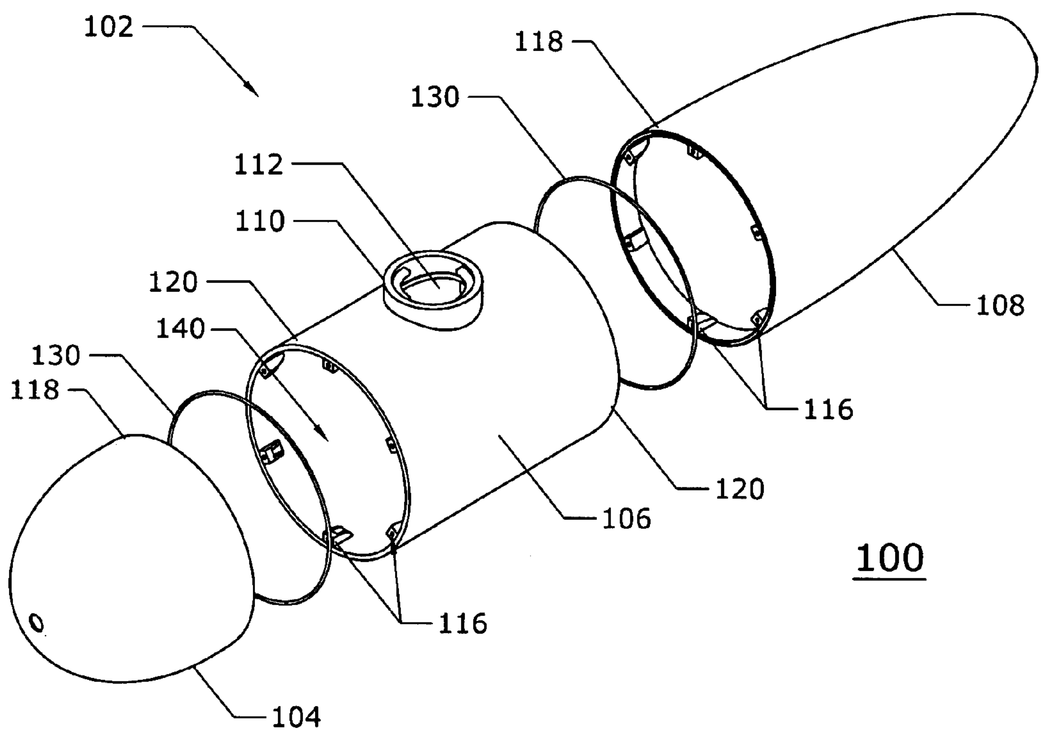
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FIG. 1

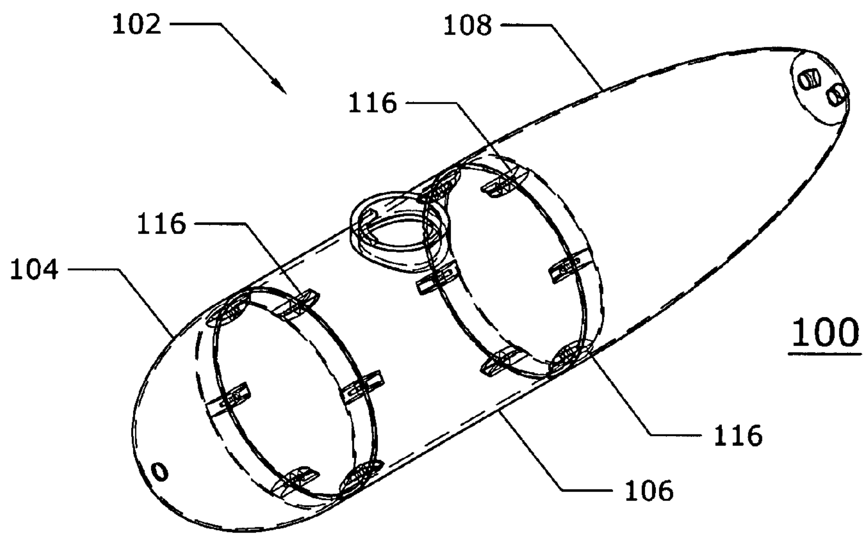
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FIG. 2

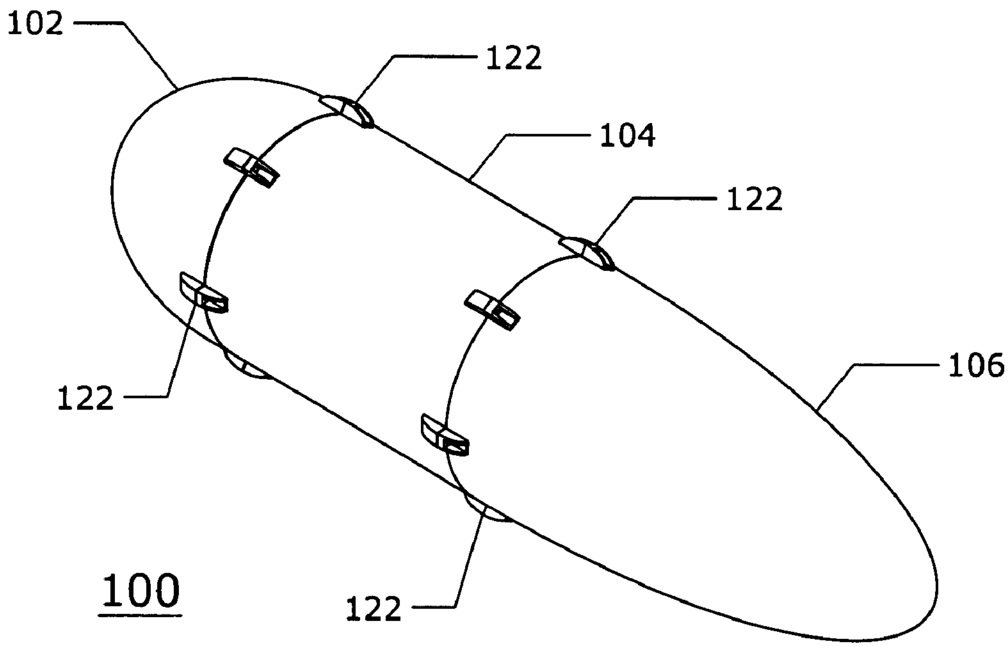

FIG. 3

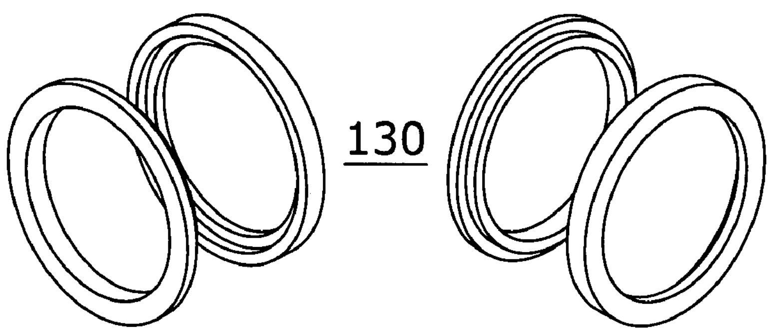

FIG. 4

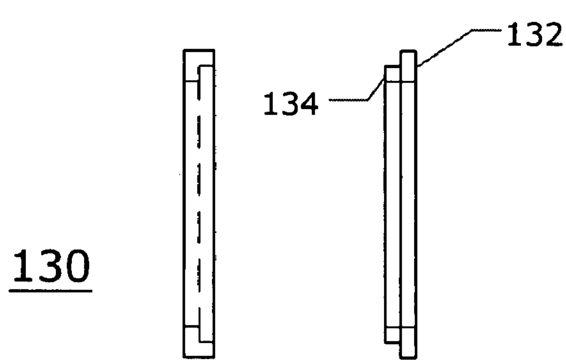

FIG. 5

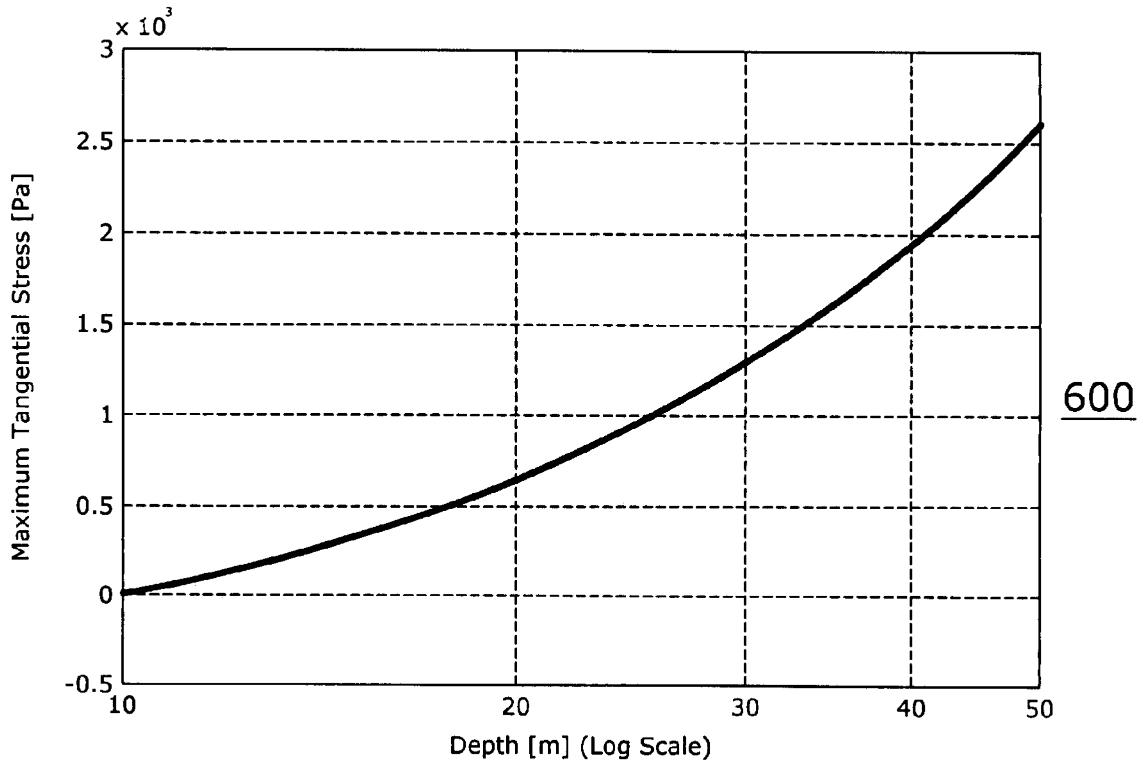
x 10^3
3
2.5
2
1.5
1
0.5
0
-0.5
10
20
30
40
50
Maximum Tangential Stress [Pa]
Depth [m] (Log Scale)
600

