Mini Remote Operated Vehicle

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Inspecting ship hulls, searching for items dropped in murky water, and exploration at depth or in contaminated water can be difficult, expensive and hazardous to a diver. ROV's are traditionally meant for industrial functions such as surveillance of pipeline networks, offshore platforms, and rail systems. However, in the current age, ROV's are utilized for numerous applications including scientific functions and search and rescue operations. One of the most common significant applications is ocean exploration and aquarium development where they establish a viable link between scientific voyage and live presentations through the web. The oldest utilization of ROV's is in Royal Navy where they were deployed for recovering thrill torpedoes. In the 1960's the US Navy designed the Cable-Controlled division between the center of buoyancy and CoG to facilitate stability and operability under water. This project intends to design and build a submersible Remotely Operated Vehicle (ROV), which allows an operator to remain safely on shore out of harm's way and eliminate costs and risk associated with having a diver in the water. This ROV was designed initially using hand sketches, once an agreed upon shape has been established from these sketches, a CAD model was developed using Autodesk Inventor to obtain a more clear picture of the overall design. Once these models have been completed, the materials for the ROV was selected, formed and assembled to create the ROV. In addition, a control box was created to house and transport the ROV and its necessary components. Once these steps have been completed, the ROV was tested to ensure it meets the required capabilities set by the team. This paper will present a design of submersible Remotely Operated Vehicle that can be used for ship hull inspection.

Introduction

Remotely Operated Vehicle (ROV) are a class of manually operated or automated robots utilized in the maritime environment. Commercial ROV's are extremely maneuverable and operated by skilled operators aboard ships and other platforms. The ROV's are linked to the operator aboard ships and other vessels through cables that transmit electrical signals. The ROV's are traditionally equipped with cameras and lighting equipment to increase their usability. Other equipment that might be integrated with the ROV's include magnetometers, sonar's, graspers, water sampling devices, temperature sensors, light penetration devices, and water clarity measuring devices [1]. ROV's are traditionally meant for industrial functions such as surveillance of pipeline networks, offshore platforms, and rail systems. However, in the current age, ROV's are utilized for numerous applications including scientific functions and search and rescue operations. One of the most common significant applications is ocean exploration and aquarium development where they establish a viable link between scientific voyage and live presentations through the web. The oldest utilization of ROV's is in Royal Navy where they were deployed for recovering thrill torpedoes. In the 1960's the US Navy designed the Cable-Controlled division between the center of buoyancy and CoG to facilitate stability and operability under water. The prompt for selecting a ROV as a design project stems directly from one of the team members background working in the US NAVY and on offshore oil platforms. As a result there was direct exposure to commercial and defense ROVs. Additionally the same team member volunteers at Granby High school and helps a group of 10-15 girls design and build ROV's that are used in the Marine Advanced Technology Education (MATE) competition.

Some ROVs, such as the AQUA EXPLORER 2 (AE2) are used to autonomously track underwater cables and measure their burial depth. This kind of vehicle can communicate with a mother vessel with an acoustic link, only high-level commands are sent to the vehicle and most of the control is done by a built-in computer. The vehicle can locate and track cables by detecting the magnetic field generated by the current [2]. Other ones, such as ROMEO are specially design to work in harsh environments [3]. ROVs can be used for surveying, inspection, and research purposes [1]. The main purpose of the ROV that is designed during this project was to provide a way to eliminate the risk and costs associated with sending a person into potentially dangerous environments. ROVs can operate in toxic or radiated water, fit into small areas and operate at depths far too dangerous for a diver to be in [4]. ROV's have a longer operating endurance than a diver has, as long as power is applied an operator is present a mission or recreational dive can continue. During this research on ROV's a number of industry catalogs, hobby forums, textbooks and videos were studied. While not every source has been cited in this paper, the information gathered by research did help guide design considerations on the design and technology selection.

The main objective of this project was to design a ROV that will be capable of traveling up to 30 feet underwater, fully submerged and transmit video back to a monitor located in a control box on shore. The main constraint was that the design should be large enough to house the electronic components necessary for operation, have enough external space for a minimum of three motors, and be made from material that is commercially available. Several designs were contemplated before the final design was chosen.

Propulsion Considerations

The main purpose of propulsion was to provide a desired motion to the ROV. The chosen voltage was 12 V, DC. There are five different motors that were considered for this ROV.

