The Development of a Highly Maneuverable Underwater Vehicle

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ABSTRACT

A highly maneuverable underwater vehicle that can be operated remotely with computer assistance was designed, fabricated and tested by researchers at the University of Florida. The vehicle incorporates many off-the-shelf components in order to minimize cost. The body was constructed using a foam core with a fiberglass/carbon fiber outer shell. Energy was provided by an Exide 12V gel cell wheelchair battery. Four trolling motors, two oriented horizontally and two vertically, provide forward/backward thrust, turning, and ascend/descend movement. Attitude and heading are furnished by Precision Navigation's TCM2 digital compass. Vertical position in the water is sensed with a pressure gauge. Two valves are used to fill a buoyancy compensator with air from ballast tanks, or to operate an air-actuated valve to release the air and fill the buoyancy compensator with water. A 68HC11 microcontroller from Novasoft is used to read in data from the sensors, and provide controlling signals to the motors.

Approximately 0.9144 m (3 feet) wide by 0.9144 m (3 feet) long by 0.6096 m (2 feet) high, the sub is highly maneuverable due to its small size and tight turn radius. Weighing about 40.82 kg (90 pounds) out of the water, it is close to neutrally buoyant in the water. Since buoyant forces are near the top of the sub, while the heavy weight is located at the bottom, it is also inherently stable. The paper will detail the vehicle design and the resulting performance capabilities.

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INTRODUCTION

The ocean remains one of the last unexplored terrestrial regions on the planet. Manned exploration is expensive and dangerous. Because of this, the need has risen to develop technology to explore this territory in a cost efficient and effective manner.

Figure 1: SubjuGator

The majority of current underwater vehicles are tethered to a mother ship (called Remotely Operated Vehicles or ROV's), and are used to investigate sunken vessels, examine pipelines and offshore oil rigs. The many variations of the ROV Hysub from International Submarine Engineering Ltd., preform operations such as mine countermeasures, drill rig support, and cable retrieval and burial (McFarlane 1995). Extensive and laborious work hours are needed to operate the vehicle. Operator fatigue results in poor control, while the tether can snag on an underwater object. An autonomous vehicle is ideal for the inspection and service of underwater activities. Having a vehicle which requires little or no input from the operator, allows the operator to concentrate on higher level activities.

Of the vehicles which are fully autonomous (called Autonomous Underwater Vehicles or AUV's), most are torpedo shaped and are intended for gathering information in the open ocean. While efficient for forward motion, this shape limits maneuverability in tight quarters. Florida Atlantic University has two in this category, the Ocean Voyager II and the Ocean Explorer (AUV 1997). International Submarine Engineering (ISE) Ltd. Has developed Theseus, which is a 10.668 m (35 feet) long and 127 cm (50 inches) in diameter (Ferguson, Pope 1995). Since 1975, ISE and ISE Research have built over 168 undersea vehicles. Of the 168 undersea vehicles, 145 have been unmanned, tethered systems (ROVs), 15 vehicles have been unmanned and untethered (AUVs), and 7 have been manned submersibles (McFarlane 1995). The MARIUS vehicle, developed by a multidisciplinary team of scientists and engineers from Denmark, France and Portugal, is 4.5 m (15.7 feet) long, 1.1 m (3.6 feet) wide and 0.6 m (1.96 feet) high (Pascole 1994). MIT, through the Sea Grant program, has developed many autonomous vehicles with varying purposes (MIT 1997).

It was the goal of the researchers to design a small, highly maneuverable vehicle which can fully realize three-dimensional movement underwater. The vehicle, shown in figure 1, was designed with these parameters in mind.

SUBMARINE COMPONENTS

Body and Cage. The main body of the submarine, used for floatation, is composed of a foam core covered with fiberglass, bidirectional, and unidirectional carbon fiber adding strength and rigidity, shown in figure 2. The horizontal tail and vertical fins are fabricated from 1/8" aluminum plate and bolted to the body. The tail structure provides directional, roll and pitch stability.

