Development of Educational Marine Soft Robotics STEM Platform as New Iteration of SeaPerch K-12 National Outreach Program

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***Abstract*—In the past thirty years, educational programs like the Massachusetts Institute of Technology/Office of Naval Research's SeaPerch have been effective at introducing students to robotics, science and engineering concepts through low-cost, hands-on curricula [1], [2]. These programs have been integral in preparing students to pursue degrees and careers in STEM that meet the needs of a 21st century global economy [3]. In order to address rapid technological growth and our dynamic digital climate, such vital STEM educational opportunities must continuously evolve to provide students the tools necessary for meaningful engagement within a future global workforce.**

First developed at MIT Sea Grant three decades ago, the SeaPerch program was a novel approach at hands-on project based learning with a STEM curriculum for K-12 audiences. Students built their own remotely operated vehicle (ROV) unit with low-budget materials and learned about concepts such as buoyancy and circuits while being given the opportunity to compete in design challenges that built off the base SeaPerch unit [4].

Returning to the roots of the program, MIT Sea Grant is again investing in the fundamental ideas behind SeaPerch by developing SeaPerch II in order to keep up with emerging and even since-established advances in technology. We found soft robotics and Arduino microcontrollers to be the most suitable areas of focus which further increase exposure to STEM topics at the K-12 level. The redesign will include the implementation of tiers in the curriculum, which will help cater to different ages and experience levels. SeaPerch II will emphasize the iterative model of design engineering with opportunities for students to take creative direction by exploring these universal and utile technologies.

SeaPerch II will bridge the gap between the previous educational modules of SeaPerch and advances in emerging technologies. Introducing innovative science to students at an earlier age in an accessible, low-cost manner will increase the diversity of STEM programs and will reinforce interest and awareness in pursuing careers in STEM. SeaPerch II serves to inspire the next generation as well as contribute to the decentralization of robotic systems and their dissemination into the public domain.

***Keywords*—STEM Education, SeaPerch, Soft Robotics, Arduino, Sensors, Marine Engineering Education**

I. Introduction and Background

Incorporating modern developments in technology into education is necessarily at the forefront of scientific progress. Therefore, it is critical to update successful educational programs to include currently relevant technology and subjects. The SeaPerch program consists of an underwater robotics kit with supporting educational materials which guides educators and students to build their own underwater remotely operated vehicle (ROV). The program's main function is to "reduce traditional barriers to participation in robotics programs and promote…inquiry-based learning with real-world applications" [5]. Since it was first conceived in the 1990's, SeaPerch has been picked up and adapted by groups like the Association for Unmanned Vehicle Systems International Foundation (AUVSI) for a widespread national and international audience. SeaPerch has reached thousands over the span of decades and has become a rich community of students and educators with an established infrastructure [6].

However, technological capabilities have greatly increased since SeaPerch's initial design. Including new modules which display such capabilities would inspire even more student growth and preparedness for future careers. The two areas of technological advancement we found to be most relevant to Seaperch's vision are soft robotics and Arduino microcontrollers [7], [8]. As such, SeaPerch II includes modules that build on these ideas.

In an effort to increase the breadth of program engagement, we have developed SeaPerch II to enable young scientists to take their creations to the field and make discoveries in their communities using a modular set of instruments. The program's core learning values are laid out in several modules which are designed to accommodate students of different experience levels and will be disseminated with educators in mind. The modules will include Arduino-enabled sensors for the higher levels and soft robotic actuators throughout all levels.

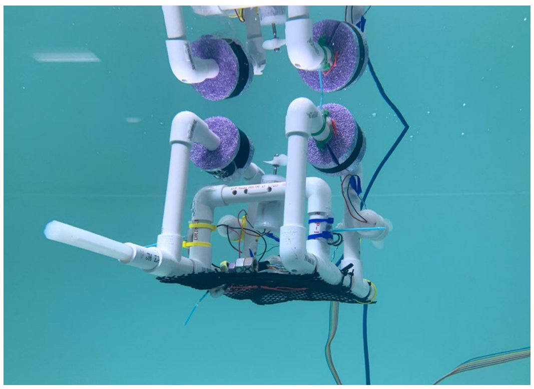

Fig 1. SeaPerch II ROV Unit.

