iPad Interface for Remotely Operated Vehicles

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SeaPerch remotely operated vehicles (ROVs) are intentionally simple; they employ minimum technology as they are educational tools. The current SeaPerch design is difficult to transport to remote locations, and makes no accommodation for a camera. An improved system was designed, centering on an Apple iPad interface, to emphasize portability while adding a camera and improving performance. This article discusses the construction of this instrument and gives rationales for design features and considerations. In addition, this article discusses performance of this instrument by analyzing power output and rise time for three controlled motors. Power output was found to be fairly consistent between the three electronic speed controllers (ESCs) used, with a maximum forward power output of 19.34 Watts. The reverse maximum power output was found to be 13.49 Watts. Mean forward rise time was found to be 0.985 seconds with a standard deviation of 0.166 seconds. Mean reverse rise time was found to be 1.001 seconds with a standard deviation of 0.130 seconds. Stock SeaPerch forward and reverse power output was found to be 45.6 and 44.8 Watts respectively. Forward and reverse rise times of 0.995 and 1.00 seconds respectively were also found. The power discrepancy between the two systems is a result of the differing batteries used. The stock SeaPerch uses a 12 V battery, while the developed system uses a 7.2 V battery. Power in the new system could be increased with a higher voltage battery. With this data and analysis, the developed system is found to be a functional and innovative alternative to the typical SeaPerch control system.

Introduction

The purpose of a remotely controlled vehicle (ROV) is to act as an extension of the user. The ROV should return as much data as possible, therefore "communication with the ROV is probably the most critical aspect of vehicle design" (Christ, 2007). To reduce cost and complexity, the ROVs built as part of the SeaPerch program lack such a feature, hindering communication between the ROV and the user. This is understandable because the SeaPerch program is aimed at teaching the younger generations of students basic principles of science and engineering rather than providing the most effective ROV. However, advances in technology have made state-of-the-art products prevalent in schools and classrooms, causing students to expect and desire technologically advanced interactions. These students are able to learn more than just the basics of science and engineering and would appreciate an innovative teaching medium; in this case, an improved SeaPerch design.

The lack of video streaming on a SeaPerch leaves the operator to pilot the ROV essentially blind from the surface. Refraction occurs due to the change in medium from air to water, which greatly hinders user vision and control. To alleviate this issue, most ROV systems use a charge-coupled device (CCD) paired with some sort of monitor at the surface. CCD cameras capture varying light intensities on an array of capacitors, which are then transferred through varying circuitry to the monitor (Christ, 2007). Differing systems exist, but most rely on the same principle of a small camera tethered to a monitor at the surface.

These monitors can be bulky and difficult to transport to the lakes and other remote bodies of water where ROVs are commonly used.

The control system of the SeaPerch is also lacking. A simple printed circuit board (PCB) meets the requirements at a low cost, but also offers students little insight into the principles of electricity. The current system works well, but is dependent on a large and cumbersome 12-volt battery. This battery is useful for providing lasting power, but becomes impractical to transport if the ROV is to be used in remote locations.

Given the weaknesses of the typical SeaPerch, a streamlined remote viewing and control system was researched and developed. Considerations were made in design to accommodate the technology advancements of many schools. These advances are seen in schools such as Dixon Middle School in Provo, UT, where each student is issued an Apple iPad for school use. To use available resources, streamline design, and to pique students' interest, the new SeaPerch system hinges on an iPad interface onto which video and virtual control joysticks are streamed.

Not only does this system allow students greater exposure to principles of electricity and robotics, it fosters interaction and collaboration. Up to five iPads can connect to a single SeaPerch while sharing video feed and motor controls.

Goals

This research and development is centered on creating an innovative SeaPerch control interface, so certain constraints were assumed. The system was designed to be simple enough that a middle school student would have little difficulty understanding and building their own. Readily available, off-the-shelf parts would be used to promote simplicity. The system would be as compact as possible to avoid hindering transport and usability of the SeaPerch. Finally, the system would perform as well or better than the current system.