The first motor that was considered was a rim-driven-thruster. This motor is the most reliable thruster available to date. It integrates an electric motor that engulfs the propeller to give a powerful thrust that provides a high torque. A properly designed rim-driver comprises of a single moving element- the propeller that rotates between the rotor and the outer winding. The configuration provides a simplified and inexpensive mounting of the rim bearings. Some of the benefits of such design choice are: minimal noise emissions, compact size, and no need for a center shaft. Some of the problems of using this specific motor are: high energy cost, and inefficiency due to friction losses.

The second motor that was considered was a Voith Schneider Propeller that is a specialized marine system for harbor tugs. The system is highly flexible with the capability to alter the direction of the thrust. The capability allows deployment in ferries and tugs. The VSP comprises of the circular plate that rotates around a vertical axis within circular arrays of vertical blades that protrude at the bottom of the vessel. Individual blades rotate around a vertical axis, and this is facilitated by the internal gear that changes the angle of action of the blades in unison with the rotation of the blade. Each blade gives a thrust in any direction the same way a cyclic helicopter does [5]. Cyclorotors can quickly vector thrust by altering the pattern of blade pitching. Some of the benefits of such design choice are: high degree of control, low noise emission, powerful and efficient. Some of the problems of using this specific motor are: support spokes because off added drag, relatively high cost, and poor hydrodynamics.

The third motor that was considered was a brushless motor. There are different types of motors that have been developed over time. The brushless motor comprises a rotor with multiple stationary magnets that produce a DC magnetic field. The resultant magnetic field interacts with the currents flowing through the stator core of thin and stacked laminations to generate a torque between the motor and the stator. The rotation mechanism of the rotor necessitates a changing magnitude and polarity of the stator currents in a manner that preserves the torque and maximizes the electrical to mechanical energy conversion. Notably, the device that reigns over the current control is referred as the inverter. Without the inverter, the brushless motor is inefficient [5]. Two brushless motors types were purchased for use in the ROV.

The fourth motor that was considered was a RC aircraft motor. The low cost option most commonly used for quadcopters also referred to as “drones” and requires modification to be used in a marine environment. Testing showed that this motor was able to deliver 0.8 lbf of thrust. Ultimately this option was abandoned due to the additional time required to prepare these motors for water, additional testing with different propeller sizes and pitch angles and designing a shroud to protect the motor. One of the benefits of such design choice was a very low cost. One of the problems of using this specific motor was: that additional engineering required to make suitable for water environment.

The fifth motor what was considered was a T100 Thruster from Blue Robotics that was designed specifically to operate in a marine environment [6]. This motor is capable of operating in the ocean and delivering 5lb of thrust it may be used to drive small boats, modified surf boards and other personal propulsion devices. It has found common use in robotic education and competition settings such as the Marine Advanced Technology Education (MATE) Competition. Some of the benefits of such design choice are that this motor was designed for ROV use, for saltwater environment use, and it has a configuration that is plug and play use, and it incorporates a KORT nozzle as its shroud for added efficiency. Some of the problems of using this specific motor are: it is very expensive compared to other alternatives, and it has a noticeable delay in operating.

Power System Considerations

The main objective of the power system was to develop an adequate power supply to sustain all components of the ROV as well as provide power to the internal monitor contained inside the control box or inside the ROV [7]. The main design considerations were to select a proper sized battery that can be contained inside a control box or inside the ROV, deliver a 12VDC supply for at least 20 minutes, and be easily recharged. The second one was to select a power supply wire that is large enough to carry the required voltage over a distance of 30 feet, but not be oversized. The third one was to ensure voltage regulators are in place to reduce risk of voltage drops at any point in the system. The most common batteries that are used in ROVs are Lithium Polymer, NiMh, and gel cells. Two main power source location options were considered:

Surface Power: This is a very safe, easy and common option that usually yields the best results if properly designed. The drawback is that the weight of the power wiring usually doesn't help the ROV in terms of neutral buoyancy, and can in some cases make the tether not as flexible. This option allows for the most sustained power though, because with the supply on the surface there is no limit to power, so the operating time of the ROV is potentially limitless. The amount of power that can be supplied from the surface is greater as well, because there is no limitation on space or weight, so more powerful motors, lights, and other accessories can be used while still maintaining the size of the ROV.

