Improvement of the Electrical and Control System for an Underwater Remotely Operated Vehicle

Victor Miller†, Qing Li‡
Electrical Engineering Department†/Mechanical and Industrial Engineering Department‡
University of New Haven, Connecticut, USA

Abstract

As a continued effort, this project entailed the improvement of the electrical and control systems for an existing underwater ROV which was developed at UNH. The on-board electrical system was reworked with the purpose of increasing its data communication capabilities, incorporating new functions, and enhancing its overall quality. The previous system proved to be sufficient enough to provide full functionality, however, improvements were needed for better performance. For instance, the previous USB extender unit only transferred data at low speed and full speed rates. In this new design, it was replaced with a unit that supports high speed rates. With all the improvements made, the functioning ROV possesses the ability to maneuver in an aquatic environment with lighting, camera view adjustment, real-time video recording and thruster control. New functionalities such as water sample collection and water condition measuring will be developed as part of the future work.

Keywords

Underwater ROV, Educational Robot, LabVIEW, Arduino

Introduction

The purpose of this endeavor is to design an ROV which will supplement the educational experience of students studying Marine Biology and Geography by making possible the exploration of aquatic environments. The ROV will be designed to collect relevant data from underwater environment to assist learning. A prototype ROV was developed by previous senior design groups based on the requirements and specifications suggested by faculty and students from marine biology and geography majors. The prototype model was fully operational, however its electrical system required refinement, as it could not endure sustained use and lacked a few critical capabilities. The goal of this project was to improve the electrical and control system by overcoming the weaknesses of the current design and providing more new functions[1,2,3].

The Prototype State

Albeit the prototype model was functional, it possessed three main flaws: some components such as the SubConn plugs and USB Extender were not durable for repeated usage, the wiring and electrical setup was more akin to an amateur design, and an important safety factor was not considered in the previous design.

The existing SubConn plug sending external power to the ROV had five contacts and a maximum current rating of 5A per contact. If two contacts were utilized as the positive source and two contacts as the negative source, the plug would not meet current specifications of the ROV which is 16A total. There were also other problems with the SubConn plugs. The hexagonal bolt heads of the plugs sheared off from the threaded bodies during construction. The other critical fault was the wrong choice of the USB Extender. The previous extender units were compatible with USB 2.0, however they were only capable of transferring data at Low Speed (1.5Mb/s) and Full Speed (12Mb/s) rates, but not at the High Speed (480Mb/s). This caused failures during actual testing. In conjunction with the aforementioned issues, the ROV's internal wiring was also problematic. Several wires were of thin gauge and others had unnecessary splices. In addition to the necessary repairs and enhancements mentioned above, the ROV provided no means by which an operator could toggle the running state of the thrusters. If power was suddenly delivered to the ROV while the thrusters were receiving a non-neutral control signal, the thrusters could act sporadically and dangerously. The system lacked the ability to deactivate the thrusters without deactivating the entire ROV if running in an undesirable state.

Given all the flaws, a redesign of the electrical and control system was absolutely necessary in order to improve the performance of the ROV. The details are stated in the following sections.