Materials and Methods

After extensive research into the availability and capabilities of current remote control technology, the Dension WiRC was chosen as the foundation of the system. The WiRC is a wireless receiver paired with a webcam and iOS application designed for remote control models. This avenue was selected to avoid custom development of an iOS application. Creating a custom application would make total development time unfeasible. Furthermore, requiring application development would be prohibitive to others interested in this system. The WiRC application allows for the streaming and recording of video from a webcam directly to the iPad. Both the video feed and control signal are transmitted through an ad hoc Wi-Fi network. Ad hoc networks are created by motes, which "combine the functions of sensing, computing, and wireless communication into miniature smart sensor nodes" (Kumar, et al., 2008). Ad hoc networks require less equipment, and are therefore mobile. The WiRC provided a simple solution to many issues, while meeting the assumed constraints.

To power the system, a 7.2 V 1800 mAh nickel cadmium (NiCd) battery was selected. This battery is cheap and small enough to be mounted to the SeaPerch, rather than remaining ashore with the user. While there are smaller and more powerful batteries available, a NiCd battery was chosen to avoid the complicated charging procedures and potentially dangerous operation of other battery types. NiCd batteries supply high peak power and are commonly used in other electronic products (Ovshinsky et al, 1997) while being easily maintained. This is a perfect battery for use by middle school students.

The motors supplied in the SeaPerch kit are 12 V DC brushed motors. To control these motors electronic speed controllers (ESCs) are required. An ESC allows control of a DC motor by employing pulse-width modulation (PWM). In PWM, time is divided into increments. During each increment, the ESC supplies a voltage to the motor. This method of supplying voltage allows for proportional control of a motor (McDonough, 1998). The user is able to increase voltage sent in each increment to speed up the motor, or reduce voltage to slow down the motor. By decreasing the increment time, control becomes more continuous; as time increments approach zero, the input signal to the ESC resembles an analog signal rather than discrete voltage levels. To control the SeaPerch motors, the HPI SC-15WP ESC was chosen. This ESC is commonly used in remote controlled cars, and has the advantage of allowing for forward and reverse control as well as being relatively waterproof. Each motor of the SeaPerch must be controlled independently. Therefore three ESCs are required for full maneuverability.

To put these parts together into a functional SeaPerch, a wiring harness was also required. The wiring harness was created using 14-awg wires with "Deans" connectors. In addition to these parts, a wide mouth Mason jar was employed as a housing. Refer to the appendix for a complete list of parts, costs, and potential sources of parts.

Instrument Setup

Per material specifications above, and following subsequent instructions, the control system was created. If additional instruction is required, reference the how-to video titled "iPad SeaPerch" on YouTube.

1. Cut positive battery lead near connector taking care to avoid contact with negative battery lead. Tape positive lead out of the way.
2. Cut negative battery lead near connector and strip ~5mm of wire casing from end. Slide heat shrink tubing onto wire. Solder to negative marked terminal of new female Deans connector. Position heat shrink tubing over connection and heat to cover connection.
3. Strip ~5mm of wire casing from positive lead. Slide heat shrink tubing onto wire and solder to remaining connector terminal. Cover with heat shrink tubing.
4. Obtain an ESC. Cut wires near the white connector. Following the same process completed on the battery, solder positive wire to the positive terminal of a male Deans connector, and negative wire to negative terminal.
5. Repeat step 4 for two remaining ESC's.
6. On two of the three ESCs, remove red wire from receiver connector using a small blade and tape back.
7. Using soldering technique as previously described, construct the wiring harness as outlined in Fig. 1. Take care to properly heat shrink each connection. Use male bullet connectors to connect harness to each ESC.
8. Assemble components as outlined in Figures 1 through 3.
9. In the lid of the wide mouth Mason jar, remove a circle of material 2.0" in diameter. Pass PVC reducer bushing through created hole and seal with plumber's goop and liquid tape.
10. Arrange components and fasten with tape or Velcro strips as shown in Figure 3.
11. Pass cables through remaining PVC flange and fill hole with wax. Fill remaining space with epoxy as shown in Figures 4 and 5and let cure.

