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Challenge-based Engineering through the Design, Assembly and Testing of Underwater Vehicle

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Abstract

A team from North Carolina A&T State University participated in a two-semester research, design, assembly and demonstration project named Perseus II, sponsored by the Office of the Secretary of Defense's Rapid Reaction Technology Office (RRTO). The goal of this challenge-based engineering project was to explore if a team (a) with just a general background in engineering (role filled by undergraduate students), (b) modest resourcing and (c) in a relatively short period of time, could assemble an underwater vehicle to perform a specified mission. The project culminated with the operational demonstration of the underwater vehicle in a dive lagoon and the acquired engineering skills. Ultimately, we believe this project uniquely exposed undergraduate students, including minorities, to challenging real-world ocean engineering problems so as prepare or create interest for the Geoscience workforce of the future.

Introduction

It is well-recognized that early engagement and challenge-based instruction of students including underrepresented students in cutting-edge research is the key in promoting their learning opportunities and outcomes [1]. A team of undergraduate students from North Carolina A&T State University under the guidance of faculty advisors participated in a two-semester research, design, assembly and demonstration project named Perseus II, sponsored by the Office of the Secretary of Defense's Rapid Reaction Technology Office (RRTO). The overarching goals of this initiative were multi-fold: (a) to expose undergraduate students including freshmen, sophomore and minorities to ocean engineering challenges so as to prepare the Geoscience workforce of the future [2], (b) to excite and challenge students in Science, Technology, Engineering and Mathematics (STEM) areas and demonstrate how real-world problems can inspire America's next generation of scientists and engineers and (c) to encourage non-traditional, out-of-box and emerging technologies that may be of significant interest to the Department of Defense (DoD) agencies. Specifically, the objective of the project was to explore if a team with (a) just a general background in engineering (role filled by undergraduate students), (b) modest resourcing and (c) in a relatively short period of time, could assemble an Unmanned Underwater Vehicle (UUV), Remotely Operated Vehicle (ROV) or Autonomous Underwater Vehicle (AUV) that is capable of searching for, locating, and collecting information on objects that are potentially unexploded ordnances (UXO). Five academic institutions including North Carolina A&T State University participated in this project. The teams were only provided with modest funding for the design, procurement and testing of components for the AUV/ROV/UUV.

Top-level Objectives

The top-level objectives were two-fold: (a) respond to a report of potential UXO sighting and search a rectangular area approximately 100 feet by 75 feet with depths of water up to 40 feet for the potential UXO; (b) If potential UXO was located, then (1) provide as precise of a geo-location as possible in order to enable the Explosive Ordnance Disposal (EOD) expert to respond to the exact location and (2) provide as much information as possible on the located object(s) to an EOD subject matter expert (SME) on shore. The goal of providing this information was to enable the SME to assess if the object was potentially dangerous, not dangerous, or potentially so dangerous that perhaps divers should not be in their vicinity. It is important to note that the top level objectives provided to the student team were purposely generalized and not directive in nature, in order to encourage non-traditional and out-of-box solutions and to avoid driving the student team toward a specific solution. Finally, the project culminated (in November 2013) with demonstration of the acquired engineering methods and skills by running the underwater vehicle in a dive lagoon at Florida Keys Community College in Key West, FL.

Expected Challenge-based Engineering Outcomes

It is increasingly being realized by educators that when undergraduate students are posed with challenges, it can motivate them to explore and seek the desired science and engineering skills. This type of education is called Challenge-Based Instruction (CBI). Studies by Pandy et al. [3] and Barr et al. [4] have also showed that CBI, as compared to traditional approaches increased the students' conceptual knowledge and their ability to transfer acquired knowledge to newer situations. We therefore believed that the introduction of challenge-based engineering projects will create a favorable atmosphere for creativity, increased participation and teamwork. Furthermore, the expected outcome for the participating students are valuable technical and problem-solving skills, teamwork, project and time management and other soft skills including written and oral communication. In addition, the Perseus demonstration, and associated presentations and reports, will provide the Department of Defense (DOD) and related stakeholders insight into a number of rapidly evolving technical areas of interest through non-traditional lenses.