Improved Electrical System

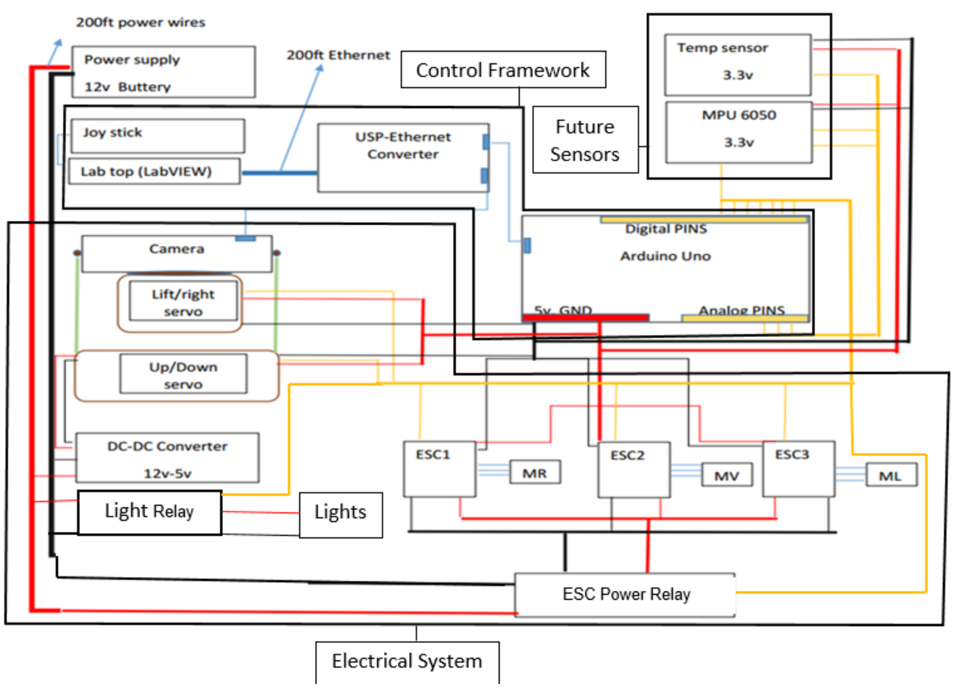

Figure 1. Electrical System Layout Schematic

Fig.1 maps out the connections of the electronic components which make up the electrical system. Some components, such as the temperature sensor, are not currently integrated into the system, but this map shows how they will be included when they are ready to be installed. The improved electrical and control system contains three major portions.

A. Hardware Interface

***Joystick* -** A Logitech Extreme 3D Pro gaming joystick was chosen as the motion control interface because it allows inexperienced student operators to intuitively control the ROV. The abundant buttons provided on this joystick allow for great versatility if additional functionalities are needed later on. The ROV's left and right rotational capability as well as its horizontal linear motion are determined by the position of the stick itself, while its vertical linear movement is determined by the position of the rotatable tab at the base of the joystick. The joystick generates a series of numeric data corresponding to the positions of stick and rotatable tab respectively. The control program will then read and interpret this series of data and send the appropriate control signals to the Arduino.

Data Communication - During a normal operation situation, a laptop will be placed on a boat and the ROV will be operating about 150ft underwater. Sending data merely through USB cable is not viable since data speed and video resolution would be severely degraded over the long distance. To enable efficient data communication, two IOGEAR GUCE64 USB extender units are employed, with the local unit connected to the laptop and the remote unit placed within the ROV. The data is then transmitted between these two units through the Cat5e cable within the tether. These units allow for efficient data communication for a distance up to 164ft.

***Voltage Converter* -** The ROV unit requires a 24V power supply which comes from two surface-side batteries. However, the remote USB extender unit requires an electrical input of 5V at 2A. Therefore, a PYB10-Q24-S5-U DC-DC converter is employed here to for the purpose of voltage conversion so that the remote unit may receive power.

***Microcontroller* -** An Arduino Uno was chosen as the microcontroller for this project. This microcontroller receives LabVIEW commands from the operator and sends appropriate control signals to the devices on the ROV. The list of control actions includes 1) Toggling the LED strips on and off, 2) positioning of the camera through two servo motors, 3) controlling the motion of the ROV by regulating the PWM signals to the Electronic Speed Controllers (ESCs) of the thrusters, and 4) Toggling the ESC voltage control relay. The Arduino Uno has an excess of input and output pins which will allow for simple integration of new sensors and electromechanical structures, such as a robotic arm and gripper.

***Camera* -** A Logitech C310 webcam was chosen to provide visual feedback of the underwater environment for the ROV. The 1280 by 720 pixel video provides a reasonably good resolution for teaching purposes. The camera is mounted to two HiTec HS-85BB+ Mighty Micro servo motors which operate based on PWM signals. The operator can adjust the position of these servos by manipulating a thumb stick which lies on top of the joystick.

***L.E.D. Strips* -** In order to illuminate the underwater environment, twelve 1ft UB-AS-24V L.E.D. strips are installed in the vision acquisition module. These 5.1W/ft strips operate with a supply voltage 24v and are capable of providing 519 lumens of light per foot of strip, which means that the ROV can provide a total of 6,228 lumens. This magnitude of illumination should be able to pierce the murky waters and provide clear visual range for the webcam. When the operator desires to toggle these lights, the Arduino sends a low signal to the Songle SRD-05VDC-SL-C relay, which closes the circuit containing the power supply and the L.E.D. strips. This allows the 24V of the surface side batteries to be dropped across the strips, enabling them illuminate. To deactivate these lights, the Arduino will simply send a high to the relay, which in turn breaks the connection between the power supply and the strips thus turning them off. These strips are highly appropriate for this application as they can provide a high magnitude of light capable of piercing dark environments, operate based on the voltage that is supplied to the ROV, and are physically flexible, thus making them easy to work with and install.