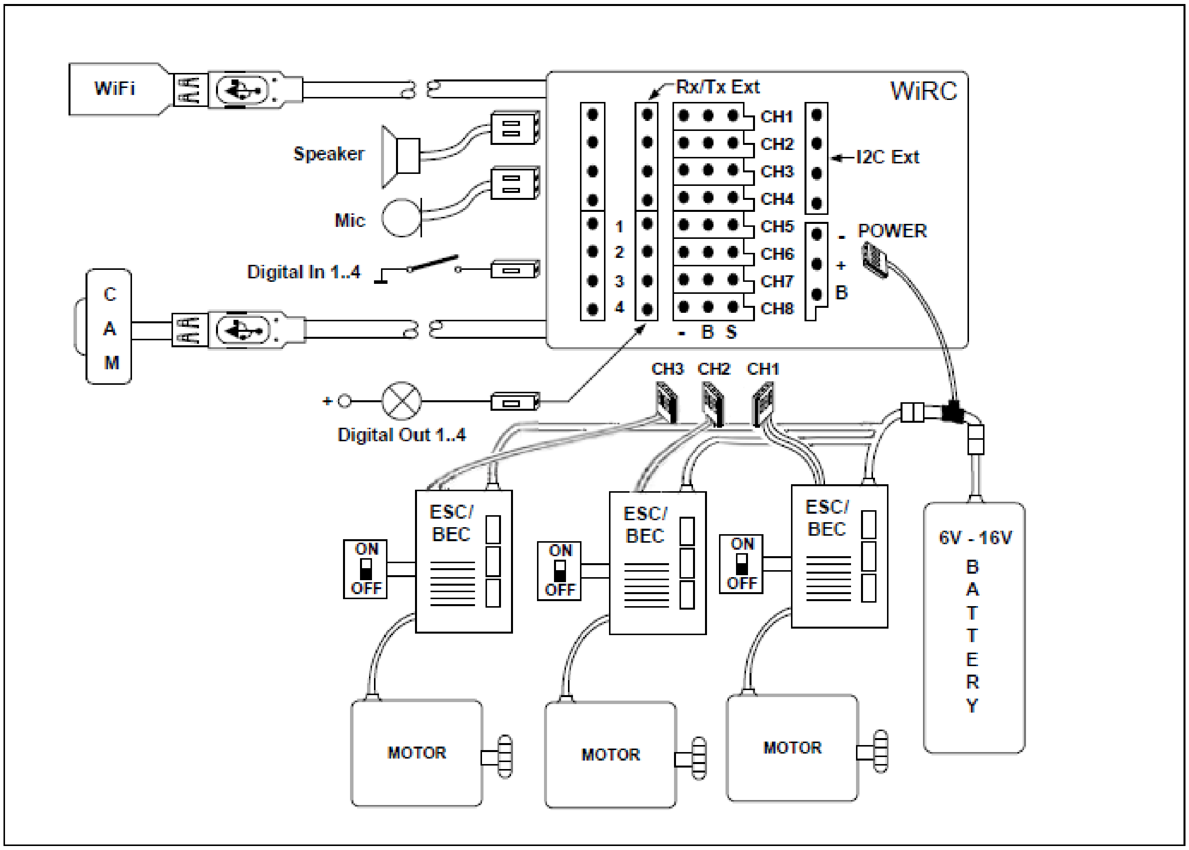

Figure 1. Instrument Schematic (original image courtesy of Dension Audio Systems).