Internal Power: This is a very good option as well, but in my opinion much more dangerous. There are two ways to do internal power: One is with small gel cells that are sealed lead-acid 12 V batteries, and the other is using Lithium Polymer battery packs. With the gel cells there is not as much danger associated with their use, but there is a limit to how much power can be used at once. For instance, a 6 Ah battery cannot have 12 A of current pulled from it for sustained periods of time, because they are not designed to have this high power rating. Lithium Polymer battery packs on the other hand can handle many times their capacity in current, but if lithium is exposed to water it reacts vigorously, and produces hydrogen gas, which can cause an explosion if there is a spark or other source of flame.

Power Sources: Voltage

Switching Power Supplies: These power supplies are sort of unique in their ability to be very costly (in most cases), not very portable, and need a connection to 110 V AC power. These power supplies can supply more than 1,000 W of power on a typical 15 A single phase household circuit, which at 48 V means about 20 A. The other great thing about these power supplies they have been in use for a long time, so even the power supplies that are a few years old are still good enough to use to power an ROV.

12 V Batteries: The first option is using to use 12 V batteries one, or several in series or parallel. They are very common, and their capacity ranges from 6 or 7 Ah all the way up to 100+Ah marine batteries. They prices vary greatly. Smaller 10-20Ah batteries are used in motorcycles, and alarm systems. The project team selected a 31 Ah 12V battery.

Motor Control Circuit

The main objective of the motor control circuit was to design or provide an existing method for propulsion of the ROV, to be simple, low cost, and easy for repair and troubleshooting. The component that allows the circuit card to drive the motors is an Electronic Speed Controller (ESC). This circuit transforms the duty cycle of the Pulse Wave Modulation (PWM) output from the ServoShock 2 card into a signal transmitted over three wires to rotate the DC motor. The specific ESC used was one from Bluerobotics.com simply because the company has prefaced the ESCs they sell for forward and reverse drive of DC motors. Some of the main benefits of such design are: such design is simple and easy to use plug and play component, and that no programming required if purchased pre-flashed.

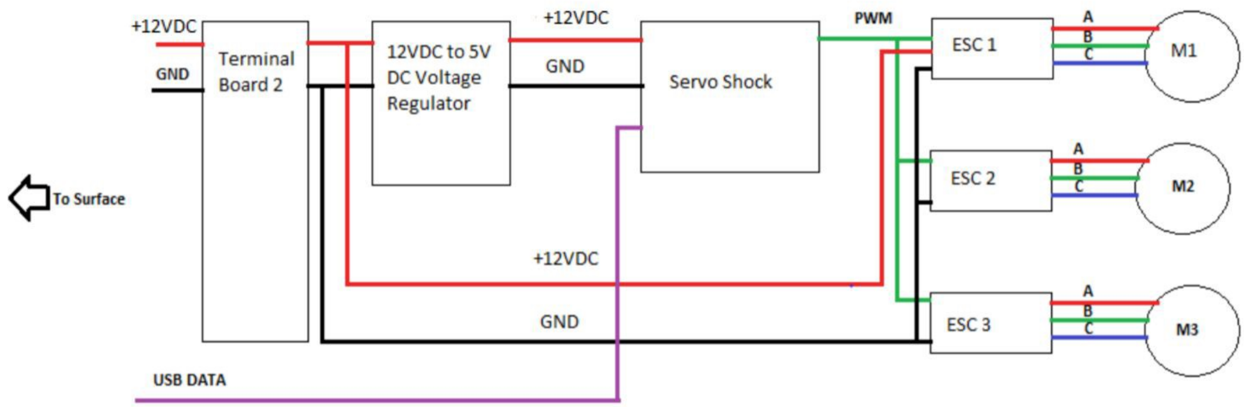

Figure 1: Block diagram of motor control circuit

Microcontroller

The circuit card is the "brains" of the ROV. It converts commands given by the operator into a format that is understood by the ESCs, motors and any additional outputs. Two technologies were considered for this role. These are Arduino and Servo Shock 2.