B. Electronic Speed Controllers

In this ROV design, three Turnigy Marine HV-80A B electronic speed controllers (ESCs) are used to control three thrusters. The ESCs are responsible for reading the control signal from the Arduino and sending corresponding power signals to the thrusters with the purpose of controlling their speed and power. The ESCs are supplied with 24V power directly from the marine batteries. The KUP-14D15-24 relay allows the operator to ensure that the ESCs receive a neutral control signal before applying power to the ESCs. Since the ESCs deal with high levels of current up to 6A, they are fused at the positive supply as a precaution against potential surges. The ESCs operate based on PWM control signals, with pulse widths ranging from 1000us to 2000us. When reading a signal that has pulse widths of 1500us the ESC will supply no power to the thruster. When reading a signal that has pulse widths of 2000us the ESC will supply maximum power to the thruster, allowing it to achieve maximum forward propulsion. However, any signal with pulse widths below 1500us will cause the thruster to rotate in the opposite direction and provide reverse propulsion. Therefore, a 1000us pulse signal will cause the thruster to provide maximum reverse propulsion.

C. Thrusters (Electromechanical Operation)

The last electrical components in the electrical system are the CrustCrawler HiFlow_400HFS-L thrusters. They can draw up to 130W of power and approximately 5.28A each and operate on a voltage range of 12V to 50V. With all three at maximum throttle, a total power of 389.48W is drawn. They individually provide 2.72kg of continuous thrust which is enough to allow adequate mobility for the ROV.

D. Servo Motors

The servo responsible for altering the horizontal position of the webcam receives its control signal from output pin 3 and is set to respond to pulses of widths ranging from 700us to 2200us. When the PWM signal pulses are set to 700us the servo will turn the webcam to its leftmost position, while it will turn to its rightmost position when receiving a PWM signal with 2200us pulses. The servo responsible for altering the vertical position of the webcam receives its control signal from output pin 5 and is set to respond to pulse widths ranging from 1080us to 1850us. When the PWM signal pulses are set to 1080us the servo will turn the webcam to its lowest available position, while it will turn to its highest available position when receiving a PWM signal with 1850us pulse widths. This servo is set to respond to a lesser range of pulse widths as the acrylic housing and mounting platform constrain the available range of vertical motion.

However, combined, these two axial ranges provide a great degree of visual coverage for the webcam and observational ability for the operator. Pair this capability with the inexpensive, compact and practical nature of these servo motors and it is evident why this model of servo motor was chosen.