Project Demonstration

At the end of the two-semester period during November 2013, the Perseus II demonstration took place in the Dive Lagoon at Florida Keys Community College in Key West, FL. The confines of the lagoon provided for a controlled environment with a very low likelihood of weather conditions forcing a postponement of in-water events. The lagoon also provided an enclosed environment that ensured the vehicles do not venture into waters where they could impact or foul commercial or pleasure craft. The notional laydown of the two areas of uncertainty in the lagoon was provided by the organizers to the student teams. The type, location, or other details of the potential UXO were not given in order to encourage a search of the entire area of uncertainty. The teams were tasked to hunt for objects ranging in size from a medium caliber machine gun bullet to a 500-pound bomb. The vehicle was inspected by the diving safety officer prior to in-water testing to ensure that it was safe to operate. The diving safety officer could have disqualified any vehicle that may be deemed to pose an unreasonable safety hazard.

Team Description

The North Carolina A&T State University team was intentionally kept multi-disciplinary with students selected from various disciplines, while maintaining a good mix of all levels of undergraduate study. The team selection was not just based on academic record but more importantly their interest and determination to undertake challenging projects. The team consisted of 7 undergraduate students (1 freshman, 2 sophomores, 2 juniors, and 2 seniors) from Mechanical Engineering, Physics, Atmospheric Science and Meteorology, and Computer Science and Technology disciplines. The overall team was divided into four sub-groups, with each sub-group responsible for one of four thematic areas involved in the project – (1) Mechanical Design (MD), (2) Power and Propulsion (PP), (3) Detection Technologies (DT) and (4) Navigation and Communication (NC). Each sub-group had a thrust leader, along with one or two members. Thrust assignments were based again on interest, background and tenacity. Overall, co-leaders were elected to be responsible for team management, decision making and resolving conflicts. It is important to note that the participation was voluntary with no financial compensation or course credits.

Vehicle Description

The team was tasked to: (1) identify and examine candidate technologies for the mission, (2) document information and methods (including those selected and rejected), (3) select enhanced detection methods and calculate required power, vehicle weight, buoyancy and propulsion requirements, (4) develop potential course of action and timelines, (5) document vehicle design, trade-offs and challenges during the process, (6) assemble/build the vehicle, (7) document and cost the "as built" Bill of Materials, (8) do field demonstration, (9) submit a final report of the mission scenario, design, build and test process, including on lessons learned and recommendations. The strategy was to design and build a simple Remotely Operated Vehicle (ROV) using a multitude of commercial off-the-shelf (COTS) components only. The vehicle consists of two major units – the surface raft and the underwater vehicle with an on-shore RC operator control (Figure 1). Each unit can be independently steered and controlled using separate set of underwater thrusters and servo motors. However, both units were connected via a water hose to carry power and communication cables.

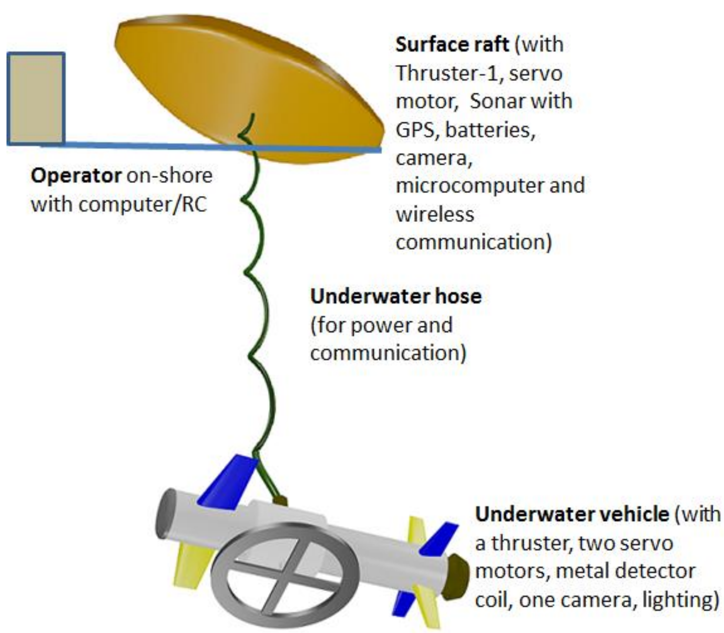

Figure 1. Remotely Operated Vehicle (ROV) design – Surface raft and underwater vehicle