Arduino: Arduino described an open-source and simplified electronic platform encompassing both software and hardware. Arduino is a microcontroller company producing kits for designing and developing digital devices and interactive applications that can manipulate devices in the physical world. The software for implementing Arduino projects is the Arduino IDE that simplifies coding as well as the implementation of the Windows, Mac OS or Linux board environments [8]. It is possible to connect two Arduino's in such a manner to establish communication between the two. The kind of communication is critical for numerous projects including one Arduino running motors while the other senses the surrounding environment. The appropriate configuration is using I2C and serial communication [9]. There are two types of serial communication: RX and TX port communication. I2C (Inter-Integrated Circuit) is a protocol for communicating between the components and the motherboard in embedded electronics and cameras. Embedded electronics concerns the interlinking of circuits to generate a symbiotic system with a common protocol and information swapping capability. The communication protocols, though varied, have a defined data exchange, either parallel or series.

There are advantages and disadvantages to both. The parallel interface transfers numerous bits at the same time and requires buses of data, usually within eight, sixteen, or thirty-two wires. The data is characteristically transferred in huge but crashing waves of ones and zeros. Contrary to the parallel transfer is the serial configuration. The data is usually transferred in a stream, bitwise at a time. Majorly, the interfaces employ a single wire but not more than four for data transmission. The benefits of parallel communication include speed, clarity, and ease of implementation. The disadvantage is the requirement for more input-output data channels. In moving data from one Arduino to the other, the limitation usually emerges in the number of I/O lines of the microprocessor. Therefore, serial communication is preferred for robust bin numbers rather than potential speed. The Arduino was the first choice due to having experience with the card in other projects. Ultimately the Arduino solution was abandoned due to underestimating the degree of difficulty and the amount of time spent in attempting to program the card to work with a PlayStation 1, 3, or 4 controller. It is estimated that roughly 75% to 80% of the code had been worked out before switching to a simpler solution. Some of the main benefits of choosing this option were: large degree of capability, large open source code community, low cost, the option of a multiple Arduinos working together in a master/slave configuration via I2C. The main problems of use of such configuration were that programming can be difficult and time consuming, and that a lower cost generic cards may not be as robust as genuine Arduino cards.

ServoShock 2: The ServoShock 2 card is a preprogrammed circuit card designed specifically to convert output commands from the Sony Dualshock 4 controller into PWM signals for use with ESC's or servos, as well as providing a digital output command for each push button [10]. As of the time of this writing the servo shock 2 card is in a fundraising campaign via kickstarter.com. The group was able to acquire the cards from the designer directly and bypass the fundraising efforts. The card has a 10 meter wireless range via a Bluetooth connection, 18 digital outputs, and 12 servo outputs. The card can also use a SPI bus data and control interface and can interact with the Arduino to expand its capability. The circuit receives the 12V input to drive the card. Onboard it has a regulator to drop the voltage down to 3.3V to drive the digital outputs on the side of the card, and to 5V for the PWM outputs used by the ESC's. Power Draw during testing Card Power: 12V 0.418 Amps. Some of the main benefits of using such card is that it is already programmed for many outputs, program is user modifiable, it has flexible voltage inputs, and it can work with Arduino cards for expanded capability. The main downside was that it is more expensive than Arduino board. While testing the motors, two Servo Shock cards were damaged. Both cards failed due to onboard 5V regulator overheating. This was caused by not having adequate circuit protection. A 12VDC voltage regulator was installed before the Servoshock 2 card and it eliminated this problem.

Lighting Subsystem

The main objective of the lighting system was to provide an external light system and control drive circuit, to be waterproof and to work with the tether of ROV of 30 feet. Potential of ROV to reach that depth though all areas locally for testing and planned operating areas are less than 30ft. Research team considered two options: one making a waterproof light, second one buying one off the shelf. Team made the circuit with a LED and a resistor housed within a waterproof body. However right LEDs need special heat shedding considerations that increase the cost and it was for this reason the DIY option was eliminated. This option was easy to build, but bright LEDS produced large amounts of heat that need heat sinks, which drew up the cost. Several off the shelf options were considered from modifying a low cost dive light to be driven off of a wired 12V instead of batteries to buying wired waterproof lights. The option selected for the ROV was an aftermarket LED light designed for daytime running light use on automobiles from Theretrofitsource.com, as shown in Figure 2.

Figure 2: Morimoto Mini ModPod aftermarket LED side and front views

Discussions with the light manufacturer indicated that the light was not tested for IP6x rating. The light can be switched between low (300 lumen) and high intensity (600 lumen) modes allowing the operator to increase and decrease light as needed to ensure good video.

