#Robosub Influencer 2020 – Inspiring the Next Generation of Systems Engineers

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Abstract. RoboSub is an exciting underwater robotics program in which teams design and build an Autonomous Underwater Vehicle (AUV). These vehicles are designed to autonomously navigate through a series of tasks mimicking ongoing research. The annual competition attracts the best engineering students from around the world to test their skills in a professional competition environment at Naval Information Warfare Center Transducer Evaluation Center Pool. Industry observers at the competition often offer hiring on the spot to recruit the best of the best.

Team Inspiration, a middle/high school RoboSub team trained in systems engineering process, was able to achieve remarkable success in their first year of competing in 2019. They ranked 2nd in US and 3rd in the world for static judging of robot design, technical paper, technical presentation, video, and pre-qualification. Their overall robot performance ranking of 7th in US and 12th in the world was remarkable as over 90% of the 59 participating teams were from universities around the world with better technical knowledge, better equipment, and better resources. Team Inspiration with 9 middle and 5 high school students also earned the Most Inspirational award and IEEE's award for the Most Innovative Engineering in a Competition System.

The systems engineering process the team learned has been proven by our advisors developing national systems. The systems engineering process is tailored to develop the team members, the next generation of systems engineers, so they can pursue their dreams, push their limits, and achieve the team goals. Readers will learn how systems thinking can minimize the impact of limited technical knowledge, resources, schedule and budget to achieve the end objectives. The goal of this paper is to share our experience to inspire young engineers that anything is possible and to encourage experts to mentor the next generation.

About Team Inspiration's RoboSub Journey

Team Inspiration began its RoboSub journey in mid-March of 2019, 20 weeks before the competition. In contrast, majority of the teams that competed in 2019 RoboSub began their preparation in September of 2018. Being a new RoboSub team with limited time and resources, Team Inspiration chose to be an integrator of existing technology in developing their AUV. We used a commercial-off-the shelf (COTS) remote control robot, BlueROV2, to jump start the learning curve. We started by learning the basics of underwater robotics and reading underwater robotics textbooks, and the operation and technical manuals of the BlueROV2. We went over all aspects of underwater robotics to gain systems awareness vs focusing on one specific aspect initially. The BlueROV2 served its purpose well. After the systems overview, we decided to focus on learning autonomous control as the primary objective because autonomous control is the brain of the robot.

We then started to build our own custom AUV. We developed a reliable, modular, simple, and sturdy extruded aluminum frame as the base of the AUV based on our past experience of building ground robots. We used the existing BlueROV2 architecture because it had all the basic elements necessary for control and communication. However, for faster image processing capabilities, we replaced the main processor of BlueROV2's Raspberry Pi with an NVIDIA Jetson NANO.

Our baseline goal for the season was to achieve all deadlines as stated by the competition organization, RoboNation, including the optional pre-qualification milestone. The RoboNation competition schedule is carefully designed to ensure that participating team is ready ahead of the competition.

The pre-qualification is a "simple" maneuver defined by RoboNation. Simple is relative; only one-third of the competition teams are ready prior to the competition event, and Team Inspiration is one of them.

The pre-qualification maneuver, depicted in Figure 1, consists of starting the vehicle at 9.8 ft (3m) behind the Gate. It must be a fully autonomous run, and everything attached to the vehicle must submerge with the vehicle with nothing breaking the surface of the water. The vehicle must autonomously pass through the Gate, circle around the Marker and pass back through the Gate.