Figure 2 provides the detailed description of both units - surface raft and underwater vehicle. The surface raft was an Intex Explorer 100 inflatable boat (58”x14”x33”). It consists of (a) a marine cooler packed with $LiFePO_4$ polymer batteries (36V), Fishers Pulse underwater metal detector control box, cables, and an electrical box, (b) Humminbird Dual scan SONAR/Fish Finder with internal GPS and GoPro HERO3 camera with wireless output, (c) 2.4 GHz wireless communication, and (d) an inflatable boat/raft fitted with remotely operated Crustcrawler High-Flow thruster-1 and Savox servo motor. The underwater vehicle was 3 inch in diameter by 3 feet long with wing span of 9”x 3”. It consists of multiple capsules of water-tight sealed PVC pipes – one end of PVC capsule contains the second Crustcrawler High-Flow thruster-2, its control box and two sets of adjustable wings with Traxxas servo motors for steering, the middle section of PVC was connected to an underwater hose with power and communication cables, and the other end had the fixed wings (with LED lighting) and the front facing and sea-floor facing GoPro HERO3 cameras. The 18” Fishers Pulse metal detector coil was fixed at the bottom of the underwater vehicle. However, the metal detector’s control box was placed in the surface raft, connected through a long cable. In terms of build cost, the entire cost of vehicle parts was kept around $10K including the cost of its many iterations and vehicle optimization. More than 60% of the build cost was spent on the purchase of a high sensitive underwater metal detector, two underwater thrusters and on two high-density $LiFePO_4$ 36V Prismatic Batteries.