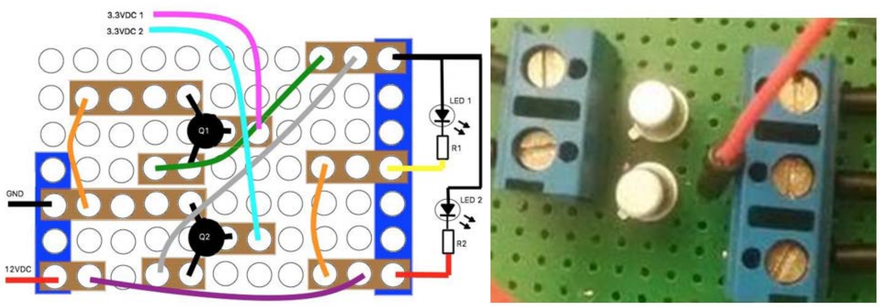

Figure 3: LED drive schematic and a wiring layout sketch

Camera Subsystem

The main objective of camera system was to provide a means of viewing objects underwater, to be compact and waterproof.

Figure 4: Parts of the camera assembly left to right: Camera, camera in pvc housing, potting material applied, acrylic lense in place with JB weld

Considerations for the camera system were a low cost bulk electronics option, an off the shelf camera such as a GoPro or a Remote Pilot View (RPV) camera system also referred to as a First Person View (FPV) typically found on quadcopters. The RPV/FPV systems required design modification in added waterproofing. Other modification resulted in a need that a wireless radio transmission needed a new configuration that can transmit over a CAT5 or USB cable. The off the shelf cameras require less modification but are still prohibitively expensive. The camera system was selected to be simple and low cost. It is simply a rear view camera used in automotive applications. To view the video the camera was mated to a similar low-cost bulk electronics monitor. This components were designed to be hard wired via composite audio/video (A/V) cables. This configuration proved to be suitable to our application. The camera is housed internal to a 1in schedule 40 PVC tube. Waterproofing is provided by filling the rear and front with epoxy potting. The front was also capped with a 1in clear acrylic lens secured in place with JB Weld, as shown in Figure 4.

Electronics Mounting Platform

The main objective of the electronics mounting platform was to design a platform for all the electronic hardware inside the ROV to be mounted [11]. Overall size is limited to the dimensions of the 4in diameter PVC tube. Two platform materials were considered. The first option was to mount the electronics on the remaining HDPE left over from the ROV Body to save money. The main problem of such design choice was that the standoffs would need to be purchased to allow the circuit cards to be mounted and provide ample room for wires and components mounted on the bottom to have space. The other option was to 3D print a custom platform so that final assembly would be easy as all the mounting positions would have been pre-measured and custom formed for each component. To facilitate the custom configuration of the mounting plate, each component needed to be measured and rendered in a CAD software. During testing of the electronics, two ESC's were damaged at the same time two Servo shock 2 cards were. The vendor had changed their design of ESC's into a more compact form factor. As a result the platform needed to be designed to be able to hold either the small (modeled in blue) or large (modeled in green) ESC's. To facilitate the two sizes, spacers were made to go into the gaps so the ESC would be stationary. 3D printer unable to print full size, added complexity to print part in two pieces.

Control Box

The main objective of a control box was to design and create a box that will fully contain all components to the ROV, establish positions for each of the dedicated systems, be ready to deploy at any time by opening; wire the internals of the control box to allow the ROV to simply plug in, turn on, and begin operation. [12].