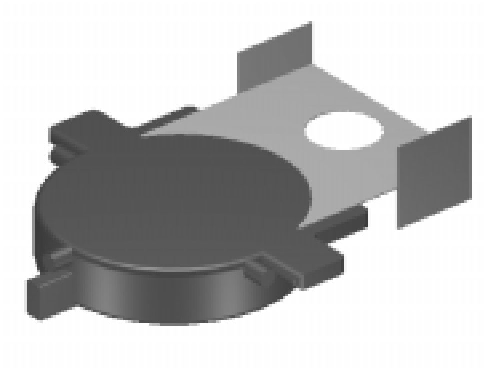

Figure 2: Submarine body and tail

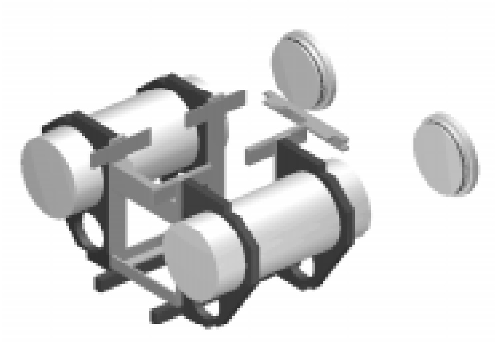

Figure 3: Cage and electronics tubes

The cage, shown in figure 3, which mounts below the body, is constructed of welded aluminum angle and Delrin plastic. The main battery is housed within the aluminum frame, while Delrin tabs are mounted to the outside of the frame. The upper cutouts in the Delrin house the electronic tubes, while the lower cutouts support the cylinders used in the buoyancy compensator. Delrin is also used as skids on the underside of the aluminum cage.

The electronics for the submarine are housed within two clear, 10.16 cm (4 inch) inner-diameter acrylic tubes, also shown in figure 3. The clear tubes allow visual inspection of the electronics and to quickly check for the presence of water. Each endcap is o-ring sealed, and one is fashioned from aluminum. The motor drivers are bolted to the inside of the aluminum endcap, acting as a large heatsink between the drivers and the water outside.

Power and Propulsion. Power for the motors is supplied by an Exide 12V Gel cell battery, shown in figure 4. The battery was intended for use with wheelchairs, and is capable of supplying 40 amp-hours (A-hr) of service. A separate power supply, housed within the acrylic tube, is used for the electronics. The electronics are optically-isolated to minimize coupling between the electronics and the electrical noise from the motors.

Four Minn Cota trolling motors are used for propulsion. Each motor provides 10.88 kg (24 pounds) of thrust. Two are fixed vertically, fore and aft, and provide pitch stability and ascent/descent thrust. The other two are fixed horizontally, port and starboard, and provide forward/backward thrust when both motors are running in the same direction, and a turn when one motor is run at a different RPM then the other.

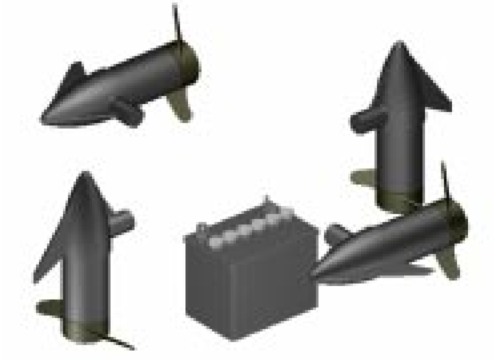

Figure 4: Gel cell battery and trolling motors

Sensors. Currently, there are two sensors on the submarine. A digital compass to sense heading, roll, and pitch, and a pressure transducer to sense depth.

A high-performance digital compass manufactured by Precision Navigation, Inc. is used in the sub for heading reference. The TCM2 combines a proprietary triaxial magnetometer system to provide heading information at a resolution of ±0.1°, and a biaxial electrolytic inclinometer to provide tilt and roll information at ±50° at a resolution of ±0.4°. This extra data allows the TCM2 to provide greater accuracy in the field by calibrating for distortion fields in all tilt orientations, providing an alarm when local magnetic anomalies are present, and giving out-of-range warnings when the unit is being tilted too far.

The pressure sensor, manufactured by Omega, converts the pressure exerted by the water into a voltage in the range from 0-5V. The microprocessor reads the value and converts the voltage into a depth.

Buoyancy Control. Buoyancy can be adjusted through the buoyancy control. The schematic is shown in figure 5, and the actual hardware (and it's placement) is shown in figure 6. The reservoir of air is stored in two 0.0765 m^3 (2.7 ft^3) 3000 psi spare air tanks