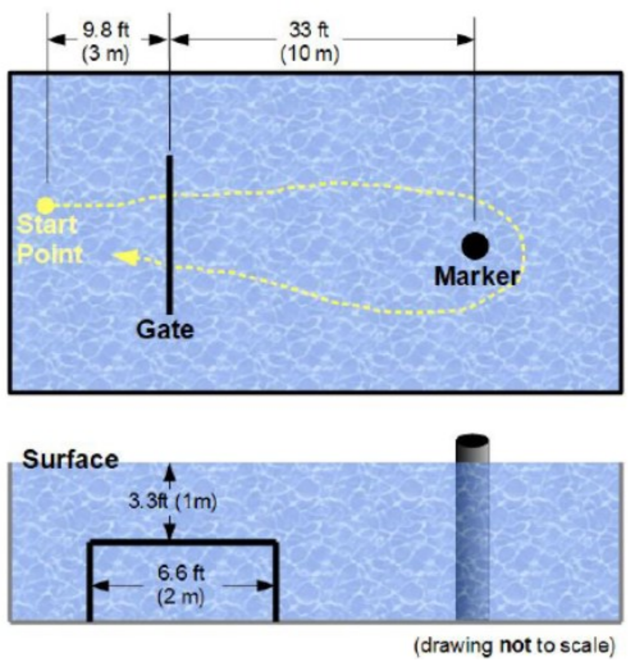

Figure 1. Vehicle Pre-Qualification Specification

For robot performance, the actual competition consisted of multiple missions of varying difficulty. Our goal was to complete the “Gate” mission within the first three and a half months of work, and then focus on the “Slay Vampires” and “Surface in an Area” missions. These missions require a minimum of 4 axes of movement, computer vision, and hydrophone localization. To complete those missions, our AUV implemented the following sensors: depth sensor, sonar, leak sensors, cameras, and hydrophones. We utilized these sensors to help our AUV in recognizing its environment.

We had two robot platforms at all times - benchtop setup, BlueROV2 and/or our custom AUV. Our mechanical subteam worked in parallel to develop the custom AUV and attachments while our programming subteam developed their code through testing on our BlueROV2, benchtop test setup, and imagery obtained online before the camera sensor was integrated into the system. This testing allowed us to ensure the reliability of our AUV by debugging and simplifying the code before we put it in the water. We also balanced learning and being competitive. We prioritized tasks that the team could reasonably perform and had a high point value so we could maximize the competition result.

Systems Engineering Execution

Systems Engineering V Process. The Systems Engineering V process has been taught and refined over the years. The process itself and related details are all available online and at the fingertips of the readers. However, not many programs utilize the process due to higher upfront costs and more detailed upfront planning.

Team Inspiration is taught by an experienced system engineer who has worked on many national systems including planetary spacecraft, satellite, manned/unmanned air vehicle, large scale simulation modeling and data processing. The process is adapted based on the team’s capabilities and knowledge.

Our team members were first exposed to the System Engineering V process when we were in 3rd grade. As the team matured, the expectation of the engineering life cycle understanding was raised to the industry standard. We are taught to identify the problem/challenge that we are going to solve. We perform requirement analysis and prepare design reviews that are supported by prototyping and trade study. We conduct tests and development in a rapid iterative fashion similar to the agile process used in the industry. The end product goes through verification and validation to ensure it is built according to the plan. The process focuses heavily on self-awareness and reflection at every stage. The cycle is then repeated based on lessons learned.

Figure 2 below is the process our team executes with emphasis on self-awareness and reflection.

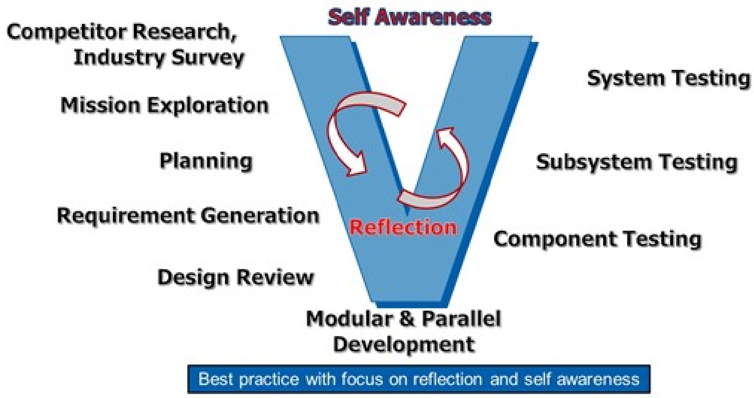

Figure 2. Team Inspiration Systems Engineering V Process for RoboSub

Competitor Research & Industry Survey. The success of Team Inspiration is not an accident. We have been watching RoboSub competitions for eight years. However, watching and doing are quite different as we learned from our first competition.