FIG. 6

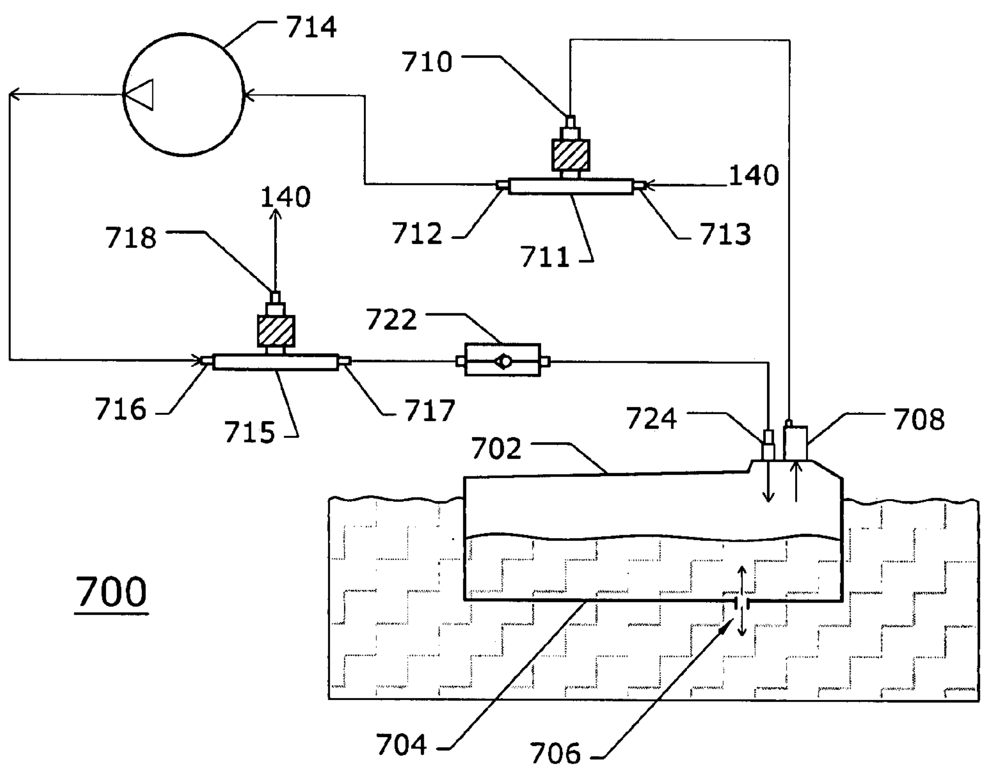
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FIG. 7

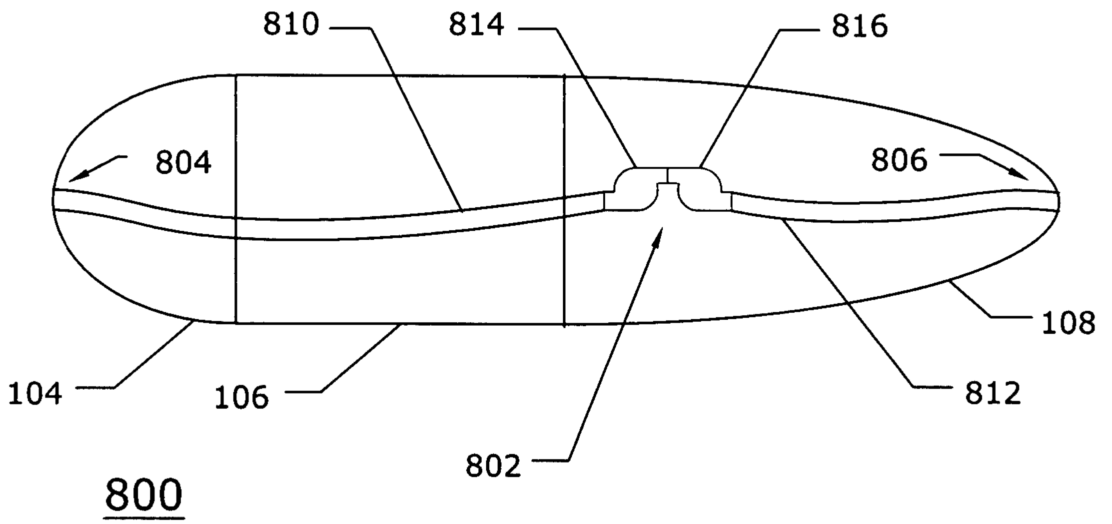


FIG. 8

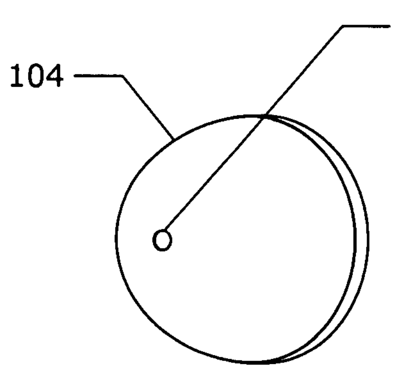
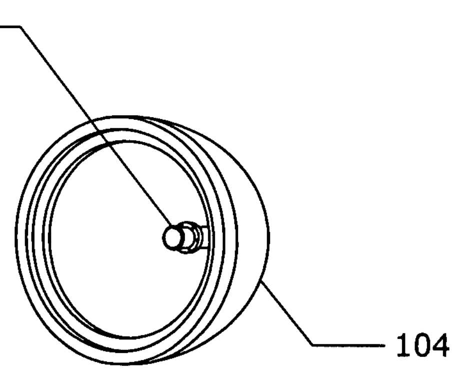


FIG. 9



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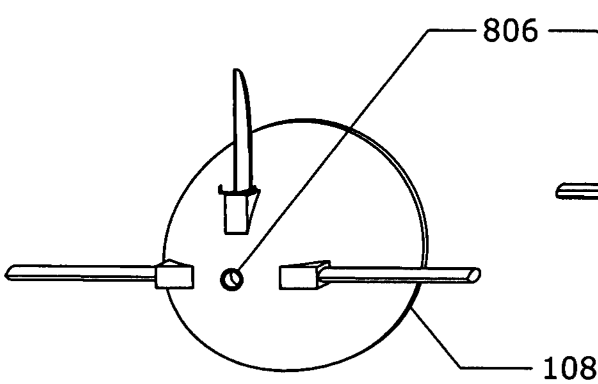

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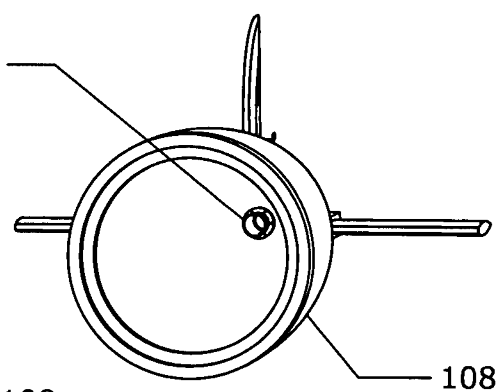

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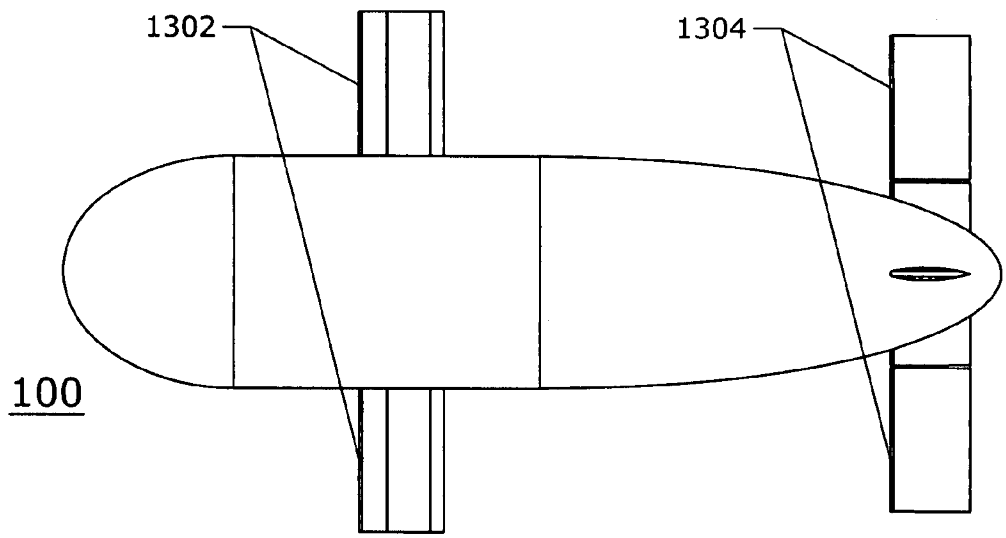