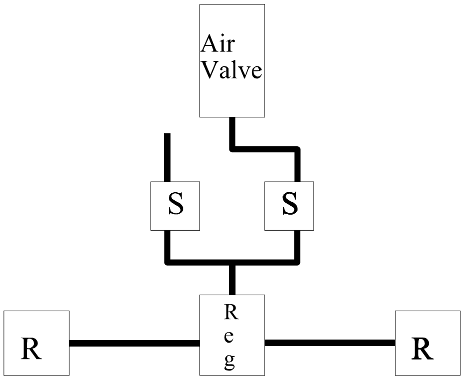

Figure 5: Buoyancy control schematic

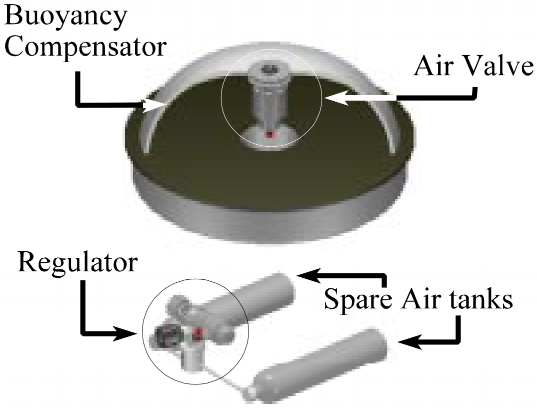

Figure 6: Buoyancy control hardware

(so named, because they complement a scuba diver's regular tanks), represented as an **R** in figure 5. The tanks both feed to a regulator, which drops the pressure to 150 psi. From there, the air is branched off to two air solenoids (shown as an **S** in figure 5, and not shown in figure 6). The output of one solenoid feeds directly into the buoyancy compensator, filling the chamber with air, and increasing the buoyancy. The other solenoid attaches to the air valve shown in figure 7, and vents the air, allowing water to fill the chamber and decreases buoyancy.

The air valve, cutaway shown in figure 7, is composed of an air actuated piston and return spring (not shown in the figure). The 150 psi air enters from the bottom and forces the piston and plunger upward. This allows the air at the top of the buoyancy compensator to exit from the horizontal holes and out the plunger. Tolerance between the piston and sleeve allow the air to move around the piston, and the return spring to close the plunger after a short delay.

Figure 7: Air valve

The submarine is set to be neutrally buoyant with the buoyancy compensator is filled with water. The buoyancy control allows buoyancy to be increased if an external object is grasped, or to allow the sub to return to the surface without motor control.

PERFORMANCE

The submarine is currently under semi-autonomous control. A Motorola 68HC11 microprocessor supply by Novasoft is used to control the submarine. The 68HC11 is an 8 MHz 8-bit microcontroller offering multiple digital inputs/outputs and eight 8-bit analog input. The microcontroller has complete control over the two vertical motors, taking input from the pressure sensor and digital compass to maintain a preset depth and zero pitch as the submarine is maneuvered above and below the water

The submarine is inherently stable due to it's configuration. Buoyant forces are place near the top, while weight is place lower, as shown in figure 8. As the sub pitches, the buoyant and weight forces set up a restoring moment with the viscosity of the water acting as a dampener.

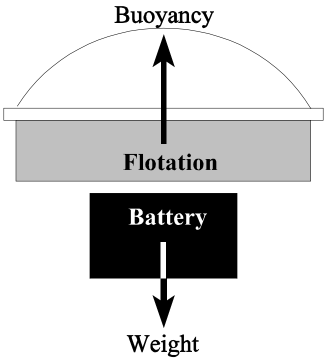

Figure 8: Submarine stability

For testing, the submarine is controlled from a Helicopter remote control (R/C). The left stick controls the selected depth (up/down stick movement) and the actuation of the two air solenoids (left or right stick movement). The right stick controls the speed (forward - up, stop

- centered, backward - down), and the turning (left and right stick movement).

The two trolling motors used for forward movement provide great speed and power. The submarine can outrun a non-enhanced swimmer (i.e., one without flippers), and is capable of dragging a person through the water who is holding on to the vertical fins. The motors are run using Pulse Width Modulation (PWM) providing an efficient means of control. Turning the submarine can be anything from a gentle curve, by slightly decreasing the RPM of the motor on the side of the sub in which to turn, to a quick and tight rotation, by driving the motor in reverse on the side of the sub in which to turn.

CONCLUSIONS

It was initially desired to build an autonomous underwater vehicle which was small in size but considerable in performance. Using off-the-shelf technology, a vehicle was built with both of these characteristics and generated the added benefit of being inexpensive. The motors provided the needed speed, while the positioning and control of the motors allowed true three-dimensional movement below the surface.

REFERENCES

[1] AUV Home Page, *http://www.oe.fau.edu/AMS/auv.html*, 1997

[2] J. Ferguson, A. Pope, " 'Theseus': Multipurpose Canadian AUV", *Sea Technology*, April (1995):19-22.

[3] J. McFarlane, *International Submarine Engineering, Ltd. Group Corporate Profile* (1995).

[4] MIT Sea Grant, *http://web.mit.edu/seagrant/www/mitsg.htm*, 1997

[5] A. Pascole, "The AUV MARIUS: Mission Scenarios, Vehicle Design, Construction and Tesing", *Proceedings of the 2nd Workshop on Mobile Robots for Subsea Environments*, Monterey Bay Aquarium, Monterey, California USA, May (1994).