In response to the increasing importance of computer science since SeaPerch's early development in the 1980s and '90s, we are establishing a roadmap towards autonomy by creating a series of modules which build on each other and utilize the capabilities of Arduino microcontrollers. Since the design of SeaPerch's curriculum, there have been major advances in microprocessing capabilities resulting in lower barriers to use. Sea Perch II will use the user-friendly, open-source interactive Arduino hardware and software to help students understand the construction of circuits and basic programming principles. Much like SeaPerch's well-established community infrastructure, Arduino has a rich volume of resources that students can reference to help them innovate with their ROV designs. The Arduino module will provide an introduction to feedback control and sensor integration that gives students a solid foundation for electromechanical systems.

SeaPerch II will also allow students to experiment with state-of-the-art soft robotic technology which has far-reaching applications, especially piquing the interest of the marine sector [9]. We are developing silicone-based soft robotic modules for gripping actuation that aim to introduce students to this emerging paradigm in robotics. The most accessible versions of the soft robotics module will only require standard classroom supplies along with easily obtained castable silicone. More complex implementations of the module are also available, which require 3D printed molds for casting the silicone. By covering the fundamentals of soft robotics, we hope to encourage students to design, prototype, and test their own soft robotic actuators. The modules will prepare students for soft robotics' increasing prevalence as a technology.

SeaPerch II will expand accessibility and relevance of ocean robotics to classrooms while enriching the existing community of the original SeaPerch program. The following sections describe the design, roadmap, and development of the new SeaPerch II modules, as well as our findings and areas for future improvement.

Fig. 2. Students participating a in SeaPerch challenge [10].

II. Program Design and Roadmap

The SeaPerch program was successful in part due to its simplicity and effectiveness. With SeaPerch II, we strive to maintain these two facets of the original program while simultaneously adapting to how the world has evolved since SeaPerch's initial inception. We want to provide a path to higher levels of technology without compromising the original SeaPerch mission. Through a series of quarterly incremental improvements to the existing SeaPerch platform, the SeaPerch II modules will be made available to teachers starting with update and additive modules, then integrating the modules into basic feedback control and eventually an integrated system that gives the SeaPerch ROV a level of autonomy.

A continued focus of the updated modules is for learners of all ages to have the opportunity to engage with their environments in ways that optimize their potential for discovery. All of SeaPerch II's modules strive towards this goal and are thoroughly backed by support materials that we continue to test, adapt, and improve as the community embraces these new capabilities.

One of the most critical components of SeaPerch II are the supporting materials that have been synthesized in order to walk students and educators through the implementation of any of the new modules. These materials should ensure that students are given freedom and encouragement to explore the design approach of the SeaPerch II modules from a critical perspective while aid is provided wherever necessary.

SeaPerch II is designed with educators and students in mind, ensuring it works with existing SeaPerch programs in the field today. For example, if an educator teaches different grade levels and doesn't want to detract from what they are already doing, we provide a structure that allows for gradual additive implementation. The first level is the entirely new sensors or soft actuator modules one can add to the SeaPerch with which they are familiar. Then if the educator decides they want a more complex project for more advanced students, they can move forward with our forthcoming high level modules which will include the autonomous depth maintenance and obstacle detection.

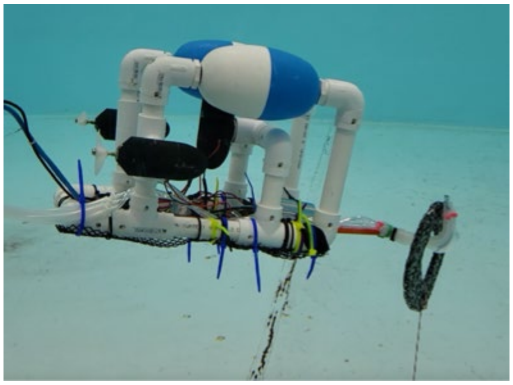

Fig. 3. Image of SeaPerch vehicle with soft robotic three-chambered pen gripper module testing.

The modules will be continuously developed and released on the MIT Sea Grant website every quarter. These quarterly releases will consist of new modules as well as associated educational materials, videos, documentation and more. In some cases these may be entirely new modules like the soft robotic actuators, or in others they may be updated versions of a pre-existing module.

We hope that seeing the different alternatives to the same modules will help students feel capable and comfortable as they take the design of these components into their own creative hands. Once learners have attained familiarity with the fundamentals of soft robotics and electronic systems that SeaPerch II provides, they can use these concepts to construct ROV units that are uniquely their own using an iterative model of design in the same way that students currently do for SeaPerch, except now with more tools under their belt.