The RoboSub competition is designed for participating teams to challenge themselves to go above and beyond their abilities. The main goal of the competition is focused on learning. Past technical papers and videos are posted online so teams can learn from past achievements and lessons learned.

Each member of team Inspiration was responsible to perform a detailed study of a minimum of three teams to list out each team's technology, bill of materials, and lessons learned. The information was compiled into a master list to support our requirement generation and material selection which are discussed in a later section of this paper.

Mission Exploration. There are many missions to complete in the 2019 RoboSub competition. The missions are designed to challenge even the graduate students. Some teams chose to develop software programs with artificial intelligence and machine learning. Some endeavored to create better underwater sensors, while others concentrated on hardware design to waterproof the container, wet cable connections, among other hardware concerns. Our team decided to learn the AUV motions and basic functions with the goal of achieving a minimum of three missions while exploring all potential missions. The reason for trying out all missions was because we did not know what we did not know.

Our team acquired the necessary equipment within our budget to try out all those missions: Inertial Measurement Unit (IMU), camera, depth sensor, leak sensor, hydrophone, torpedo, processor, and gripper. About half way through our 20-week building schedule, we quickly narrowed the equipment down to key sensors that we wanted to investigate further so that we could complete our AUV on time for the competition.

Figure 3 below highlights the various missions of the competition and the layout of the mission objects in the competition pool.

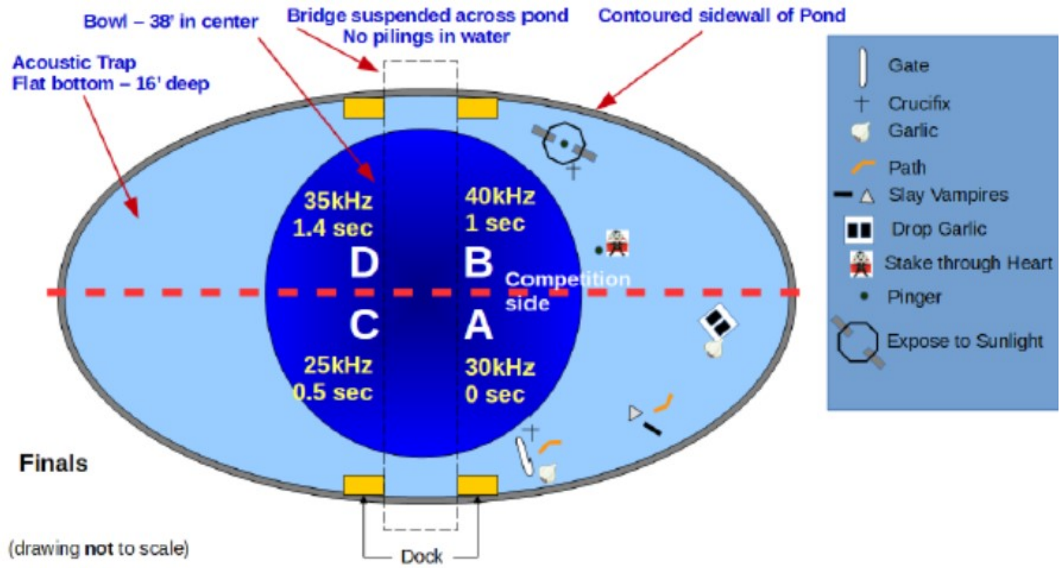

Figure 3. 2019 RoboSub NIWC TRANSDEC Layout and Mission

Planning. Planning is paramount for the RoboSub competition. Many marine components have a long acquisition lead time. Due to a short 20-week time frame, the team needed to prioritize tasks on how we could jump start from zero RoboSub knowledge to competition ready. With both team members and mentors new to the RoboSub competition, there were many unknowns. We adopted the strategy of rapid prototyping and parallel testing to maximize our learning opportunities. Our goal was that if we were to fail, we wanted to fail quickly so we could move on to the next tasks. We built many milestones into the detailed schedule such as components selection, components order placement, and decision deadlines for using COTS or custom AUV for the competition, among other tasks.