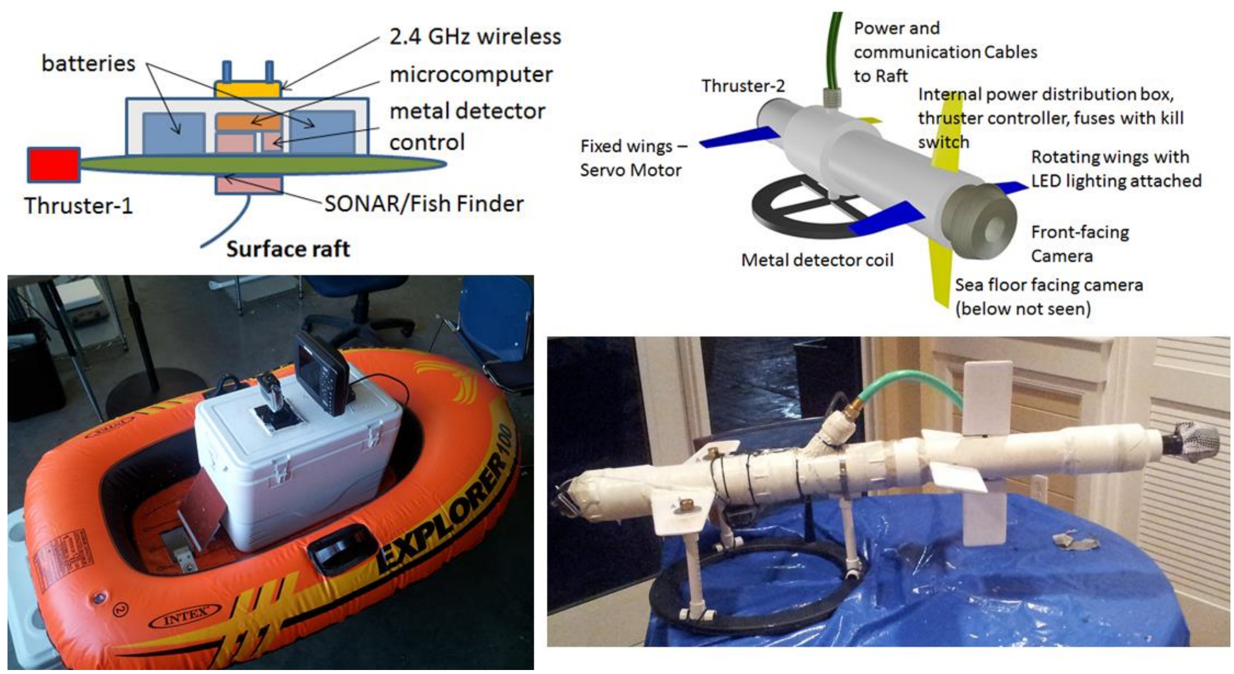

Figure 2. Design and assembly of the surface raft and underwater vehicle

The strategy to detect the unexploded underwater ordnances/explosives (UXO) either buried or sitting on the sea floor was multi-fold. (A) Using the underwater metal detector with 18" coil and long cable to detect both ferrous and non-ferrous metals. The output was captured using an earphone. (B) Real-time down/side SONAR with internal GPS to identify and relay geo-location using pre-defined waypoints. (C) Through visual identification and detection using two sets of GoPro cameras - front facing and sea-floor facing fitted on the underwater vehicle. The multi-fold strategy is expected to enable reliable detection and identification of the UXO. The geo-location will be acquired using the internal GPS on the SONAR, with verification from the time stamp in the camera and metal detector output.

Demonstration Results

Overall, the team performed very well considering our team entered the project later than the other groups, and team didn't have any significant experience in the field. The students came a long way and made significant progress towards the later part of the project. The team members started with a concept for the vehicle and worked hard to succeed in constructing a water-tight and functional underwater vehicle. In addition, the team was able to successfully overcome several setbacks that delayed the overall progress; for example, due to programming issues, the original Beaglebone Black microprocessor controller was not able to control the vehicle's thrusters and to overcome this, the team modified a simple RC controller to control the thrusters. This was a successful solution to an unexpected and significant design issue. The team's combined efforts resulted in a successful first-time attempt at building an underwater vehicle (Figure 3).

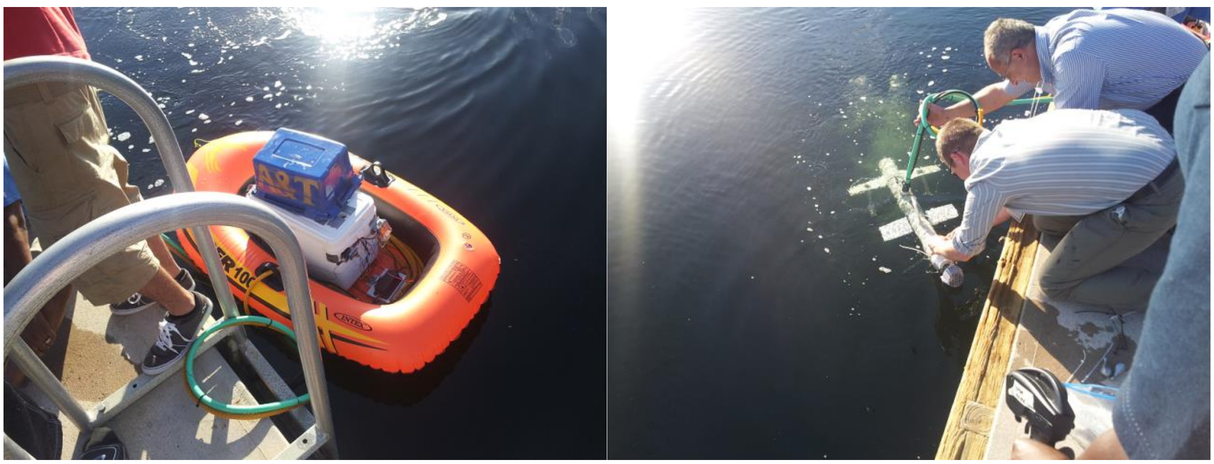

Figure 3. (Left) Surface raft placed in the lagoon, (right) underwater vehicle dropped in the water.