Introducing students to these new technologies produces benefits far beyond their applications in SeaPerch II. Bringing soft robotics, casting silicone, and Arduino into classrooms is part of a larger shift occurring in STEM as a whole [7], [8]. SeaPerch II is meant to serve as a lens which concentrates a wave of novel engineering materials and methods into an accessible and digestible platform.

III. Modules

A. Overview

This update aims to increase the functionality of a SeaPerch ROV while remaining true to the core principles of SeaPerch. We have taken new technologies and adapted them to the platform which allows students to interact with objects using soft actuators, record data with sensors not previously accessible, and explore marine environments using their SeaPerch ROV.

A fundamental update made to the SeaPerch curriculum is the castable silicone material that is utilized for sensors and soft robotic actuators. We have selected the Smooth-On Ecoflex 00-30 castable silicone due to its availability and versatility. This flexible and extensible material has been used for soft robotics in the past and creates a low barrier of entry into the field of soft robotic actuation due to its ease of use [11].

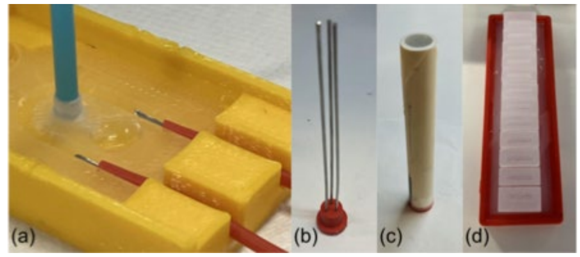

Fig. 4. A-D. Various uses of silicone in Sea Perch II modules: (a) whisker sensor mold, (b) PVC pipe gripper mold, (c) PVC gripper casting, (d) chambered network gripper casting.

The soft robotic actuators are another core component of the program update. SeaPerch's three configurations of soft actuators allow students to interact with objects in classroom challenges or marine environments by pairing the actuators to the motion of the chassis.

Additionally, Sea Perch II electronics include specially repurposed sensors. SeaPerch II takes generic, inexpensive, open-air sensors that are commonly used in introductory surface autonomous systems and adapts them with economical waterproofing methods enabling an underwater autonomous learning experience.

The updated program also required development of waterproofing methods for a cost-effective, open-air pressure sensor that works with Sharp IR Sensors in underwater environments. The pressure sensor is waterproofed using some common materials like a balloon and a pill bottle as its case, whereas we developed two ways to waterproof the IR sensor: one using an acrylic box, and the other using plastic wrap.

SeaPerch II notably utilizes a new sensor which was developed entirely in-house with the casting silicone. The whisker sensor is a touch sensor that detects distortions on SeaPerch; students can easily build it by combining everyday materials, a 3D printed mold, and the Ecoflex 00-30 silicone rubber. Particular consideration was given to ensuring these sensors are effective for SeaPerch yet not costly to students.

Fig. 5. SeaPerch II ROV outfitted with whisker sensors (left). Educational Demo for pressure sensor (right).

Another important consideration with this update was the growing accessibility of 3D printing technologies. This increasingly ubiquitous technology is incorporated into SeaPerch II modules to ensure there are generally methods that do not require 3D printer access, but included are other methods which take advantage of this revolutionary fabrication process.

All of these different components come together to impart fundamental concepts and experience to our entire learner base, providing the room necessary for students to expand upon those concepts.

B. Waterproof Motors

The largest change to the core SeaPerch modules is the motor waterproofing methodology. All new methods to seal the motors utilize the same Smooth-On Ecoflex 00-30 Silicone. Additionally, 3D printing is incorporated into SeaPerch II motors as an alternative but not primary method for fabrication so as not to limit students without a 3D printer.

Fig. 6. Materials necessary for casting with EcoFlex silicone rubber.

There are three main methods of waterproofing the motors. The first uses the original SeaPerch film canister and the silicone to seal in the classic SeaPerch 12V DC motor without wax. Similarly, the second method uses a pill bottle and the silicone to seal the motors. The third method uses a 3D printed mold to cast the motor in a silicone encasing so that it can move freely with a soft exterior. By supporting these different methods, we hope to cater to students' experience level and on-hand materials as much as possible to increase accessibility of the program.