FIG. 13

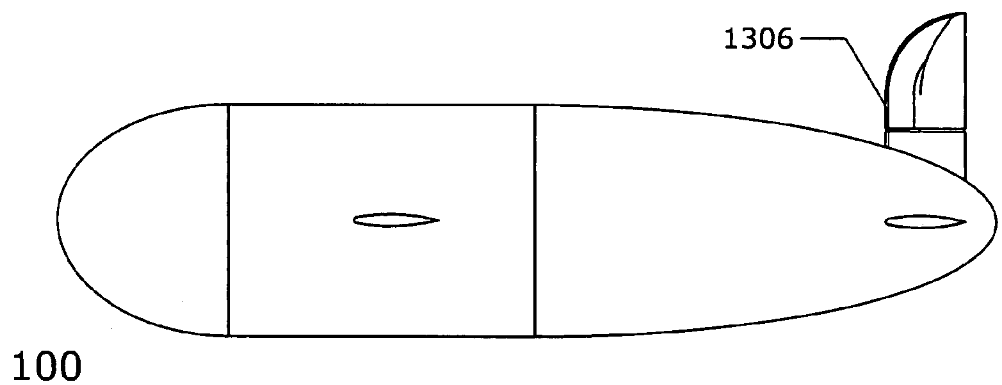


FIG. 14

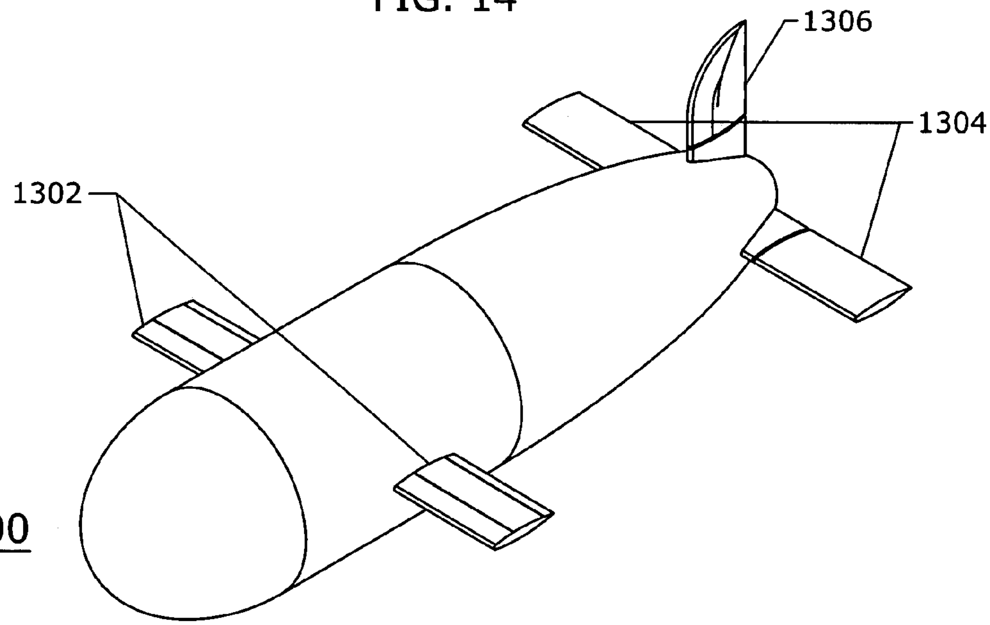


FIG. 15

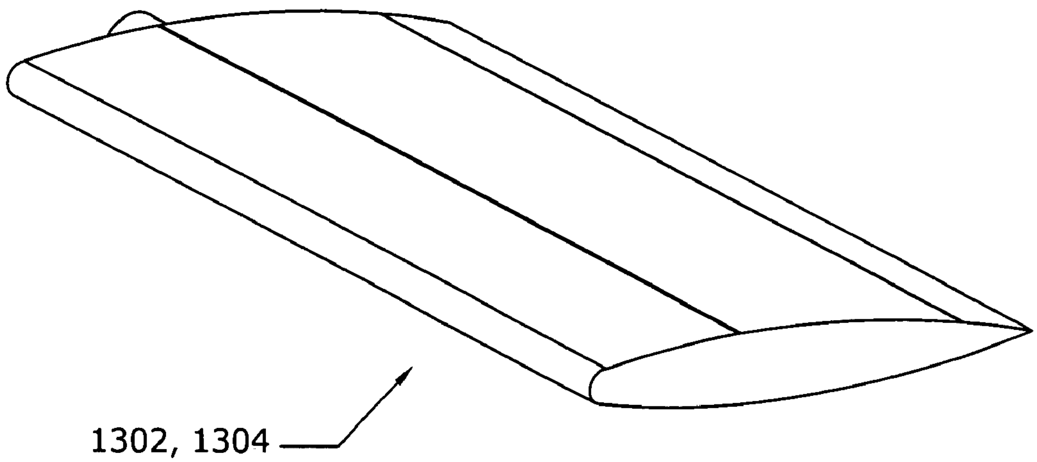


FIG 16

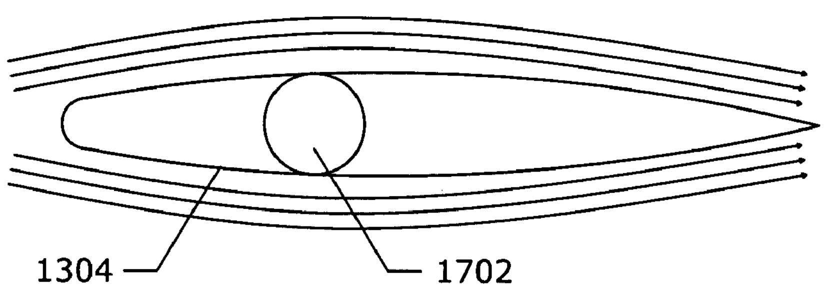


FIG 17

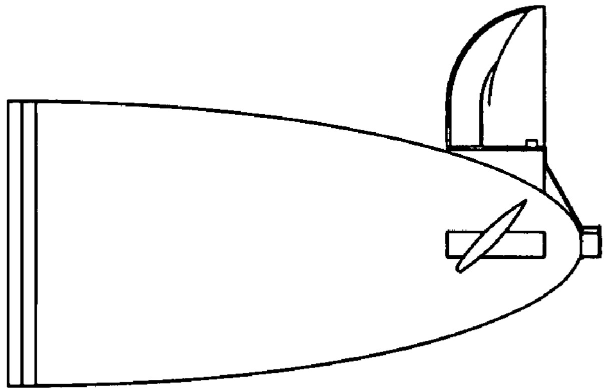


FIG. 18A

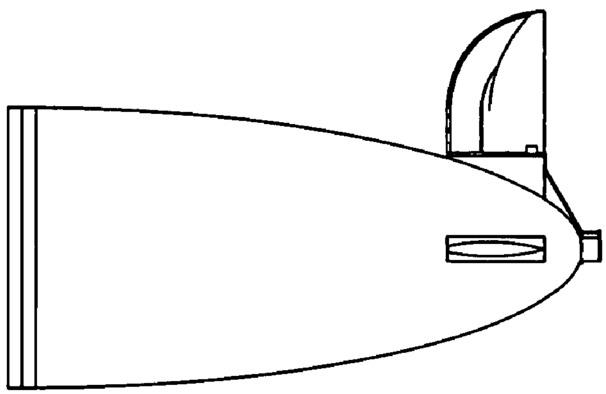


FIG. 18B

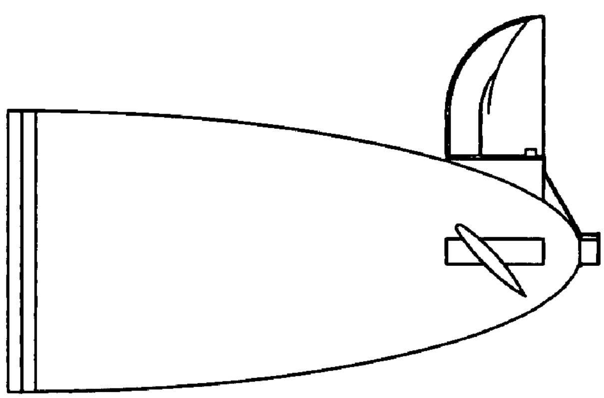
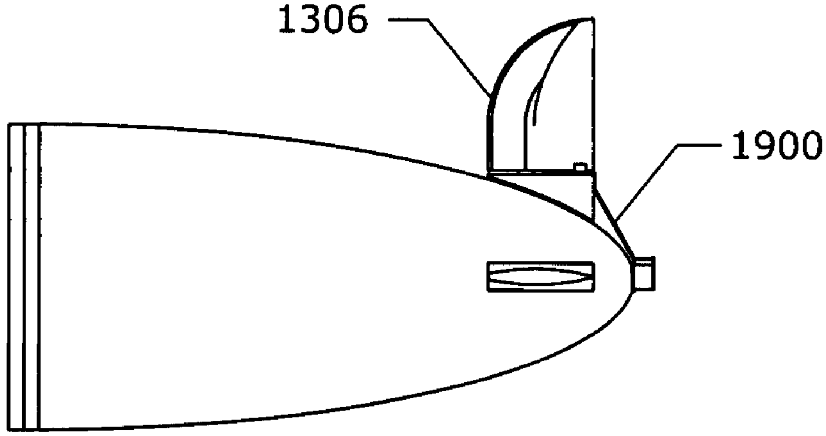


FIG. 18C



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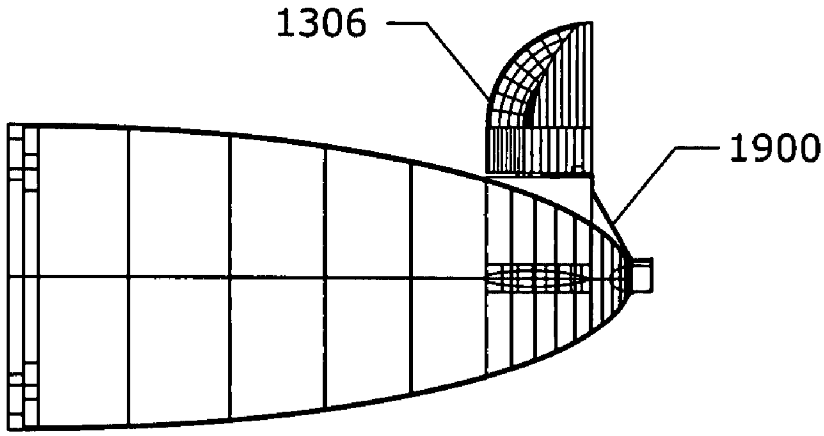