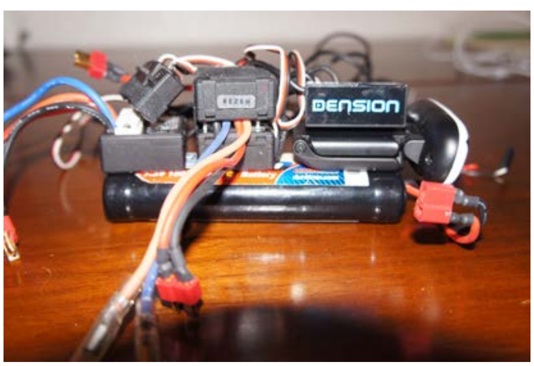

Figure 2. Instrument Layout

Figure 3. Assembled Instrument

Figure 4. Housing and Tether Cable

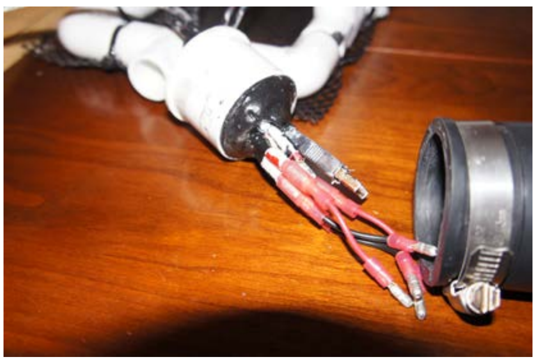

Figure 5. Tether Cable Seal

Experimental Setup

To evaluate instrument quality, two factors were tested: motor power output and motor rise time. Using only these two factors, maneuverability and performance of this system can be analyzed. Each ESC, designated by its serial number, was tested individually with the same motor to isolate ESC performance rather than motor performance. It is assumed each motor has similar resistance and properties.

The instrument was designed and built so that each motor was wired in parallel with the other motors. Kirchhoff's voltage law shows that elements in parallel branches of a circuit will have the same voltage (Rizzoni, 2007). Each motor was given the same input voltage to produce similar outputs and avoid motor bias.

To test power output from each motor, the voltage at varying throttle positions was found using a multimeter attached to the motor terminals. Both the forward and reverse voltages were found as well as resistance of the motor.

Also considered in performance is the rise time of each motor control. Rise time is defined as "the time it takes for a signal to rise to a given percent of the steady output" (Figliola, 2011). Steady output was assumed to be the previously measured output voltages. The 90% rise time was found by measuring the time required for the motor output voltage to enter 90% of the steady output.

Results and Discussion

Power Output

The measured voltages were related to the resistance of the motor using the following equation:

$$P = \frac{V^2}{R}$$

where P is power (in watts), V is voltage, and R is resistance (in ohms). Resistance of the test motor was measured to be 2.9 Ω. The measured motor output voltages can be seen in Figure 6. Power outputs were calculated for both forward and reverse at varying throttle positions. These results can be seen in Figure 7.

As can be seen in Figures 6 and 7, each ESC produces a similar output curve. This is to be expected, as power is directly related to voltage. However, significant differences can be found between the controllers. Each motor control produced a max output power of 19.3 Watts, but this output was reached at different positions of the throttle. Both N5329 and H9238 had very similar forward power curves, and reached full power at ~55% throttle. This contrasted with X1512, which didn't reach full power until ~70%.

Reverse power output had significant variance. X1512 and N5329 had similar max power outputs of 15.51 and 14.91 Watts respectively; but reached these values at significantly different throttle positions. H9238 produced considerably weaker results; it only reached a max power of 10.31Watts, much less than its counterparts' power. To produce reverse power, the ESC must switch the polarity of the motor. In this process some of the input voltage is not transferred to the motor, and this loss is seen with the lower reverse powers from all three ESCs.

Reverse power variance is not a significant issue in maneuverability if taken into consideration in instrument set up. If X1512 and N5329 are designated to be the forward/reverse thrusters while H9238 is the vertical thruster, no imbalance of power will occur. While exactly equal forward and reverse powers would be ideal, with these ESCs it cannot be obtained without modification. When compared to the total performance, reverse power loss becomes a minor issue.

Data from the stock SeaPerch control system was also collected. Forward output voltage was found to be 11.5 V and reverse output voltage was found to be 11.4 V. These voltages correspond to a forward power of 45.6 Watts and a reverse power of 44.8 Watts. Comparing these values to the other measured values, it is apparent a stock SeaPerch produces more power. The difference lies in the chosen battery for the instrument. The stock SeaPerch battery supplies 12 V, compared to the 7.2 V output of the battery used in this instrument.