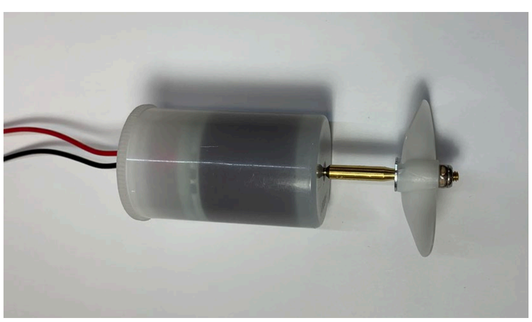

Fig. 7. Updated Waterproof Motor in a film canister using the Ecoflex 00-30 Silicone as a sealant.

C. Soft Robotic Grippers

An entirely new item on the SeaPerch roster is the soft robotic actuators. The fundamental concern of soft robotics is the construction of physically flexible systems. Working with alternate materials can shift the paradigm of what students consider to be robotics, and it opens doors to unique biomimicry applications. However, there are very limited soft robotic educational materials which are accessible to classrooms and tailored towards a large range of age groups. Due to these factors, we developed three separate actuators as part of the Sea Perch II soft robotics modules. The construction of the two main actuators (a PVC pipe gripper and a chamber network gripper) require basic 3D printing capabilities and some materials that are already being used in SeaPerch II. The third actuator mold (a three-chambered pen gripper) only requires common classroom materials and is more simply assembled and customized.

a) PVC Pipe Gripper: The simplest soft actuator that we developed is a PVC pipe gripper. It uses a PVC pipe for its structure and three small metal rods for the chambers, which are used for actuation. Two 3D printed end caps go on each end of the PVC pipe to position the rod chamber-molds accordingly. This actuator has three separate chambers which can all be inflated to operate the tentacle using vinyl tubing (which is inserted and zip tied off) and controlled by three craft syringes. Its three degrees of freedom make this actuator the ideal choice for a multipurpose SeaPerch II ROV seeing as it can curl in nearly any direction.

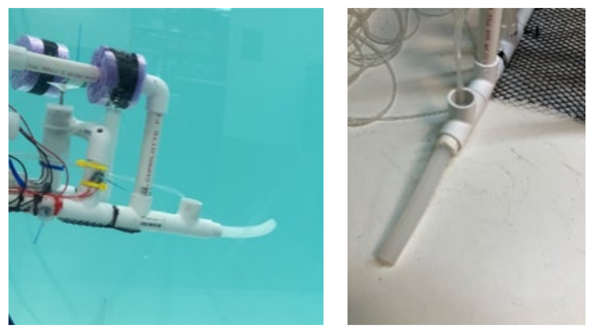

Fig. 8. PVC Pipe Gripper mounted on SeaPerch ROV.

b) Three-Chambered Pen Gripper: The most accessible soft robot included in the new module is the three-chambered pen actuator, cast using parts from common pens, which can grasp small objects. This design is based off of Instructables and YouTube content developed by Harrison Young [12]. It shares similar capabilities with SeaPerch II's other three-chambered actuator. Each individual chamber is cast using standard BIC ballpoint pens or similar pen models, with the inkwell forming the interior chamber. The three chambers are then joined with more silicone to create the final product. A flexible tube is placed within each chamber, zip-tied to create a seal, and then controlled using three separate craft syringes. Since each individual chamber is manufactured separately, students can creatively configure the chambers to make compound actuators with more degrees of freedom.

equipped with a fully functional depth sensor up to 12 meters. This opens up the possibility of both providing depth feedback to students (which is a key element in exploring new terrains or simply operating an underwater ROV in general) and having the ROV autonomously maintain a certain depth at any level.

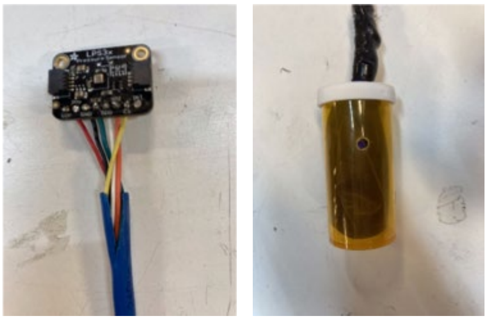

Fig. 12. Pressure sensor without waterproof casing (left) and with the pill bottle, balloon and butyl tape enclosure (right).

c) Whisker Sensors: The whisker sensor is a physical touch sensor that functions using soft robotics. Originally developed to mimic seal/cat whiskers, this iteration consists of a layer of conductive grease connected to wires in between two layers of Ecoflex 00-30 silicone, with a cotton swab protruding from the silicone acting as the "whisker." Fundamentally, the whisker is a variable resistor that increases resistance when the cotton swab is struck due to stretching of the silicone and grease. When set up in a specific circuit, this increase in resistance can be constantly monitored using an Arduino board, turning the whisker into a waterproof touch sensor. The steps to make the whisker are easy and repeatable for students. It is constructed with reusable 3D-printed parts and other everyday items.