A draft high-level schedule with contingency activities were laid out at the season kickoff. Only 10% of the schedule needed to be adjusted later as the team discovered challenges along the way. The detailed schedule and assignment of team members to subteams were then derived from the high-level schedule. The strategy of having a high-level schedule helped the team to focus on the big picture while the detailed schedule took care of day-to-day operations.

Requirement Development. Systems requirements for our AUV were derived from the Robosub competition mission and scoring guideline. The requirements were then flowed down to hardware, software, test, and operation. The interfaces were defined for hardware to hardware, hardware to software, and software to software. The requirements were prioritized based on team capability, schedule, cost, risk, and performance.

Self-Awareness. With no knowledge of RoboSub and a short execution time frame, our young team had to prioritize what to learn and what to do within a short time. Complex algorithm development such as machine learning, neural networks, artificial intelligence, and circuit board design were postponed to next season.

Design Review. The design reviews that our team performed were similar to the standards used by industry preliminary design reviews and critical design reviews. The review covered requirements, architecture, hardware and software design with concentration on the interfaces between hardware to hardware, hardware to software, and software to software. The design was then checked against requirements to ensure completeness.

Mechanical design was modeled via CAD to ensure proper fit and allowed easy reconfiguration as needed. Electrical design was detailed via schematics with signal and data information including power usage and cable length estimation. Software design included language selection, source file control, configuration management, architecture, and control/data flow chart.

The first major design review was conducted in the first quarter of the 20-week duration. Based on prototype and test results, subsequent design reviews were conducted continuously every week.

Modular and Parallel Development. To ensure the AUV development could meet a tight schedule, the development was performed in parallel with focus on propulsion & control, sensor development & integration, and algorithm development. Propulsion had direct impact to the mechanical layout while control was key to autonomous function. Alongside with parallel development, modular development was used in testing the following sensors independently and then integrated into the AUV: camera, sonar, and hydrophone.

Power and leak sensors were incorporated to monitor the health and safety of the AUV. An algorithm was put in place to execute failsafe maneuver when such maneuver was warranted. Other algorithm development was focused on object detection and identification for computer vision to integrate with the IMU for navigating the AUV.

Testing. Testing is key to identify shortfall and limitation of the product. Very often testing is postponed until the last minute in a big bang approach. However, testing is much broader and it can happen even prior to the kickoff.

Our team began working towards the development of an AUV starting mid-March of 2019. Due to the fact that we started late into the competition season, time was among one of our biggest constraints. In order to create a competition-ready autonomous program, we needed to optimize our efficiency when we tested our solutions across all components, including navigational, data collection, and vision.

For our team, we utilized a SeaPerch robot prior to the RoboSub kick-off meeting to gauge the interest of potential team members. Illustrated in Figure 4, SeaPerch is a simple PVC constructed robot with three motors, and a simple control box with three on-off switches to control individual motors. The simple robot took less than an hour to put together and it allowed team members to learn the effects of buoyancy, weight, velocity vector, control, thrust, and drag. This early testing provided a valuable lesson for later design activities.