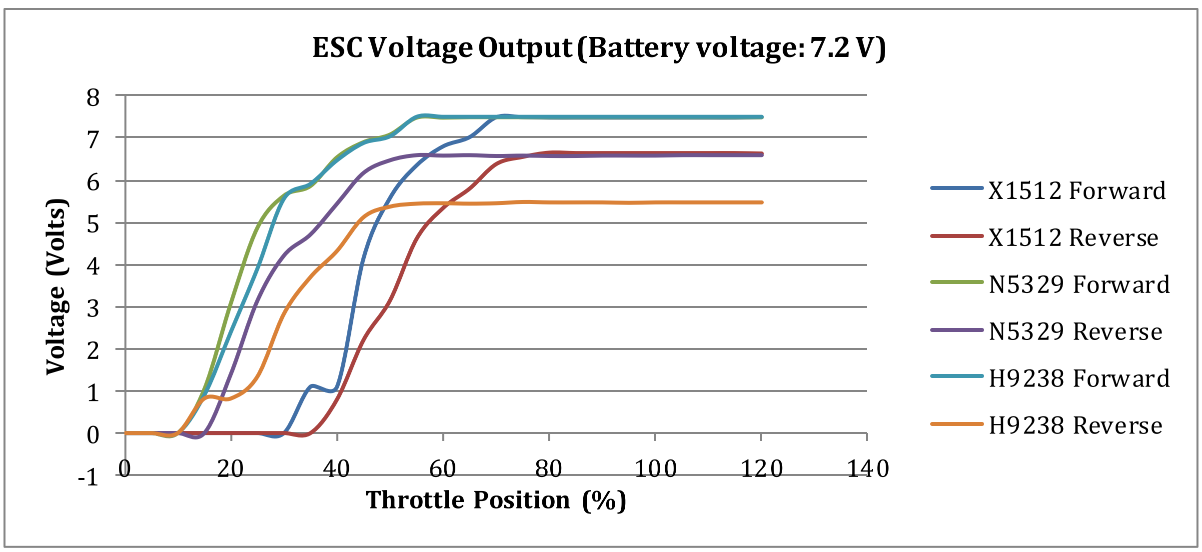

Figure 6. Graph of forward and reverse output voltage from three ESCs at variable throttle positions.

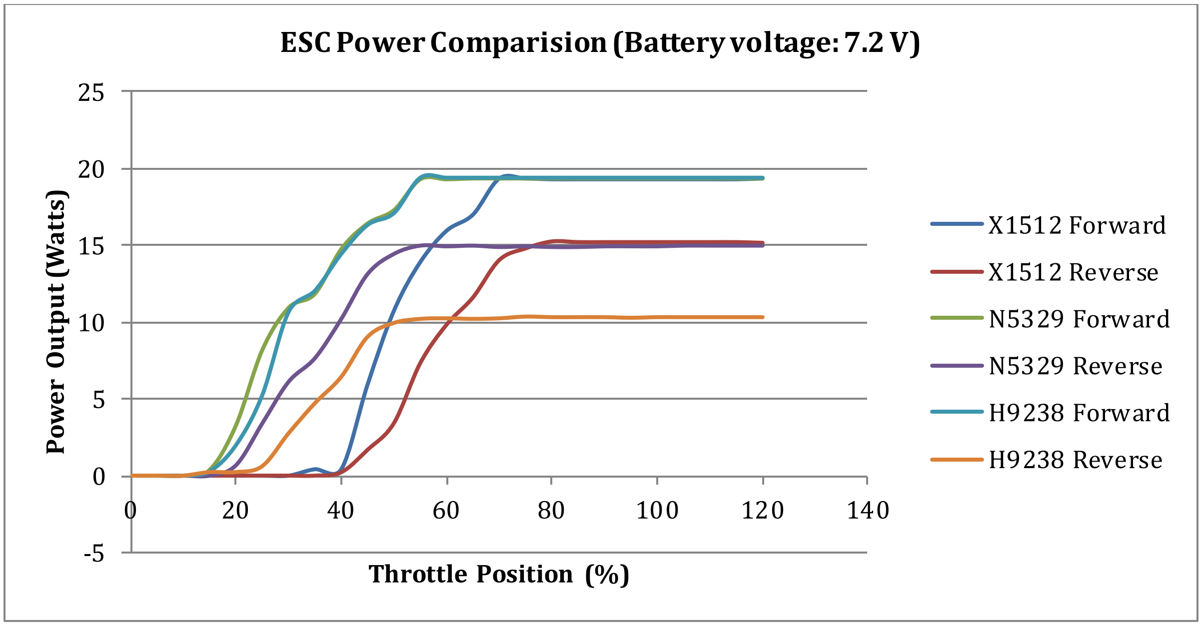

Figure 7. Graph of power output compared to throttle position from three ESCs. Each ESC yielded similarly shaped curves. Throttle position at which max power is reached varies between each ESC.