FIG. 20

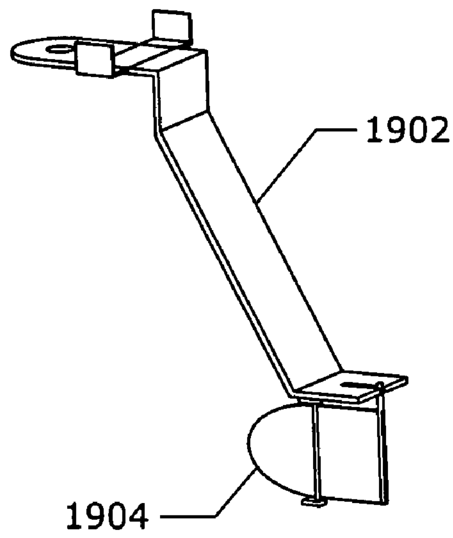


FIG. 21

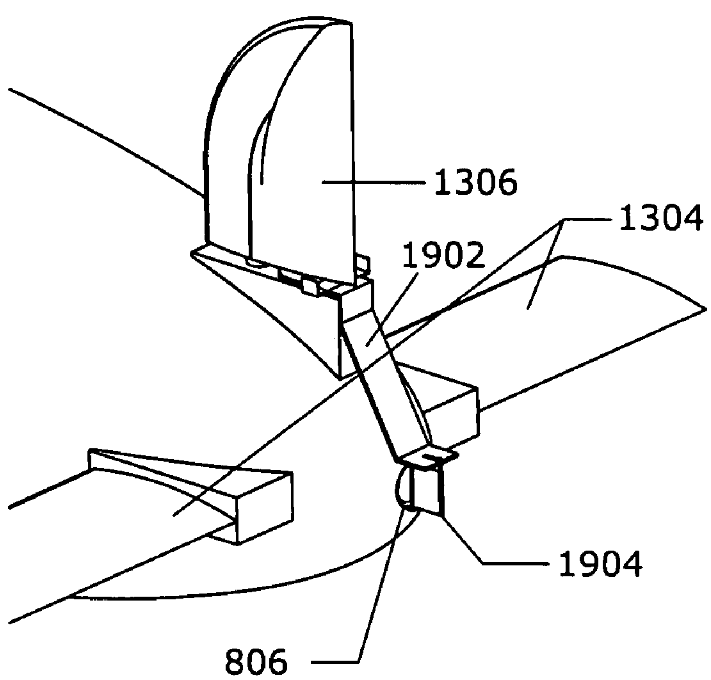


FIG. 22

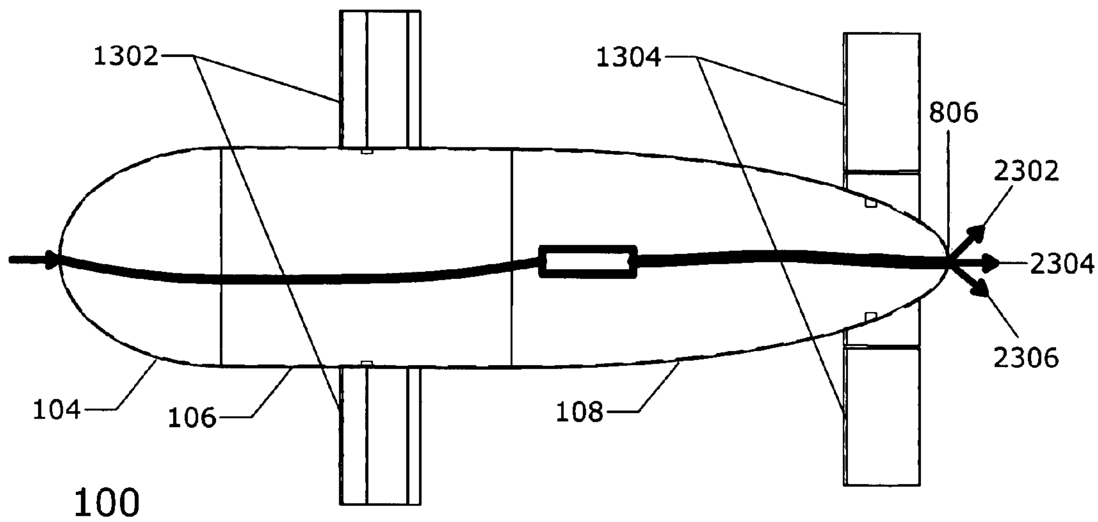
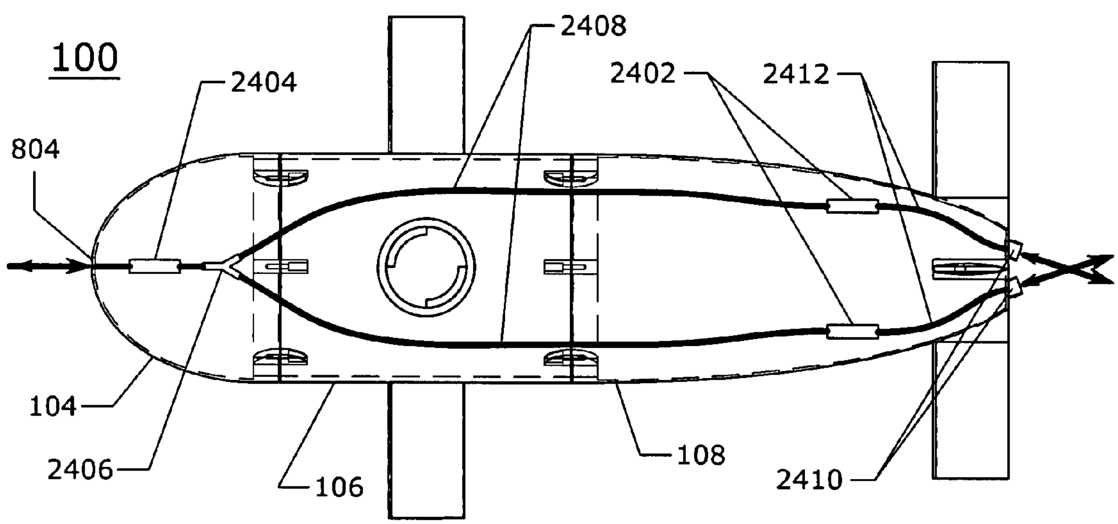

1302
1304
806
2302
2304
2306
104
106
108
100

FIG. 23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2402
2412
2404
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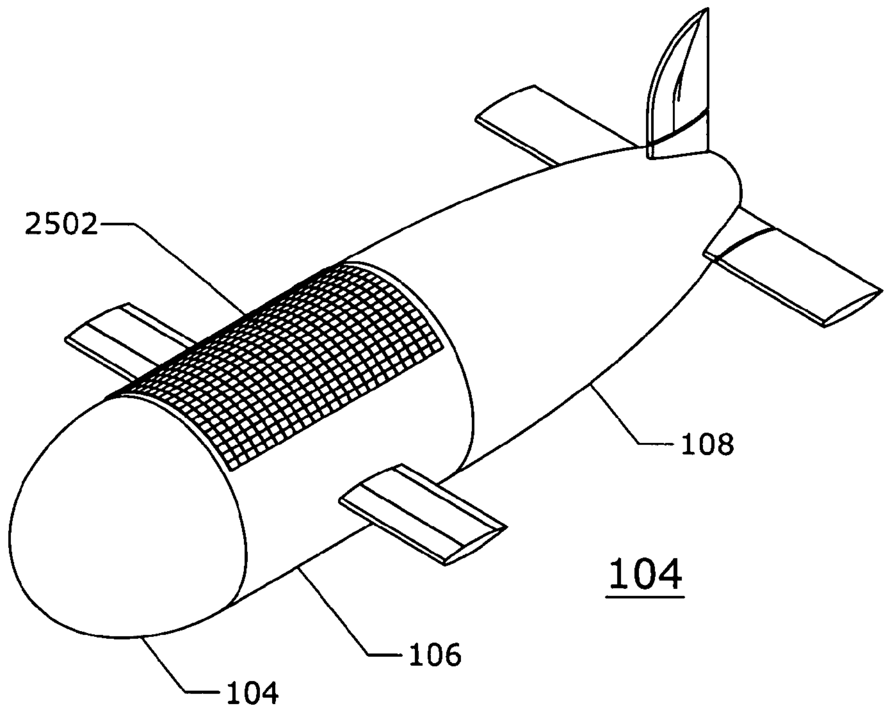
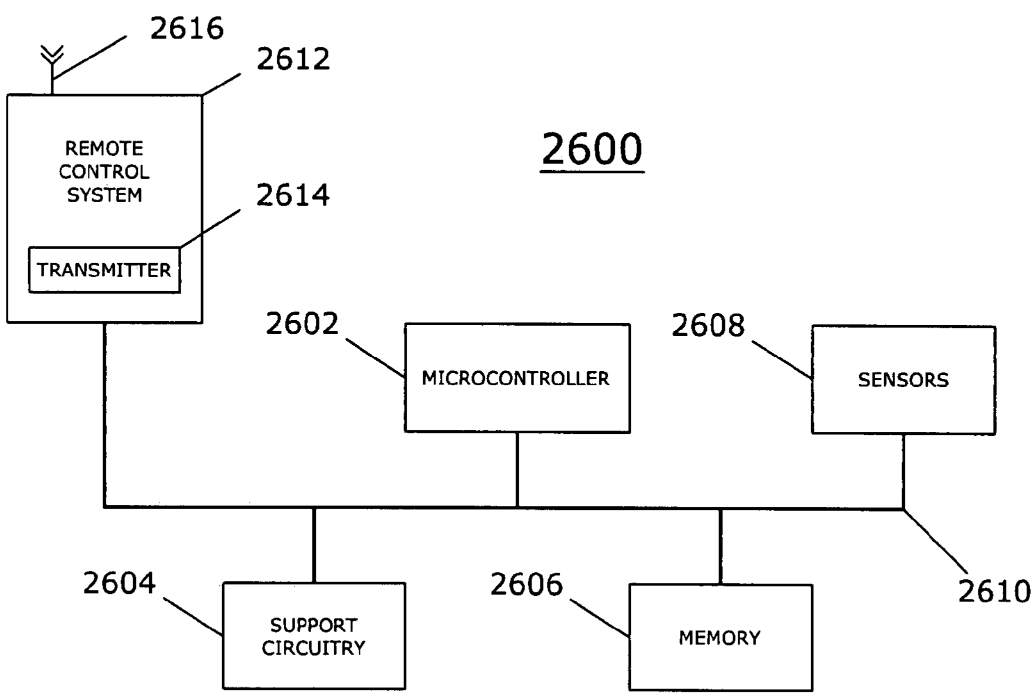
2406
106
108
2410

FIG. 24



2502
108
104
106
104

FIG. 25



2616
2612
2600
REMOTE CONTROL SYSTEM
2614
TRANSMITTER
2602
MICROCONTROLLER
2608
SENSORS
2604
SUPPORT CIRCUITRY
2606
MEMORY
2610

FIG. 26

UNMANNED AUTONOMOUS SUBMARINE

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application Ser. No. 60/726,498, filed Oct. 12, 2005, and U.S. Provisional Application Ser. No. 60/778,004, filed Feb. 28, 2006, the contents of which are incorporated by reference herein and made a part of this application.

FIELD OF THE INVENTION

The present invention relates generally to submersible vehicles, and particularly to unmanned autonomous submarines, and sometimes referred to as "small" submarines.

BACKGROUND OF THE INVENTION

There have been numerous unmanned submarines designed to explore or perform other underwater tasks and functions, as required. The submersible vehicle (i.e., a submarine) includes various systems, such as a ballast system for submersing or floating the submarine, a propulsion system for propelling the submarine, a navigation or steering system for maneuvering the submarine, and various sensors and controllers for controlling the submarine and providing information regarding the underwater environment.

For example, U.S. Pat. Nos. 1,571,833, 5,235,930, 5,711,244, and 6,655,313 disclose a submarine body from separate sections that are joined together and include seals. U.S. Pat. Nos. 1,310,877, 1,488,067, 3,379,156, 3,478,711, 3,667,415, 3,800,722, 3,818,523, 3,943,869, 3,946,685, 4,029,034, 4,265,500, 5,129,348, 6,371,041 and 6,772,705 disclose ballast means combining water and air through a system of valves and piping for controlling the depth direction of a submarine. U.S. Pat. Nos. 3,122,121, 3,176,648, 3,474,750, 3,492,965, 3,550,386, 6,065,418, 6,807,921 and 6,581,537 disclose fluid propulsion of a vessel through the handling of the fluid from the bow to the stem of the vessel. U.S. Pat. Nos. 3,561,387, 6,269,763, 6,484,660, 6,662,742 and U.S. Publication No. 2002/0134294 disclose use of a plurality of sensors and structural concepts and relate generally to the state of the art. U.S. Pat. Nos. 6,926,567, 6,800,003, 6,716,075, 6,629,866, 6,453,835, 3,301,132, 340,237, U.S. Patent Publication No. 2001/0010987 and Japanese Pat. Application No. 356071694 relate to fluid deflection.