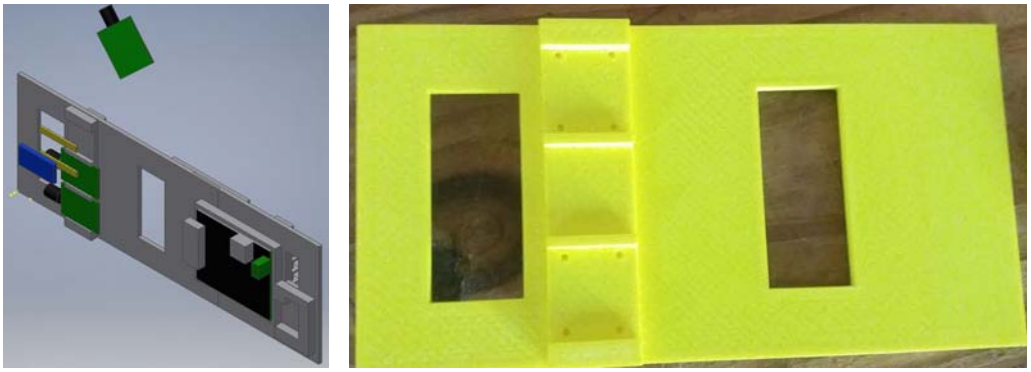

Figure 5: CAD design and 3D printed electronic platform

The control box selection included a few principal ideas. The first idea was that the box needed to be large enough to contain the entire system including the ROV itself. The second principle was that the box should have a latched lid to protect the internals from weather damage.

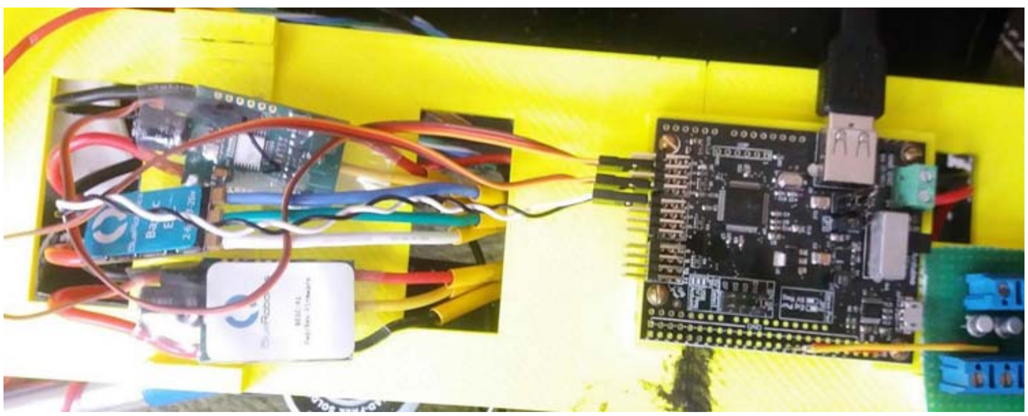

Figure 6: Electronics platform assembled

The final principle was that the box should be portable to allow for easy travel to and from applicable sites. The internals of the box would house the monitor on the attached lid, a position for a removable battery, and a connection box to allow for easy connection of the tether cable to the ROV. Additionally, enough room must be left to place the ROV inside. This design left for two options: custom built or commercially available. Custom building a box would entail full construction from wood with the need for finishing and waterproofing. Commercially there were several options from different companies to choose that would be immediately ready for final assembly. Due to time constraints and the scope of the overall project the commercial Pelican 1640 case was chosen to fit the design needs, as shown in Figure 6.

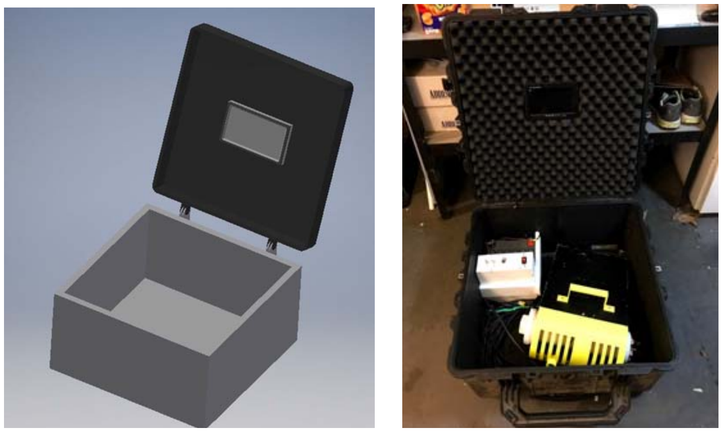

Figure 7: Electronics mounting platform and control box

The ROV CAD designed is given in Figure 8.