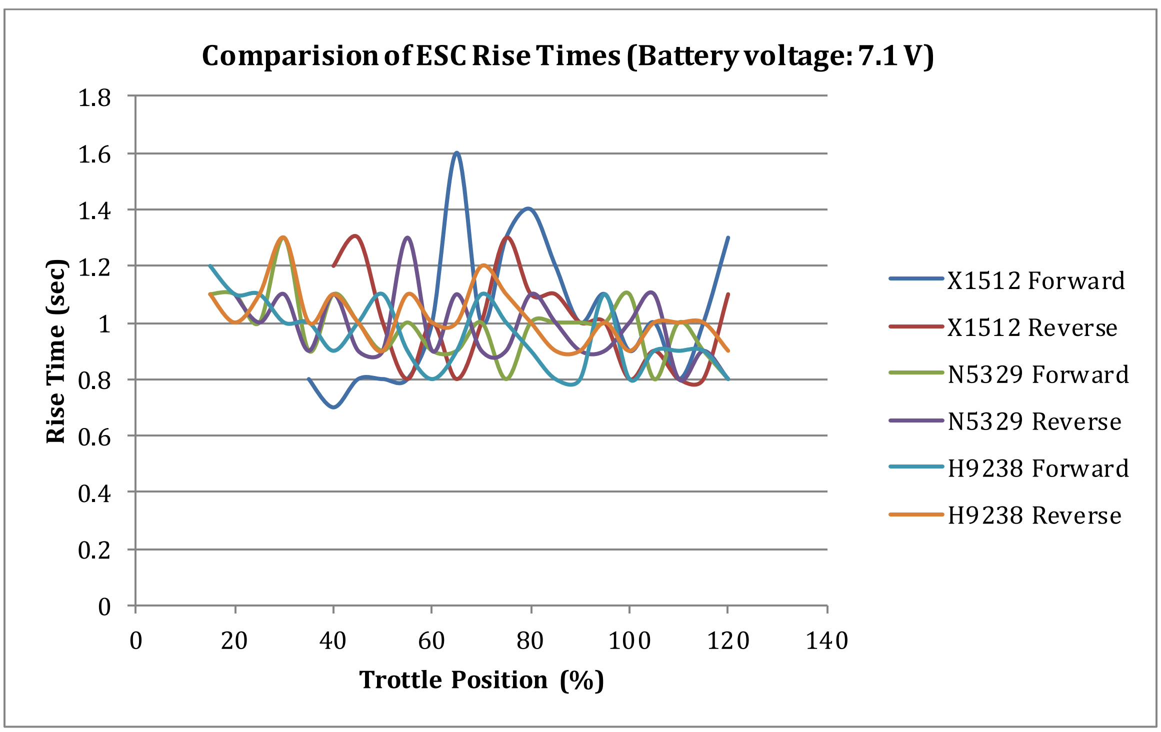

Figure 8. Graph of the time required for three ESCs (in both forward and reverse) to reach the previously measured steady output voltage for varying throttle positions. The mean forward rise time was found to be 0.985 seconds with a standard deviation of 0.166 seconds. Mean reverse rise time was found to be 1.001 seconds with a standard deviation of 0.130 seconds

Rise Time

The measured 90% rise times were found using the measured voltages at varying throttle positions and are shown in Figure 8.

From these results we see rise times were fairly consistent; the mean forward rise time was found to be 0.985 seconds with a standard deviation of 0.166 seconds. The mean reverse rise time was found to be 1.001 seconds with a standard deviation of 0.130 seconds. Outliers exist, but could easily be attributed to inaccurate time measurement or time lag inherent in the multimeter. These results show the 90% rise time to be essentially independent of output voltage and throttle position. This means motor response at both low and high throttle will be essentially the same, a major contributor to predictable and consistent performance.