None of the known patents or publications disclose or suggest an unmanned autonomous submarine as disclosed and claimed herein.

SUMMARY OF THE INVENTION

In general, it is an object of the present invention to provide an unmanned autonomous small size submarine as described herein. This submarine is a surface/underwater vehicle which can float, dive and move in water to perform various tasks. One important feature of the submarine is the pressurized cabin which is necessary for the diving and flotation system to work properly. This also helps to increase its sealing power against water leakage into the cabin. The submarine is autonomous, that is, automatic and self controlled. It is propelled by water jet propulsion. It can be programmed to dive to preset depths, move along preset trajectories, and return to the base after completing the assigned tasks. In addition to the autonomous part, a remote

control option is provided for emergency situations or in order to perform special tasks. The submarine is equipped with several sensors that can measure depth, orientation, attitude, location and speed. It is also equipped with an underwater video camera that can send wireless video pictures from underwater to a monitor above water surface.

Various objectives of the unmanned autonomous submarine are to perform several tasks above and under water replacing human divers who can be subjected to danger in such environment; minimize the cost of underwater operations such as exploration, rescue, photography, and inspection of submerged structures, such as ship hulls, oil rigs, dams, etc.; monitor various objects under water and transmit live video and pictures to the operator on board of a commanding boat above water; be used as a carrier and base for underwater robotics, among other undersea functions and tasks.

In one embodiment, the unmanned autonomous submarine comprises a hull formed by at least two hull sections and defining an interior cabin therein and adapted to retain pressurized air. A plurality of fasteners are affixed to the hull sections and adapted for joining the at least two hull sections. The plurality of fasteners can e internally and/or externally affixed to opposing connecting ends of the hull sections.

A plurality of hydrofoils is attached to opposed external side surfaces of the hull sections for providing stability and maneuverability of the hull. The submarine further includes a propulsion system for providing propelling force to the hull.

A ballast system is included for raising and submersing the hull. The ballast system comprises a ballast tank adapted to receive a predetermined level of water externally from the submarine and a predetermined amount of the pressurized air from the cabin; and a compressor coupled to the ballast tank to form a closed loop system. The compressor is adapted to force air into the cabin from the ballast tank to increase the water level in the tank and thereby cause the hull to submerge, and the compressor being adapted to force air into the ballast tank from the cabin to decrease the water level in the tank and thereby cause the submarine to ascend.

In one embodiment, the submarine includes a sealable opening formed in the upper portion of one of the hull sections. The sealable opening provides access into the interior cabin.

In one embodiment, the plurality of fasteners includes a plurality of clamps. Alternatively, the plurality of fasteners can include a plurality of bolts positioned on one of the connecting ends of a hull section and threaded into a corresponding plurality of nuts affixed to an opposing connecting end of an adjacent hull section.

In one embodiment, the submarine further comprises an o-ring inserted between each adjacent hull section. In an alternative embodiment, the submarine includes a reinforcing ring inserted between each adjacent hull section, either with or without the o-ring.

In one embodiment, the ballast tank comprises a plurality of partitions to prevent water in the tank from destabilizing the submarine. Further, the ballast tank can include a sealable opening formed at its bottom for controlling flow of water in or out of the tank. Additionally, the ballast system can include at least one solenoid valve for controlling air flow between the cabin and the ballast tank.

In one embodiment, the propulsion system includes a first water pump positioned in the cabin, a forward inlet port formed in a forward hull section of the hull sections and coupled to the pump via a first conduit, and an aft outlet port formed in an aft hull section of the hull sections and coupled to an output of the first pump via an aft conduit. The first pump draws water external to the hull through the forward inlet port and first conduit, and forces the water through the aft outlet port to propel the submarine in a forward direction. Alternatively, the first water pump draws water external of the hull through the aft outlet port and the aft conduit, and forces the water through the forward inlet port to propel the submarine in a reverse direction.

The propulsion system can further include a second aft outlet port formed in the aft hull section and coupled to the first pump via a second aft conduit. The aft conduits are regulated to control water flow therethrough to provide steering of the submarine.

In another embodiment of the propulsion system, a second water pump is serially coupled to the first water pump. The second water pump is deactivated while the first pump is activated to propel the submarine in the forward direction. Similarly, the first pump is deactivated while the second pump is activated to draw water external to the hull through the aft outlet port and aft conduit, and force the water out of the forward inlet port to propel the submarine in a reverse direction.

In yet another embodiment of the submarine, a plate is pivotably attached in a vertical direction in the aft outlet port. The vertically positioned plate is rotatable to direct the water jetted out of the aft outlet port at a predetermined angle to steer the submarine. Preferably, a vertical rudder rotatable attached to the aft hull section, and a link coupled between the rudder and vertical plate. Rotation of the plate is controlled by rotation of the rudder.

In yet another embodiment of the propulsion system, the propulsion system includes a forward water pump positioned in the cabin, a forward inlet port formed in a forward hull section of the hull sections and coupled to the forward pump via a forward conduit, and a pair of parallel water pumps positioned in the cabin. The parallel pumps are coupled to the forward water pump via a Y-shaped conduit. A pair of aft outlet ports is formed in an aft hull section of the hull sections. Each aft outlet port is coupled to a corresponding one of the parallel water pumps via a second conduit.

At least one of the parallel water pumps draws water external to the hull through the forward inlet port and forward conduit, and forces the water out of the corresponding aft outlet port to propel the submarine in a substantially forward direction. Preferably, the forward water pump is deactivated when the pair of parallel water pumps is activated to propel the submarine in a substantially forward direction. Alternatively, the pair of parallel pumps can be deactivated while the forward pump is activated to draw water external to the hull through the aft outlet ports and Y-shaped conduit, and force the water out of the forward inlet port to propel the submarine in a reverse direction.

In another embodiment, the pumps can be utilized to steer the submarine. In particular one of the parallel pumps is either throttled back or deactivated while the other parallel pump is activated to steer the submarine in a predetermined direction.

In one embodiment, the submarine further includes a vertical rudder rotatably attached to the aft hull section of the hull sections for steering the submarine. Further, the plurality of hydrofoils can include a pair of aft hydrofoils rotatably attached to opposing side surfaces of an aft hull section of the hull sections. The rotatably attached hydrofoils enable the submarine to submerge and ascend. Additionally, the plurality of hydrofoils can include a pair of forward hydrofoils fixedly attached to the opposing side surfaces proximate a forward hull section of the hull sections. The fixedly attached hydrofoils provide stability for the submarine. Alternatively, the pair of forward hydrofoils is rotatably attached to the opposing side surfaces proximate a forward hull section of the hull sections. The rotatably attached hydrofoils enable the submarine to submerge and ascend.

In one embodiment, the hull sections include a forward hull section, an aft hull section, and a middle hull section attached therebetween the forward and aft hull sections via the plurality of fasteners.

In yet another embodiment of the propulsion system, the propulsion system includes a pair of forward inlet ports formed in a forward hull section of the hull sections, and a pair of parallel water pumps positioned in the cabin. Each parallel pump is coupled to a corresponding one of the pair of forward inlet ports via a forward conduit. A pair of aft outlet ports is formed in an aft hull section of the hull sections, where each aft outlet port is coupled to a corresponding output of one of the parallel water pumps via an aft conduit. At least one of the parallel water pumps draws water external of the hull through the corresponding forward inlet port and forward conduit, and forces the water out of the corresponding aft outlet port to propel and steer the submarine in a substantially forward direction. Alternatively, at least one of the parallel water pumps draws water external to the hull through the corresponding aft outlet port and aft conduit, and forces the water out of the corresponding forward inlet port to propel and steer the submarine in a substantially reverse direction.

In any of the aforementioned embodiments, the submarine can further include a programmable controller for controlling operations of the submarine. Additionally, one or more sensors can be installed on the submarine for providing electrical signals to the controller for further controlling the submarine operations. The one or more sensors can include depth sensors, GPS system sensors, pressure sensors, position and orientation sensors, speed sensors, leakage sensors, audio sensors and video sensors, among other sensors. Further, at least one robotic arm can be mounted to the hull and electrically coupled to the controller.

In any of the aforementioned embodiments, the submarine can further include at least one battery for providing power to the submarine. In one embodiment, the at least one battery is rechargeable. Further, an array of photovoltaic cells can be mounted to the exterior surface of the hull. The array of photovoltaic cells can be used to provide charge to the rechargeable batteries or provide power to the one or more systems in the submarine.

In one embodiment, the submarine includes a receiver for receiving remote command signals to control operations of the submarine. Further, a transmitter can be provided for sending operational information to a remotely located receiver.

Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the invention as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an enlarged front top perspective view of an embodiment of an unmanned autonomous submarine according to the present invention having a plurality of hull sections according to one embodiment of the invention;

FIG. **2** is a front and top perspective view of the unmanned autonomous submarine of FIG. **1** having the hull sections assembled by a plurality of internal clasps;

FIG. **3** is a front and top perspective view of the unmanned autonomous submarine of FIG. **1** having the hull sections assembled by a plurality of external clasps;

FIG. **4** is a side perspective view of a plurality of reinforcing rings for coupling the hull sections of FIG. **1**;

FIG. **5** is schematic diagram of the reinforcing rings of FIG. **4**;

FIG. **6** is a graphical view illustrating the depth and maximum tangential component of stress affecting the submarine of FIG. **1**;

FIG. **7** is a schematic diagram of a pneumatic circuit for effecting the ascend and descend of the submarine of FIG. **1** in a water environment;

FIG. **8** is a schematic diagram of a first embodiment of a propulsion system of the submarine of FIG. **1**;

FIG. **9** is an external perspective view of a front port of the propulsion system of FIG. **8** formed in the forward hull section of the submarine of FIG. **1**;

FIG. **10** is an internal perspective view of the front port of the propulsion system of FIG. **8**, formed in the forward hull section of the submarine of FIG. **1**;

FIG. **11** is an external perspective view of a rear port of the propulsion system of FIG. **8**, formed in the aft hull section of the submarine of FIG. **1**;

FIG. **12** is an internal perspective view of the rear port of the propulsion system of FIG. **8**, formed in the aft hull section of the submarine of FIG. **1**;

FIG. **13** is a top plan view illustrating the rudder, stabilizers and elevators of a maneuvering system of the submarine of FIG. **1**;

FIG. **14** is a side view of the maneuvering system of the submarine of FIG. **1**;

FIG. **15** is a front and top perspective view of the maneuvering system of the submarine of FIG. **1**;

FIG. **16** is a front and top perspective view of one of the side elevators of the maneuvering system of FIGS. **13-15**;

FIG. **17** is a cross-sectional view of the hydrofoil of FIG. **16** illustrating the flow of water about the elevator;

FIGS. **18**A-C are respective side views of the aft hull section illustrating various maneuvering positions of the elevators of the submarine of FIG. **1**;

FIG. **19** is a side view of the aft hull section having a thrust vector system for steering the submarine of FIG. **1**;

FIG. **20** is a cross-sectional view of the aft hull section and thrust vector system of FIG. **19**;

FIG. **21** is a top side perspective view of the thrust vector system of FIGS. **19** and **20**;

FIG. **22** is a rear and top perspective view of the aft hull section and thrust vector system of FIG. **19**;

FIG. **23** is a schematic diagram illustrating maneuvering the submarine of FIG. **1** using the propulsion system and thrust vector system of FIGS. **8-12** and **19-22**, respectively;

FIG. **24** is a schematic diagram of an alternative embodiment of a propulsion system suitable for use in the submarine of FIG. **1**;

FIG. **25** is a front top perspective view of the unmanned autonomous submarine of FIG. **1** having a plurality of photovoltaic cells installed on the exterior surface of the hull; and

FIG. **26** is a schematic diagram of a controller and sensor array for controlling the unmanned autonomous submarine of FIG. **1**.