Figure 4. Simple PVC Robot with Remote Control

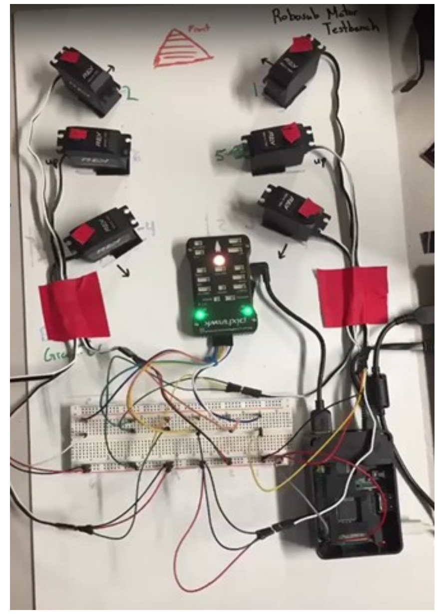

Figure 5. Benchtop Setup

The team then put together a benchtop setup, as illustrated in Figure 5, using ground robot components while waiting for the BlueROV2 to arrive. The benchtop setup allowed early learning of the IMU, image processing, motor control, algorithm development and software to software interface. The simple ground servos worked better in this setup than actual marine motors since those are not designed to operate out of the water for an extended period of time.

With the BlueROV2, the team learned how a commercial robot was put together in both mechanical and software-controlled environment. With the understanding of how a professional robot functioned, the team was able to learn how to develop autonomous control in quick succession by routing payload data in place of the remote-control value.

Figure 6. Learning from the Expert and the BlueROV2

With the knowledge gained from the benchtop study and the BlueROV2, the team was able to develop a rudimentary custom AUV within eight short weeks. Initially, the custom AUV was run via remote control to ensure all the components were put together correctly. Simple autonomous function without sensor input was then added to the custom AUV. After many successful tests, the sensor input was finally integrated into the AUV for fully autonomous operation.

The quick turnaround of development and test allowed our team to develop the final AUV, which the team named Orange, that excelled at the competition in both static judging and in-water performance.

Figure 7. Members of Team Posting with Their RoboSub Prior to the Static Judging

Reflection. Reflection is critical in the systems engineering process. At every step of the development life cycle, reflection was discussed by our team, especially after each test phase. The data was carefully analyzed and feedback was incorporated into subsequent design, procedure, plan, and drawing.

The 20-week RoboSub journey was a great way for our team to learn systems engineering. Our team members were able to apply the process in a challenging environment and appreciate how the process worked successfully in real-life application. It is much more fun than learning system engineering process in a classroom setting.

Keynotes. Knowing and being focused on the mission was key to the team's success. The team's goal was to integrate existing equipment and leverage existing technology to learn the functions of underwater vehicles. In order to achieve the end goal, many principles were utilized such as KISS – Keep It Simple Silly. Our custom AUV was reliable in executing the chosen missions. An agile process was followed to ensure if anything did not go as planned, it would fail quickly. Failing quickly allowed time to regroup and develop different solutions.

Passion, teamwork, resiliency were keys for the team to ride through the many ups and downs, triumphs and heart burns, and late-night study. Our passion to share helped us to master our subject. Prior to the RoboSub competition, the team took our custom AUV to many exhibition events to share our learning. The STEM outreach preparation and questions from the outreach audiences allowed us to push our learning to the next level.

In summary, learning systems thinking served our team very well. It showed that systems engineering/systems thinking can be taught and utilized for any project - big or small. The systems engineering process is applicable at any level, from professional to grade school students. Success is the best stimulant to entice others to learn systems engineering. Sharing and teaching allows us to understand the subject better. Thank you for reading this paper. Join us to share systems engineering knowledge to inspire the next generation of systems engineers.

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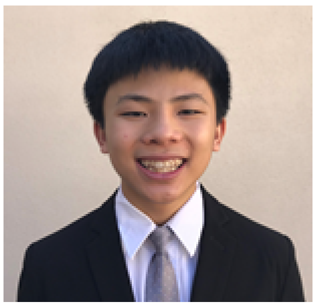
Biography

Mabel Szeto. She is a junior at Del Norte High School in San Diego. She is the Team Captain of RoboSub Team Inspiration. Besides competing in RoboSub, she also competes in *FIRST* Tech Challenge. In addition, she is a youth mentor for *FIRST* and coordinator of many robotics events. She is the principal designer of the robot game for the 2019 BeninBot Challenge (1st national robotics competition of Benin, Africa). She conducts many STEM outreach events at schools, science museums, and major STEM fairs. She is a board member of a non-profit that promotes STEM.



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