Unfortunately, no "verifiable" objects were located or identified during our test runs or during the final run (Figure 4). The team did recognize that one of the tests we should have done when we first went in the water on one of the days prior to the final demonstration day would have been to perform a search with just the SONAR to determine what the underwater "structure" of the search area was like and to determine if we could pick up any of the UXOs using only the SONAR.

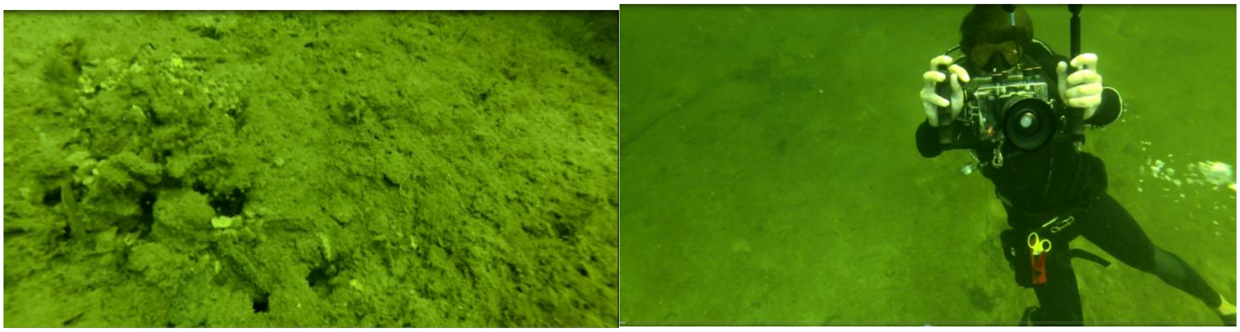

Figure 4. Picture captured with the GoPro camera mounted on the underwater vehicle.

Demonstration Outcomes and its Relation to the Perseus II Goals

Overall, the vehicle did not work as designed. One major flaw was that the vehicle was not properly balanced for buoyancy. We had to try and address this issue on-site during the final test run, and this was not a successful approach. Another significant flaw was the thrusters we had selected. The thrusters did not have enough power to actually propel the vehicle (although it did for the surface raft). This was primarily due to the manufacturer's incorrect specifications on their website, which led us to make the wrong calculations for the battery power supply. This ultimately affected the overall functionality of the thrusters. A less significant design flaw was the surface area of the "wings". In the end, these were smaller than what they should have been.

It was very evident that a critical component for success was to complete the design and perform vehicle testing as early as possible and as many times as possible after refinement. Although our approach of keeping the vehicle simple was good (and successful), we should have had a full working 3D CAD model and design to make sure all the parts fit together and functioned as designed. Also, as the vehicle was being made, we should have tested each part more completely before integration, and then again after integration. Lastly, we should have also spent more time learning about some of the technology that was used in the vehicle. For example, the Humminbird Dual scan SONAR/Fish Finder, although a "plug-and-play" device required a more sophisticated knowledge of its operation in order to exploit its full functionality. We found that in order to configure it for the kind of task we demanded from it, a deeper understanding of how it operated was a must.

Nonetheless, our student team learned a great deal during the course of this project and also contributed and fulfilled the goals of Perseus II. One of the goals of Perseus II project was encourage non-traditional and out-of-box solutions from student teams. Our design with simple "plug n play" components and innovative two-part design to minimize water exposure for electrical components was widely appreciated by DOD personnel on site and by other institutions. In addition, (a) the use of simple inflatable boat to carry the heavy components on the water surface, (b) a water hose connection between the surface and underwater vehicle and (c) the use of wireless GoPro camera to relay back to the operator the output screen of the SONAR was regarded as ingenious. However, in terms of the demonstration outcomes, the overall theme that we learned was a considerable amount of design and integration of parts is essential for successful operation of an underwater vehicle. This includes good communication between the different sub-groups working on the project. All of the group members learned a lot during the course of the project, from the mechanical team, to the electronics/power and software/programming teams. Each student learned a lot working on their tasks and came away with a better understanding of the challenges and how their specific tasks tied into the greater accomplishments of the group. In summary, the students learned important lessons during the course of this project; namely to begin designing early on, followed by routine testing of the components and their final integration for successful device operation.

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