To facilitate understanding of the invention, the same reference numerals have been used when appropriate, to designate the same or similar elements that are common to the figures. Further, unless stated otherwise, the drawings shown and discussed in the figures are not drawn to scale, but are shown for illustrative purposes only.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings FIGS. **1-26**. An exemplary embodiment of an unmanned autonomous submarine of the present invention is shown in FIG. **1**, and is designated generally throughout by reference numeral **100**.

Hull Configuration

Referring to FIGS. **1** and **2**, there is depicted in an enlarged view, with components separated for convenience of illustration, of a submarine hull **102** having a forward hull section **104**, a middle hull section **106**, and an aft ward hull section **108**. The preferred shape of the hull **102** is a slender axi-symmetric body of revolution, where the length is larger than the maximum diameter of the submarine. For example, in one embodiment, the hull **102** of the submarine is 1.645 m long, with a maximum outside diameter of 40 centimeters, although such dimensions are not considered limiting.

Several alternative configurations of the hull (body) **102** of the submarine **100** are possible within the scope of the invention. The submarine **100** can be assembled from two, three, or more hull sections with appropriate sealing devices **120**. The most structurally efficient hull shape of the submarine is a circular cross-section. A hull **102** having a substantially circular cross-section is easy to fabricate and is streamlined for maximum drag reduction. The shape of the hull **102** is not limited to being circular, as other hull section shapes can be utilized to satisfy particular applications or purposes by the submarine **100**.

In one embodiment as shown in FIGS. **1** and **2**, the forward or nose section **104** is a hemisphere, and the aft or rear tail section **108** is a semi-ellipsoid of revolution. The hull sections **102** of the submarine can be fabricated by welding or otherwise fastening together sheet metal strips (e.g. 3 mm thick steel sheets). Alternatively, the hull sections can also be cast from any suitable material. For example, the hull sections **102** of the submarine can be made from steel, fiberglass, among other well known materials and/or a combination thereof which are capable of withstanding the water pressure when submersed at particular depths.

In the embodiment shown in FIGS. **1** and **2**, an opening **110** is formed in the upper side of one of the body sections (preferably the middle hull section **106**) with a removable cover **112**. The opening **110** is provided for access to the cabin **140** during assembly and servicing of the submarine **100**. The removable cover **112** is provided to seal and protect the interior of cabin **140** of the submarine **100** from the external water environment. Additionally, as discussed in further detail with respect to FIG. **2**, the opening **110** facilitates assembly of the hull sections **108** using internal clamps **116**. Further, although not shown in FIGS. **1-3**, the hull **102** includes a number of fixed or rotatable lifting and steering surfaces preferably made from hydrofoils which provide stability and control (i.e., maneuverability) during operation of the submarine **100**, as is discussed below in further detail with respect to FIGS. **13-19**.

Referring to FIGS. **2** and **3**, the hull sections **102** of the submarine **100** are shown assembled together and secured by internal or external clamps. Referring to FIG. **2**, internal clamps **116** are preferably used, since they do not create any resistance to the submarine motion while submersed in the water and thus produce a smooth continuous surface. The open ends of the forward hull **104** and aft hull **108** sections include circular end ring portions **118** having a diameter substantially equal to the diameter of the middle hull section **106**, to thereby provide a continuous smooth exterior surface where the hull sections are secured together. All three hull sections are joined together within the interior of the submarine by suitable fasteners **116**, such as with spring clamps **116** for quick and easy assembly, or a number of bolt/nut combinations.

In an embodiment implementing a bolt/nut combination, a plurality of bolts are provided on one ring (e.g., on rings **120** formed on opposing ends of the middle hull section **106**), and each bolt is inserted through thick washers welded to the same ring **120**. The bolts are threaded into mating nuts welded to a second mating ring, for example, circular end rings **118** formed on the forward and aft hull sections. An O-ring **130** is located between each two mating parts of the hull sections **102** in order to provide sealing power against water leakage. The bolts and internal clamps **116** are accessed during assembly through the central body opening **110**.

Referring to FIG. **3**, in an alternative embodiment, the submarine body **102** is assembled by using external clamps **122**. The external clamps **122** are provide easy assembly of the hull sections **102**.

Referring to FIGS. **4** and **5**, the three hull sections **104**, **106** and **108** are joined together and assembled using O-rings **130**, such as rubber O-rings **132** for providing a watertight seal between the joined hull sections **1O2**. The O-rings **130** can optionally include steel reinforcement rings **134** to form a combined steel and rubber reinforcing/coupling O-ring. The steel/rubber O-rings serve as couplers between the hull sections, as well as stiffeners because they increase the rigidity and integrity of the body of the submarine against wrinkling and deformation.

Referring to the graph **600** of FIG. **6**, the relationship between the outside pressure at a certain depth and the maximum tangential component of stress affecting the inner radius of the cylindrical middle hull section **106** of the submarine's hull **102** is shown. Depths from 10 to 50 meters below sea level are considered. Typically, the weakest part of the submarine's hull **102** is the middle cylindrical hull section **106**, as the other elliptical hull sections **104** and **108** of the submarine's hull **102** are not subject to the same levels of radial and tangential stresses.

The average value of axial stress affecting the body of the submarine (for example, a wall thickness of 3 mm) at a depth of 50 meters (corresponding to an external pressure of 5 bars), was observed to be equal to approximately 13.4 MPa (MegaPascals), while the internal cabin pressure in the submarine was approximately equal to 1 bar.

The maximum value of the tangential stress affecting the submarine's cylindrical middle hull section **106** of the hull **102** can be found at the inner radius, and these values are much larger than those of the radial stresses affecting the submarine.

Referring now to FIG. **6**, it can be seen from the graph **600** that as the depth of the submarine increases, the tangential component of stress increases in compression. Comparing the stress to the yield strength (210 MPa) of steel (SAE 1020) used in building the hull of the submarine, it was found that the submarine's hull **102** can handle external pressures of 32 bars (i.e., corresponding to depth of approximately 320 meters).

Ballast System

Referring again to FIG. **1**, the cabin **140** of the submarine is pressurized with air all the time during operation in water. This pressurization is necessary for the proper functioning of the diving and floatation system (ballast system), especially during surfacing of the submarine. Due to the design of the ballast system **700**, low values of gage pressures are necessary (less than 5 bars). This low pressure is sufficient for the operation of the ballast system even for maximum design operating depths for the submarine **100** under water where pressures are much higher. Cabin pressurization can be provided by either an external air pressure source (e.g., an air compressor or a pressure cylinder), or by operating the submarine compressor (i.e., in the ballast tank system) for a predetermined time prior to the submarine being placed in the water (i.e., when the ballast tank is empty, air is sucked from the atmosphere to the cabin **140** through the ballast tank). This pressurization increases the submarine strength and joint resistance against water leakage into cabin **140**.

Referring to FIG. **7**, the diving and floatation (ballast) system **700** includes a ballast tank **702**, a reciprocating air compressor **714**, a plurality of solenoid valves **711** and **715**, at least one check valve **722**, and piping for transferring air between the compressor **714** and ballast tank **702**. In one embodiment, the ballast tank **702** is cylindrical in shape and is installed on the bottom of the inside wall in the middle cylindrical hull section **106** of the submarine **100**. In one embodiment, the tank **702** has a convex cover which causes air inside it to accumulate and go through the air outlet **708**. The tank **702** contains several partitions (baffles) which restrict the motion of water to prevent the water in the tank from destabilizing the submarine. The tank has a small opening **706** at its bottom for water to flow into or out of the tank **702**.

In one embodiment as shown in FIG. **7**, a sealed box, located above the ballast tank **702**, contains the reciprocating air compressor **714**. The compressor **714** removes air from the enclosed space around it through an opening in the box's wall. The removed air can come from the top of the ballast tank **702** through a one-way valve **708** and a water trap, and pumps it to cabin **140** when the submarine is submersing. The same compressor **714** can be used to pump air from the pressurized cabin **140** back to the ballast tank **702** in order to force water out of the tank during the surfacing operation. The solenoid valves are used to accomplish these two processes. The solenoid valves form part of the pneumatic circuit **700**, which control the air flow in a manner which will cause either diving or surfacing of the submarine.

In particular, the submarine **100** is designed to be floating when initially placed in water. Referring to schematic diagram of FIG. **7**, the ballast tank **702** is flooded with water through a water opening **706** in the bottom **704** of the tank **702** by sucking air from the tank through the tank's air outlet **708** (water trap). The air from the tank flows through port **710**, through port **712**, then through the compressor **714**, then through port **716**, and through port **718** into the cabin **140** of the submarine **100**. The air removed from the tank **702** is pressurized and stored in the cabin **140** of the submarine **100** for usage during a reverse operation to force the water out of the tank **702**. The removal of air from the tank **702** creates low pressure inside the tank's body **702**, which in turn causes water to flow therein, thereby enabling the submarine **100** to gain mass and submerge in the water.

During the surfacing or ascending operations of the submarine **100**, the air compressor **714** is operated along with the actuation of the two solenoid valves **711** and **715**, such that air is removed from the cabin **140** through port **713**, port **712**, through the air compressor **714**, through port **716**, through port **717**, through a check valve (non return valve) **722**, and then through the tank's air inlet **724** into the tank's body **702**. This operation causes air to be pressurized back into the tank **702**, thus creating high pressure therein the tank, which in turn causes the discharge of water through the tank's water opening **706** to reduce the mass of the submarine and cause it to ascend and/or float.