Software and Control System

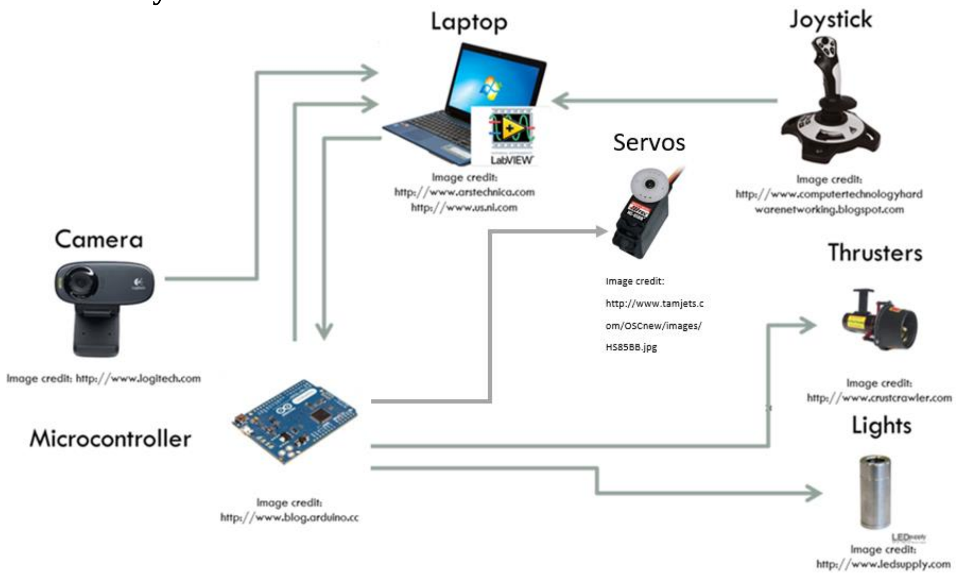

Figure 2. ROV Programming and Control Framework

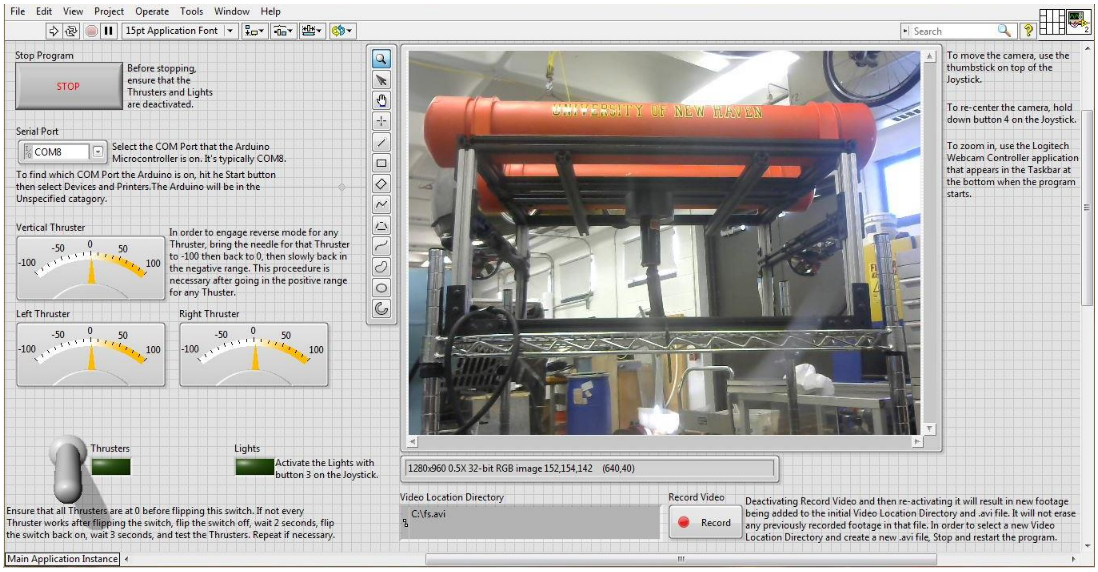

Figure 3. Control Program Front Panel

Fig. 2 displays the Arduino/Thruster communication framework for the ROV. The core control framework consists of the LabVIEW VI as well as the Arduino microcontroller. LabVIEW was the control program of choice due to its extended collection of libraries which deal with hardware communication, as well as the fact that its visual nature allows those not well versed in coding to contribute to the development of a control program. Furthermore, its robust and adaptable nature easily allows for the continued integration of additional functionalities. This LabVIEW VI serves as the mind of the ROV, and is responsible for interpreting all user inputs, sensor data and the status of the ROV. The program is coded in such a way that the only need to interact with the front panel which serves as the user interface. As can be seen from Fig. 3, the front panel is arranged in a simple layout which clearly provides thruster activation, recording, serial port, and stop controls, as well as a display for the video feedback and indicators for the state of the lights and thrusters. The front panel also provides instructions for successful operation next to the relevant front panel elements. A more detailed description of the control and software design can be found in a summer research report[4].

Conclusion

The result of this project is an ROV which proves to be more capable and professional than the previous model, as it has increased data communication capabilities due to the improved USB extenders, more reliable electrical plugs, improved wiring quality, and a heavy duty relay which improves the ROV’s overall safety factor by introducing the ability to toggle on or off the thrusters. Furthermore, the complete electrical system successfully provides all desired functionalities for the ROV and can communicate with the developed LabVIEW control program. After advanced testing and further integration of sensors and functionalities the ROV will be ready to be deployed and utilized as a supplementary educational tool for marine biology students.

References

1. Cowan. Development of a Pedagogical ROV. New Haven: University of New Haven, 2014.
2. Shunaula, Mino, Sandor, and Brundage. Development of an Underwater ROV. New Haven: University of New Haven, 2015.
3. Tafuri, Bielesz, Alshammari, Alshamarri, Alsaban, Aldossary, Alwaleedi, and Riyadh. Remotely Operated Vehicle (Seahorse). New Haven: University of New Haven, 2016.
4. Miller. Development of a Modular Multi-Task ROV for Marine Biology Education. SURF Report, New Haven: University of New Haven, 2016.

Biographical Information

1. Victor Miller is currently a junior Electrical Engineer at the University of New Haven and started his education in the field of electronics at Platt Technical High School in Milford, Connecticut. He aims to continue work on the ROV and see it to fruition.
2. Qing Li has unique cross-disciplinary educational backgrounds in Mechatronics Engineering (Control and Robotics) and Educational Psychology (Educational Program Measurement and Assessment). In her career path, she has gained extensive research experience in Mechatronics, Robotics, Control, Engineering Design, and Artificial Intelligence. She has taught a broad range of courses in general engineering, kinematics and dynamics, systems and control, robotics and mechatronics at universities in Australia, Singapore, and US. She has also accumulated a rich experience in international joint degree program coordination and international student supervision.