The mean forward rise time at 100% throttle of the stock SeaPerch was found to be 0.995 seconds with a standard deviation of 0.153 seconds. The mean reverse rise time was found to be 1.00 seconds with a standard deviation of 0.163 seconds. These values are very comparable to the rise times of the new instrument. Both systems respond to inputs in a similar manner.

Conclusion

Analysis of these results illustrates the inconsistencies between the ESCs. While maximum power output and rise times are essentially the same for each tested ESC, throttle position at which these values are first achieved varies greatly. Each ESC was wired in parallel; thus similar voltage and power outputs between ESCs were expected. Actual results deviated from this hypothesis. These differences could result from inconsistencies in resistance of the ESCs, or voltage losses along the wiring harness. This could cause issues in precision movement, as more power is available to one motor before another. While an important issue to note, it is less important in this application as a SeaPerch is not designed for precision movement.

Rise time measurement data is useful for relative comparisons between ESCs. The exact rise time is less important than the fact that the rise time is consistent between controllers. Each ESC reaches the output voltage corresponding to input throttle position at relatively the same time, resulting in consistent control.

From the data, it is clear that this iteration of control system is less powerful than the stock system. This weakness is easily explained by examining the capabilities of the batteries. Should the user require greater power output, a higher voltage NiCd battery could be used. Alternatively, a different type of battery could be considered. While not used in this iteration of the system due to cost and potential safety concerns, lithium-ion or lithium-polymer batteries could be employed. Lithium-ion and lithium-polymer batteries have higher energy densities than NiCd batteries, and can thus provide the higher voltages in a smaller size than a NiCd battery (Buchmann). To improve this instrument's performance, a higher voltage NiCd or lithium-polymer battery is recommended.

There are shortcomings and potential for improvement, but this developed instrument is superior to the stock SeaPerch control system. The most obvious improvement is the addition of a camera. With a camera, the user has a greater degree of control, as they better understand the actual position of the ROV. Additionally, data can be collected and recorded.

This system also allows for a greater degree of control than the stock system through proportional control. The user can select what power the motors will output by adjusting throttle percentage. Controls can be trimmed and modified to the user's preference. Specific maneuvers can be programmed into the application and executed at the touch of a button. Additional instruments, such as arms, sensors or additional motors can be added to the SeaPerch and controlled by this system with ease.

Additionally, this system better meets the educational goals of the SeaPerch program. Students may find stock SeaPerch control tedious as the technology can seem archaic in light of recent technological advances. This new system provides students with fun and exciting technology. Students learn more about the principles of electricity as they build a wiring harness. They control a ROV wirelessly through an iPad and are able to see what the ROV sees. One student can control from an iPad while another streams the video feed to his iPhone. Control can be transferred from one device to another. These features can make the students interested in the technology causing them to take initiative in their own learning, which can lead to greater educational opportunities. Students may desire to learn more about DC motor control and performance or wireless networking. For these reasons, this instrument is a functional and innovative alternative to the stock SeaPerch control system.

Acknowledgements

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Appendix

Complete parts list with costs and potential sources:

PN	Qty	Descripton	Cost	Source
1	1	Dension WiRC receiver with Wifi Dongle and Webcam	$150.00	amazon.com
2	3	HPI SC 15-WP Electronic Speed Control	$25.00 ea.	ebay.com
3	1	7.2V 1800mAh NiCd Battery Pack	$11.99	rcplanet.com
4	4	Deans Ultra Plug	$2.95 ea.	rcplanet.com
5	1	16 ft. USB Repeater Cable	$8.99	amazon.com
6	1	Wide Mouth Mason Jar	$2.50	Hobby Lobby
7	2	2 in x 1/2 in. PVC Reducer Bushing	$0.98 ea.	Home Depot
8	1	2 in ID by 6 in Rubber hose	$3.99	Home Depot
9	2	2 in ID Hose Clamps		Included with Hose
10	1	SeaPerch Build Kit		Supplied
11	N/A	Velcro strips	$1.50	Home Depot
12	N/A	Epoxy	$3.99	Home Depot
13	1	Box of 18-22 gauge Male Bullet Connectors	$1.49	Home Depot
14	N/A	Toilet Bowl Gasket Wax		Supplied with SeaPerch Kit
		Total Cost:	$273.29	