In order to provide enough air for the surfacing operation, the interior of the submarine's body (i.e., cabin **140**) is pressurized with air before any operation is started. Another advantage of the pressurization with air is that this technique increases the sealing power and the resistance against water leakage into the submarine's cabin **140**.

Propulsion System

Referring to FIGS. **8-12**, propulsion of the submarine **100** is provided by a propulsion system **800** having least one water pump **802**. The system **800** provides forward motion to the submarine by sucking water from a first opening or port **804** in the forward hull section **104**, and pumping water from a second opening or port **806** formed in the tail hull section **108** of the submarine. The emerging jet would provide the force needed for the submarine to move.

In one embodiment, a DC-motor-operated water pump **802**, located inside the submarine, sucks water from a front opening **804** in the nose **104** of the submarine via a first pipe **810** and ejects it from another opening in the far end of the tail **108** via a second pipe **812**.

Stopping the submarine (while in forward motion) and giving it a backward motion is achieved using the same system as in described above but with a reverse water flow. This can be done by several means: (a) connecting another identical pump with the first pump back to back and operating the second pump only for the backward motion; (b) using a flow reversal water circuit with solenoid valves and pipe connections; or (c) having a parallel system to the first one but with a reversed flow direction.

Referring to the embodiment of FIG. **8**, the propulsion system **800** includes two pumps **814** and **816** that are used to provide forward and backward motion of the submarine **100**. In order for the submarine **100** to move in the forward direction, the first pump **814** is activated to suck water from the front water opening **804** via pipe **810** and pump the water through the second pump **816** and out of the rear water opening **806** via pipe **812**, which provides sufficient thrust for the submarine **100** to move in the forward direction. To propel the submarine in the reverse direction, the second pump **816** is activated to suck water from the rear water opening **806** through the first pump **814** via pipe **812**, and out of the front water opening **804** via pipe **810**. This reverse operation provides the submarine **100** with sufficient thrust to reduce and stop the forward motion, and then propel the submarine **100** in the reverse direction.

Maneuvering System

Referring to FIGS. **13-15**, maneuvering of the submarine **100** is achieved by the use of a plurality of stabilizing fins **1302**, elevators **1304**, a rudder **1306**, and by water jet thrust vectoring, as described below in further detail. A pair of horizontal stabilizing fins **1302** is attached to opposing sides of the middle hull section **106**, and act as stabilizers to prevent the submarine **100** against rolling. In one embodiment, the fixed stabilizers **1302** are fixedly welded to the body of the submarine and do not move.

A pair of rear elevator fins **1304** is rotatably attached to opposing sides of the aft hull section **108**. The rear elevator fms **1304** assist with maneuvering the submarine and controlling its motion, as well as providing depth stability to the submarine. The rudder **1306** is vertically attached to the aft hull section **108** of the submarine. The rudder **1306** is responsible for steering the submarine **100** in a sideways direction (e.g., left and right). One skilled in the art will appreciate that the forward horizontal pair of stabilizing fins **1302** can also be rotatably attached to the sides of the middle hull section **106** to provide additional maneuverability.

The installation of the rotatable hydrofoil fms **1302**, **1304** and rudder **1306** creates three weak points which are susceptible to water leakage. Leakage problems at these points are solved using special sealing units. These seals provide a resilient, watertight opening for enabling the rotational motion of the hydrofoil fins and rudder in addition to preventing water leakage.

Referring to FIGS. **13-17**, the elevators **1304**, stabilizing fins **1302**, and rudder **1306** are formed, for example, by symmetric hydrofoil sections in order to reduce drag and enable the submarine to ascend (float) and submerge (dive) in the water environment during operation. Referring to FIG. **17**, a circular shaft **1702** is provided at one end of the hydrofoil for attachment to a motorized gear box (not shown) for rotating the hydrofoil, as required.

In one embodiment, the elevators **1304** and rudder **1306** are actuated by two DC motors; one for the elevators and the other for the rudder. In order to rotate the rudder **1306**, the motor is linked to the rudder via a friction disk. The disk is attached to a small shaft that is fixed to the rudder itself. The elevators are actuated by the second DC motor. In order to actuate both elevators at the same time, a power screw is linked to the motor. A nut near the other end of the power screw is then attached to a link which connects the elevators **1304**. Preferably, the elevators **1304** can move between −45 and +45 degrees as illustratively shown in FIGS. **18**A-C, although such range of movement is not considered limiting.

Referring to FIGS. **19** and **20**, in one embodiment, a thrust vectoring mechanism **1900** is installed proximate the second port **806** of the propulsion system which is provided at the rear hull section **108**. The thrust vectoring mechanism **1900** is provided to operate along with the rudder **1306** to assist with steering of the submarine **100**.

Referring to FIGS. **21** and **22**, the thrust vectoring mechanism **1900** includes a link member **1902** that moves a vertical circular plate **1904**, which is installed inside the rear port **806** of the propulsion system. The link **1902** is moved and actuated by the rudder **1306** with minimal motion delay. The small plate **1904** controls the angle at which the water jet leaves the rear port **806** of the submarine **100**, which causes the submarine **100** to change its direction of motion.

Referring to FIG. **23**, there are three possible directions for the water jet to leave the rear port **806** of the submarine **100**. If the water jet exits the rear port **806** along direction **2302**, then the submarine is propelled to the right. If the water jet exits the rear port **806** along direction **2304**, then the submarine is propelled in a straightforward path. Alternatively, if the water jet exits the rear port **806** along direction **2306**, then the submarine is propelled to the left.

FIG. **24** illustrates another embodiment for supporting (or replacing) the rudder **1306** in steering the submarine **100**. In particular, two parallel pumps **2402** are provided, illustratively in the rear hull **108** to propel and steer the submarine **100**, instead of using only one pump as described above with respect to the embodiment of FIGS. **8-12** and **23**. A third forward pump **2404** is located in the forward hull section **104**. The third forward pump **2404** is activated when stopping the submarine or backward motion is desired.

In particular, the forward pump **2404** is connected between the front opening **804** formed in the forward hull section **104** and a Y-connection **2406** that is coupled to a pair of main pipes **2408**, which transfer water from the front opening **804** to the rear parallel pumps **2404**. Each of the pair of pumps **2404** is coupled by a conduit **2412** to a corresponding rear port **2410** formed at the aft hull section **108**.

As shown in FIG. **24**, water enters the submarine **100** from the front opening **804** and into the Y-connection **2406** which splits the flow into two parts delivered to two parallel pumps **2402**. The parallel pumps **2402** operate to force water out of the submarine through two rear ports **2410** to propel the submarine in a forward straight direction. Steering of the submarine can be effected by operating one of the parallel pumps **2402** while shutting down the other, which causes the water jet from the corresponding rear port **2410** to change the direction of the submarine **100**. One advantage of the parallel pump propulsion system **2400** of FIG. **24** is that the thrust vectoring mechanism **1900** is not required, thereby eliminating any possible damage to the links **1902** and **1904** caused by unknown objects (e.g., rocks), which might occur while moving underwater.

In an alternative embodiment, the submarine steering system includes two openings in the tail of the submarine separated by an appropriate distance and on both sides of the first central opening. The two emerging water jets are not parallel but they meet at a point downstream from the tail end of the submarine. Allowing more water to flow in one of these side openings than the other will cause the submarine to turn right or left as desired. One or two water pumps can be used for this configuration.

In the one-pump system, the output of the pump is branched into two pipes to the two openings in the back of the submarine. The flow rate of water in each branch can be controlled via throttling valves. Alternatively, in the two-pump system, two identical water-jet pump systems are installed parallel to each other. The nose of the submarine can have either a common opening or two openings. The flow rate in each branch can be controlled by the voltage supplied to each pump, or alternatively by throttling one branch for a short time to cause a turning moment on the submarine.

Control and Power Systems

Referring to FIG. **26**, an illustrative controller **2600** is provided to control the submarine **100** such that it is completely autonomous. The controller **2600** includes a microprocessor **2602**, support circuitry **2604**, memory **2606** a plurality of sensors **2608** and one or more bus lines (conductors) for providing electrical signals therebetween. In one embodiment, a (Motorola 68HC11A8) microcontroller is chosen to serve as the main control unit of the submarine. The microcontroller utilizes programs and routines stored in memory **2606** to control the submarine and translate the electrical signals from the various sensors **1608** into electrical signals delivered to the various actuators of the submarine's systems.

The microcontroller **2602** can be programmed with special programs that enable the submarine **100** to perform various special tasks. The programs can set certain trajectories for the submarine to follow during its motion. For example, the microcontroller **2602** can be programmed to guide the submarine **100** around a docked ship and inspect the submerged part of its hull. The microcontroller **2602** can also be programmed to direct the submarine **100** to cruise while submerged in the water to search for one or more objects and then surface after finding the object. During its operation, the sensors **2608** enable the submarine to detect obstacles and decide for itself whether to stop, pull back or change its direction of motion to avoid collision.

The support circuitry **2604** can include power supplies, logic circuitry, cache, I/O circuitry, among other conventional support circuits. The memory **2606** can be cache memory, RAM, ROM, programmable memory, and can be apart from and/or integrated with the microcontroller **2602**.

The plurality of sensors **2608** are used to sense the environment and the physical properties surrounding the submarine **100**, such as the surrounding water pressure, and to convert these quantities into electrical signals that can be used by the control media of the submarine **100** to decide a sequence of operation according to the inputs.

The sensors **2608** that can be used and installed in the submarine can include SONAR sensors, used for obstacle detection and for scanning the seabed; a pressure transducer, used for depth measurement; speed measurement sensors; as well as a GPS system, to keep track of the submarine's location; an attitude sensor which keeps track of the direction of motion.

In addition, a video camera and audio equipment can be attached to the submarine **100** to transmit images and sounds to the operator at the surface. The video camera can further be used for control purposes by linking it to the controller **2600** of the submarine, and using some image processing principles.

Further, the submarine can be programmed to perform more specialized tasks by installing additional special links and equipment, such as a manipulator (robotic) arm, which can be used for gathering samples for research and for retrieval of sunken objects; laser sensors for detecting faults and cracks in underwater structures like dams, bases of oil rigs, and underwater pipes and cables; special equipment for detecting faults in submerged parts of ship hulls at seaports; underwater welding equipment, among other specialized devices and equipment suitable for underwater operations.

In order to increase the reliability of the submarine, a remote control (RC) system **2612** is installed in the submarine **100**. The remote control system **2612** includes at least a receiver, and preferably a transmitter and receiver (transceiver) **2614** that enables the operator to override one or more programs of the controller **2260** to take full control of the submarine, for example, in the case of emergency situations.