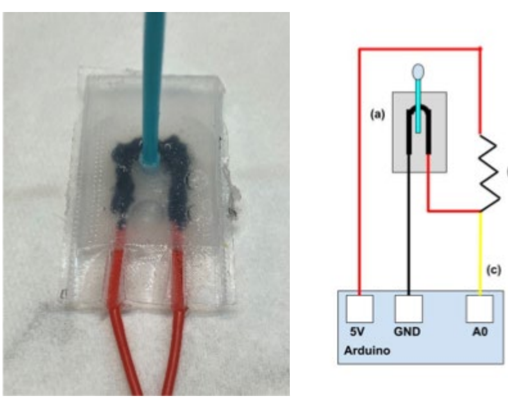

Fig. 13. Whisker (left) and Whisker Sensor Circuit (right): (a) Whisker sensor, (b) Resistor of approximately 5 kΩ, (c) Analog Read Wire.

To detect the distortions (changes in resistance) of the whisker, the whisker is set up in a voltage divider circuit, which places the whisker in series with a resistor that has a similar neutral resistance to that of the whisker. A 5-volt power supply is then applied to this series of resistors. The voltage after the normal (first) resistor is constantly being reported, along with a simple moving average that constantly averages those twenty most recent voltage readings. When the whisker is touched and the resistance of it increases, the voltage reading will increase proportionally, allowing students to track and sense these distortions.

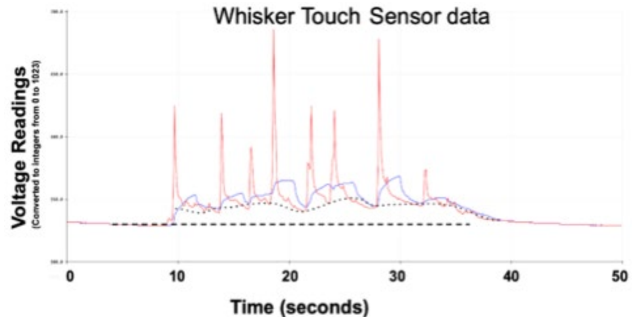

Fig. 14. Example Whisker Data Plot: The red line represents the value read from the whisker sensor; the spikes in the red line indicate a distortion of the whisker. The blue line represents a moving average of the twenty most recent values read from the whisker sensor. The dashed bottom line represents the neutral reading of the whisker before any distortions. Meanwhile, the dotted line tracks the neutral reading of the whisker after distortions. Notice how the dotted line is different from the dashed; the whisker's neutral reading changes after being distorted and doesn't return to the dashed (no distortion) neutral reading.

The learning points for the whisker sensors are extremely valuable. Students will be introduced to the concepts of electrical physics such as Ohm's Law, resistance, voltage, current, and circuit design. At the same time, they will learn the basics of programming in C and data filtering through the moving average code provided. After being introduced to the concepts of the whisker sensors, we hope that students will come up with their own unique uses for the device to explore deeper into the world of physics, programming, and engineering.

IV. Conclusion

The key principle of the first SeaPerch program iteration was making marine robotics simple and accessible for younger, beginner audiences in an unprecedented manner. From a development perspective, the current SeaPerch II program includes more modules than initially planned while keeping components low-cost and accessible at an introductory level. Our current sensor and gripper modules are so far performing to the standard we require, making the planned quarterly development and release roadmap appear very promising.

The three current sensor modules offer interesting data collection capabilities, but their potential is greatly amplified by utilizing Arduino microcontrollers. Using the Arduino UNO, students are able to learn valuable skills in programming. Students are able to engage with SeaPerch II's data focused systems by calibrating their sensors to use provided code in the support materials or even by programming entire automated guidance systems on their own (the automated guidance modules are currently still in development). The range of difficulty levels allows students to choose elements which they find appropriately challenging.

Another educational opportunity is the introduction of Arduino microcontrollers in general to SeaPerch students. The ability to integrate and program these microcontrollers is a huge stepping stone in empowering students to create any form of electronic system that they can imagine. Furthermore, students will have gained hands-on experience with sensors through Arduino, which is a powerful tool to support young scientists as they explore their own environments and test to their curiosity's limit.