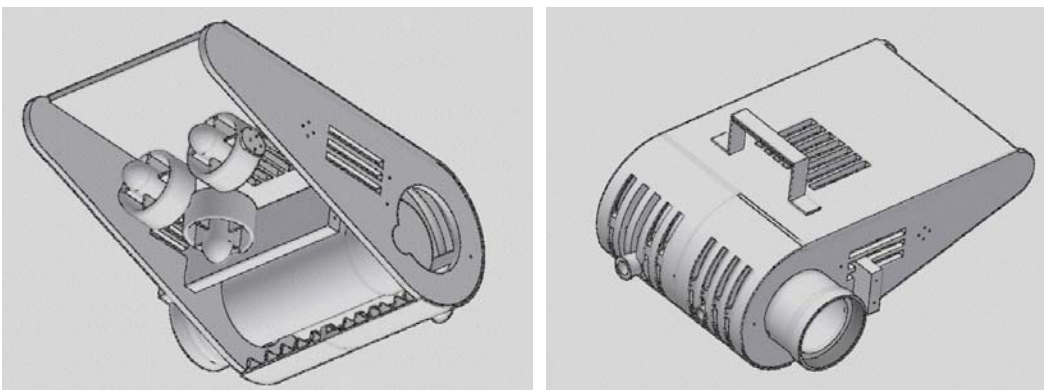

Figure 9: Isometric view of Bottom-Rear

One of the assembly steps and a ROV final design are given in Figure 8.

Figure 10: ROV housing and PVC cap with cable penetrators and completed ROV

Conclusion

A ROV presented in this paper is a small, fully contained ROV capable of transmitting video. It is lightweight, hydrodynamic design to allow for enhanced maneuverability. This project was designed during a senior project capstone course in Mechanical Engineering Technology program at Old Dominion University, Norfolk, Virginia. Students designed and fabricated ROV that included a control box capable of carrying the ROV, receiving the video, and providing power. This ROV is capable of reaching up to 30 feet. The control board was a Servoshock card containing 18 digital outputs and 12 servo outputs allowing for easy expansion of ROV capability.

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References:

[1] Christ, R. D., & Wernli Sr, R. L. (2013). *The ROV manual: a user guide for remotely operated vehicles*. Butterworth-Heinemann.

[2] Asakawa, K, Kojima, J, Kato, Y, Matsumoto, Sh, Kato, N, Asai, T, & Iso, T. (2002). AQUA EXPLORER 2 for the inspection of underwater cables. *Advanced Robotics, 16*(1), 27-42.

[3] Caccia, M., Bono, R., Bruzzone, G., & Veruggio, G. (2000). Unmanned underwater vehicles for scientific applications and robotics research: the ROMEO project. *Marine Technology Society Journal*, *34*(2), 3-17.

[4] Benthic Pelagic Solutions Ltd (2014) Why We Use an ROV, Road Mobile Underwater Robotic Vehicle Unit, Retrieved from http://www.benthicpelagic.com/why-we-use-an-rov

[5] Hendershot, J. R., & Miller, T. J. E. (1994). *Design of brushless permanent-magnet motors*. Magna Physics Pub.

[6] BlueRobotics (2017). T100 Thruster Specifications. (n.d.). Retrieved April 2, 2018, from http://docs.bluerobotics.com/thrusters/#performance-charts

[7] Wang, X., Shang, J., Luo, Z., Tang, L., Zhang, X., & Li, J. (2012). Reviews of power systems and environmental energy conversion for unmanned underwater vehicles. *Renewable and Sustainable Energy Reviews*, *16*(4), 1958-1970.

[8] Badamasi, Y. A. (2014, September). The working principle of an Arduino. In *Electronics, Computer and Computation (ICECCO), 2014 11th International Conference on* (pp. 1-4). IEEE.

[9] Gibb, A. M. (2010). *New media art, design, and the Arduino microcontroller: A malleable tool* (Doctoral dissertation, Pratt Institute).

[10] ServoShock (2018). ServoShock 2 Servo and I/O Controller, *Servoshock.com*, www.servoshock.com/uploads/7/7/2/1/7721313/servoshock2_manual_rev1-4.pdf
[11] Wadoo, S., & Kachroo, P. (2011). *Autonomous underwater vehicles [e-book] modeling, control design, and simulation* (ENGnetBASE: engineering handbooks online). Boca Raton, FL: CRC Press.
[12] Whitcomb, L. L. (2000). Underwater robotics: Out of the research laboratory and into the field. In *Robotics and Automation, 2000. Proceedings. ICRA'00. IEEE International Conference on* (Vol. 1, pp. 709-716). IEEE.

Biographies

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