The receiver **2614** of the RC system **2612** is installed inside the submarine **100** with an insulated antenna **2616** sticking out of the hull **102**. Furthermore, the antenna **2616** can be linked to a floating antenna by a reeling wire in order to guarantee that the signal transmission can not be interrupted as the submarine dives deeper and deeper due to the dispersion of electromagnetic waves in water.

Source of Power:

In one embodiment, the submarine includes a plurality of batteries as the main power source of the submarine. In one embodiment, the batteries include a set of several 12-Volt sealed lead acid rechargeable batteries. These batteries can provide enough power for the systems of the submarine for reasonably long missions. If more power is needed for lengthy missions, special Lithium batteries can be used which can provide more power for such missions.

Referring to FIG. **25**, in one embodiment, photovoltaic cells **2502** are provided to recharge the batteries during the floating period of the submarine **100**, and thus make the submarine more independent for long missions. The photovoltaic cells **2502** are used in a sealed panel that cover the top surface of middle hull section **106** of the submarine. Additional photovoltaic cells **2502** can be installed on the forward and aft hull sections **104** and **106** as well. The photovoltaic cells **2502** can charge the batteries or run the various power components in the submarine during daytime when the sun is shining even when it is diving at shallow depths.

It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention that come within the scope of the appended claims and their equivalents.

What is claimed is:

1. An unmanned autonomous submarine, comprising:

a hull formed by at least two hull sections and defining an interior cabin therein, said cabin adapted to retain pressurized air;

a plurality of fasteners affixed to said hull sections and adapted for joining said at least two hull sections, said plurality of fasteners being one of internally and externally affixed to opposing connecting ends of said hull sections;

a plurality of hydrofoils attached to opposed external side surfaces of said hull sections for providing stability and maneuverability of said hull;

a propulsion system for providing propelling force to said hull; and

a ballast system for raising and submersing said hull, said ballast system comprising:

a ballast tank adapted to receive a predetermined level of water externally from the submarine and a predetermined amount of the pressurized air from said cabin; and

a compressor coupled to said ballast tank to form a closed loop system, said compressor adapted to force air into said cabin from said ballast tank to increase the water level in the tank and thereby cause said hull to submerge, and said compressor being adapted to force air into said ballast tank from said cabin to decrease the water level in the tank and thereby cause the submarine to ascend.

2. The submarine of claim **1**, further comprising a sealable opening formed in the upper portion of one of said hull sections for providing access into said interior cabin.

3. The submarine of claim **1**, wherein said plurality of fasteners include a plurality of clamps.

4. The submarine of claim **1**, wherein said plurality of fasteners include a plurality of bolts positioned on one of said connecting ends of a hull section and threaded into a corresponding plurality of nuts affixed to an opposing connecting end of an adjacent hull section.

5. The submarine of claim **1**, further comprising an o-ring inserted between each adjacent hull section.

6. The submarine of claim **1**, further comprising a reinforcing ring inserted between each adjacent hull section.

7. The submarine of claim **1**, wherein said ballast tank comprises a plurality of partitions to prevent water in the tank from destabilizing the submarine.

8. The submarine of claim **1**, wherein said ballast tank comprises a sealable opening formed at its bottom for controlling flow of water in or out of the tank.

9. The submarine of claim **1**, wherein said ballast system further includes at least one solenoid valve for controlling air flow between said cabin and said ballast tank.

10. The submarine of claim **1**, wherein said propulsion system includes:

a first water pump positioned in said cabin;

a forward inlet port formed in a forward hull section of said hull sections and coupled to said pump via a first conduit; and

an aft outlet port formed in an aft hull section of said hull sections and coupled to an output of said first pump via an aft conduit; wherein said first pump draws water external to said hull through said forward inlet port and first conduit, and forces said water through said aft outlet port to propel said submarine in a forward direction.

11. The submarine of claim **10**, further comprising a second aft outlet port formed in the aft hull section and coupled to said first pump via a second aft conduit, wherein said aft conduits are regulated to control water flow therethrough to provide steering of said submarine.

12. The submarine of claim **10**, wherein said first water pump draws water external of said hull through said aft outlet port and said aft conduit, and forces the water through said forward inlet port to propel said submarine in a reverse direction.

13. The submarine of claim **12**, further comprising a second water pump serially coupled to said first water pump, said second water pump being deactivated while said first pump is activated to propel said submarine in the forward direction.

14. The submarine of claim **13**, wherein said first pump is deactivated while said second pump is activated to draw water external to said hull through said aft outlet port and aft conduit, and force said water out of said forward inlet port to propel said submarine in a reverse direction.

15. The submarine of claim **10**, further comprising a plate pivotably attached in a vertical direction in said aft outlet port, said vertically positioned plate being rotatable to direct the water jetted out of said aft outlet port at a predetermined angle to steer said submarine.

16. The submarine of claim **15**, further comprising:

a vertical rudder rotatable attached to said aft hull section; and

a link coupled between said rudder and vertical plate, wherein rotation of said plate is controlled by rotation of said rudder.

17. The submarine of claim **1**, wherein said propulsion system includes:

a forward water pump positioned in said cabin;

a forward inlet port formed in a forward hull section of said hull sections and coupled to said forward pump via a forward conduit;

a pair of parallel water pumps positioned in said cabin, said parallel pumps coupled to said forward water pump via a Y-shaped conduit; and

a pair of aft outlet ports formed in an aft hull section of said hull sections, each aft outlet port being coupled to a corresponding one of said parallel water pumps via a second conduit; wherein at least one of said parallel water pumps draws water external to said hull through said forward inlet port and forward conduit, and forces said water out of said corresponding aft outlet port to propel said submarine in a substantially forward direction.

18. The submarine of claim **17**, wherein said forward water pump is deactivated when said pair of parallel water pumps is activated to propel said submarine in a substantially forward direction.

19. The submarine of claim 17, wherein said pair of parallel pumps is deactivated while said forward pump is activated to draw water external to said hull through said aft outlet ports and Y-shaped conduit, and force said water out of said forward inlet port to propel said submarine in a reverse direction.

20. The submarine of claim 17, wherein one of said parallel pumps is one of throttled back and deactivated while the other is activated to steer said submarine in a predetermined direction.

21. The submarine of claim 1, further comprising a vertical rudder rotatably attached to an aft hull section of said hull sections for steering said submarine.

22. The submarine of claim 1, wherein said plurality of hydrofoils comprises:

a pair of aft hydrofoils rotatably attached to opposing side surfaces of an aft hull section of said hull sections, said rotatably attached hydrofoils enabling said submarine to submerge and ascend.

23. The submarine of claim 1, wherein said plurality of hydrofoils comprises a pair of forward hydrofoils fixedly attached to said opposing side surfaces proximate a forward hull section of said hull sections, said fixedly attached hydrofoils providing stability for said submarine.

24. The submarine of claim 1, wherein said plurality of hydrofoils comprises a pair of forward hydrofoils rotatably attached to said opposing side surfaces proximate a forward hull section of said hull sections, said rotatably attached hydrofoils enabling said submarine to submerge and ascend.

25. The submarine of claim 1 wherein said hull sections comprises a forward hull section, an aft hull section, and a middle hull section attached therebetween said forward and aft hull sections via said plurality of fasteners.

26. The submarine of claim 1, wherein said propulsion system includes:

a pair of forward inlet ports formed in a forward hull section of said hull sections;

a pair of parallel water pumps positioned in said cabin, each parallel pump coupled to a corresponding one of said pair of forward inlet ports via a forward conduit; and

a pair of aft outlet ports formed in an aft hull section of said hull sections, each aft outlet port being coupled to a corresponding output of one of said parallel water pumps via an aft conduit; wherein at least one of said parallel water pumps draws water external of said hull through said corresponding forward inlet port and forward conduit, and forces said water out of said corresponding aft outlet port to propel and steer said submarine in a substantially forward direction.

27. The submarine of claim 26, wherein at least one of said parallel water pumps draws water external to said hull through said corresponding aft outlet port and aft conduit, and forces said water out of said corresponding forward inlet port to propel and steer said submarine in a substantially reverse direction.

28. The submarine of claim 1, further comprising a programmable controller for controlling operations of said submarine.

29. The submarine of claim 1, further comprising one or more sensors for providing electrical signals to said controller for further controlling said submarine operations.

30. The submarine of claim 29, wherein said one or more sensors is selected from the group of sensors comprising depth sensors, GPS system sensors, pressure sensors, position and orientation sensors, speed sensors, leakage sensors, audio sensors and video sensors.

31. The submarine of claim 29, further comprising at least one robotic arm mounted to said hull and electrically coupled to said controller.

32. The submarine of claim 1, further comprising at least one battery for providing power to said submarine.

33. The submarine of claim 32, wherein said at least one battery is rechargeable.

34. The submarine of claim 33, further comprising an array of photovoltaic cells mounted to the exterior surface of said hull.

35. The submarine of claim 34, wherein said array of photovoltaic cells provide charge to said rechargeable batteries.

36. The submarine of claim 34, wherein said array of photovoltaic cells provide power to said submarine.

37. The submarine of claim 28, further comprising a receiver for receiving remote command signals to control operations of said submarine.

38. The submarine of claim 28, further comprising a transmitter for sending operational information to a remotely located receiver.

39. An unmanned autonomous submarine, comprising:

a hull formed by at least two hull sections and defining an interior cabin therein, said cabin adapted to retain pressurized air;

a plurality of fasteners affixed to said hull sections and adapted for joining said at least two hull sections, said plurality of fasteners being one of internally and externally affixed to opposing connecting ends of said hull sections;

a plurality of hydrofoils attached to opposed external side surfaces of said hull sections for providing stability and maneuverability of said hull;

a propulsion system for providing propelling force to said hull, said propulsion system comprises;

a first water pump positioned in said cabin;

a forward inlet port formed in a forward hull section of said hull sections and coupled to said pump via a first conduit;

an aft outlet port formed in an aft hull section of said hull sections and coupled to an output of said first pump via an aft conduit; wherein said first pump draws water external to said hull through said forward inlet port and first conduit, and forces said water through said aft outlet port to propel said submarine in a forward direction; a ballast system for raising and submersing said hull, said ballast system comprising:

a ballast tank adapted to receive a predetermined level of water externally from the submarine and a predetermined amount of the pressurized air from said cabin;

a compressor coupled to said ballast tank to form a closed loop system, said compressor adapted to force air into said cabin from said ballast tank to increase the water level in the tank and thereby cause said hull to submerge, and said compressor being adapted to force air into said ballast tank from said cabin to decrease the water level in the tank and thereby cause the submarine to ascend;

a programmable controller for controlling operations of said submarine; and

one or more sensors for providing electrical signals to said controller for further controlling said submarine operations.

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