SeaPerch II's soft actuators have also performed surprisingly well. While we are still working on methods to increase the viability of the pneumatic and hydraulic actuation within SeaPerch's tethered format, the grippers themselves are proving to be versatile and simple to make with a fairly high effectiveness with regards to manipulation. They will prove to be a solid introduction of soft robotics to the SeaPerch community.

On top of the grippers themselves, real world use cases for casting silicone expand far past soft robotics [14]. So, no matter where students end up, having experience with the material opens up new possibilities for anything from crafts and hobbies to home maintenance. On top of that, silicone and other rubbers are being used for more and more applications in robotics and engineering at large [15]. It opens up an entirely new perspective for many on how to think about robotics.

All in all, SeaPerch II provides students with the tools and materials necessary to enable significant learning achievement in fundamental STEM concepts as well as transformative discovery opportunities to foster critical inquisitive development.

V. Next Steps

A. Improvements on Current Designs

There are several key technical improvements that we are considering going forward. A few of our current modules require some additional development. Namely, we need to further test and refine our waterproofing methods to ensure that they are fully reliable, write and test example code for the automated guidance systems so it can build on the existing sensor modules, and improve the system for actuating the soft actuators as they can currently require a lot of tubing to operate at the full tether distance of the standard SeaPerch ROV.

SeaPerch II will learn from student and teacher testing for each module released and work to update the existing modules accordingly and incorporate that community feedback. The program will feature several more general accessibility, reliability, and ease of use updates which will be released with the quarterly modules. We want these modules to grow with the community and remain as relevant as possible for new learners. Along similar lines, as we find more accessible versions of these modules (any instances that may not require 3D printed or specific parts) we will be supplementing our modules with the additional build materials in the hopes that as many users be able to incorporate SeaPerch II into their SeaPerch experience as possible.

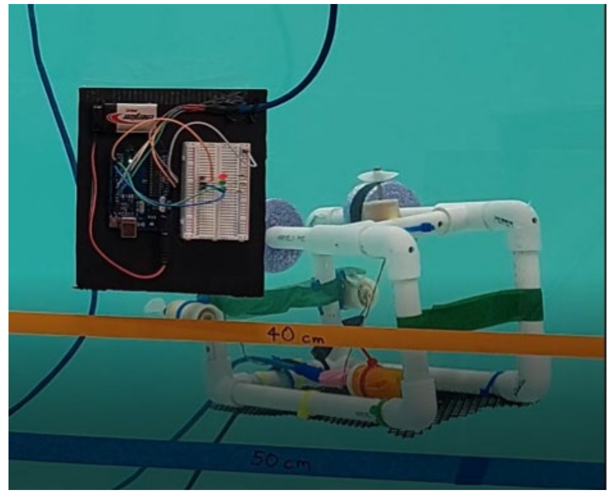

Fig. 15. Development for proof of concept depth holding capabilities using SeaPerch II's pressure sensor module.

B. Future Design Work

SeaPerch II engages students in numerous key areas, but more exploration is needed to optimize educational impact. Some avenues include integration of alternative chassis models, more soft robotics, and increased autonomous capabilities.

SeaPerch II's inclusion of soft actuators could open the door for those who are up to the challenge of designing entirely soft robotic ROV units. While they will likely lack the versatile and modular structure of the classic SeaPerch ROV, the design and construction of an entirely soft-robotic unit poses several engineering challenges to students which build on what they learned with soft actuators in SeaPerch II and will demonstrate a more advanced level of understanding for this revolutionary technology.

Another potential step for SeaPerch II would be the development of a guide to serve as a base platform for students wishing to creatively design their own soft robotic actuators. A more in-depth guide would enable students to take their knowledge from the original modules and expand upon these principles themselves. Further guidance can then enable learners to design and construct their own soft robotic actuators to fit any situation or task.

One of the big promises of SeaPerch II is that of automated guidance systems. With the addition of the SeaPerch II sensor suite, students will be constructing SeaPerch units that have the capacity to integrate certain autonomous navigation functions such as obstacle detection and avoidance, depth holding, ground following, and automatic surfacing. With much of the hardware modules developed, adding autonomous functionality to SeaPerch II seems like a logical next step.

All things considered, SeaPerch II is prepared to build upon the incredibly successful classic SeaPerch program and incorporate several 21st century technologies in order to meet the needs of any learner. With the current and future modules, we hope SeaPerch II is able to encourage a new influx of learners to foster their own passion for growing STEM fields with ever-changing problems, projects, and paradigms.

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