Technical Overview of the Development of Autonomous Submarines Lanturn and Donphan

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Abstract

For the team's 4th year participating in the RoboSub competition, the members of the CSULA RoboSub team developed 2 vehicles, Lanturn and Donphan, to complete separate tasks in the competition based on their capabilities. The team strived for modularity through the development of a removable electronics housing system on Lanturn and the reduction in size of the electrical systems on both vehicles. Based on simulations and testing results, it is predicted that both vehicles would have achieved full autonomous capability and would have completed the tasks they were intended to complete.

1. Competition Strategy

Our 2-sub strategy this year was developed in consideration of our larger budget and team than in previous years. This increase in resources allowed us to improve areas that have been weaker in the past, including sound localization and actuated systems. With more sophisticated hardware available on Lanturn than on Donphan, Lanturn would be dedicated to completing the pinger tasks using its mechanical claw, dropper, and torpedoes. Donphan would be dedicated to securing style points and completing the buoy task(s).

2. Vehicle Designs

2.1. Lanturn

Lanturn boasts several improvements upon last year's mechanical and electrical systems. Its key features include a rectangular hull with removable electronics stack, a modular frame for adding/removing components with ease, and the addition of sonar and acoustic localization capabilities.

2.1.1. Mechanical

The mechanical design for CSULA's Lanturn submarine was focused on ease of manufacture and maintenance. Key design features are a box-shaped hull with a removable electronics shelving unit and a frame with slotted mounting points for modular mounting of subassemblies.

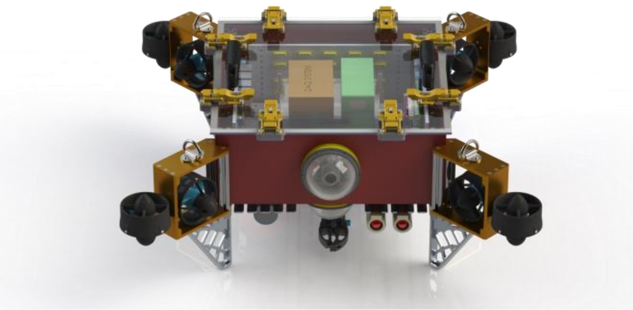

Fig. 1. CSULA's Lanturn Vehicle

Lanturn's hull primary structure is formed by TIG welded sheets of AL 6061-T6. The lid is made of transparent acrylic, and seals to the hull primary structure through a peripheral nitrile gasket compressed by latches. Lanturn is outfitted with forward and downward facing cameras and features a rear connector plate populated with a standardized set of Seacon connectors. The electronics shelving unit is made of acrylic sheets laser cut to shape/size with equally spaced mounting holes that span each sheet.

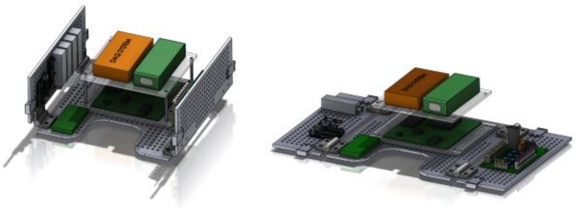

Fig. 2. Removable electronics shelving

An internal connector plate and connectorized electronics allow the shelving unit to be unplugged and removed from the hull. 90 degree snapping latches allow the shelves to be laid flat outside of the sub for easy maintenance and troubleshooting.

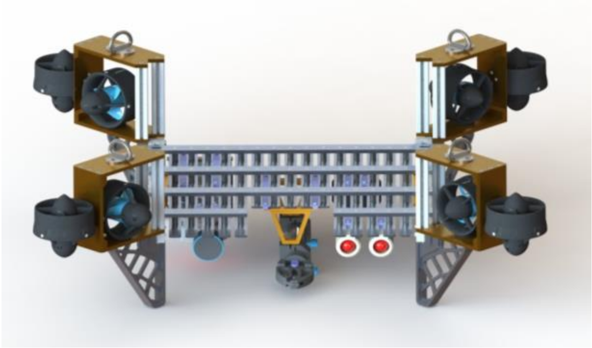

Fig. 3. Exposed frame (Lanturn)

One design criteria requires that components such as sensors and thrusters be easily added and removed in few steps to minimize time spent on maintenance, in return allocating more time to underwater testing. This requirement was met by creating a modular frame that acts as a hub for mounting components, as shown in Figure 3. The design uses a combination of 6061-t6 aluminum t-slot extrusions and flat bars to avoid complex machining, which contributes to ease of scaling if more mounting surfaces are needed.

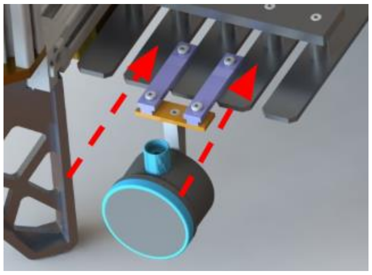

Fig. 4. Mounting of sonar sensor on Lanturn's frame

Components, such as the sonar sensor shown in Figure 4, are slid into the t-slot fixture brackets then held in place by tightening one or more set screws.

2.1.2. Electrical

The electrical system on Lanturn consists of a motherboard, a thruster signal routing board, a power distribution board, several microcontrollers, and a sensor suite, all powered by a single 14.8V, 20Ah LiPo battery. Its sensor suite includes:

- Inertial measurement unit (IMU)
- Barometer
- Hydrophones
- Active sonar module
- Doppler velocity log (DVL)
- Cameras

To reduce the amount of processing required for the detection of obstacles, the team experimented with the use of a sonar module. The sonar module data was processed on a microcontroller external to the motherboard, allowing more CPU usage for computer vision and hydrophones signal processing. In addition, the team was successful in developing a cross-correlation based sound localization system using a widely spaced, triangular array of 3 hydrophones. Data for this system is collected using an oscilloscope module, which was significantly cheaper and more open-source than commercial data acquisition systems.

2.1.3. Software

Lanturn's software consists of a stabilization controller, several intermediate data acquisition/ processing programs, a computer vision system, and a main "mission planning" module for decision making. The software architecture is shown in Figure 5.

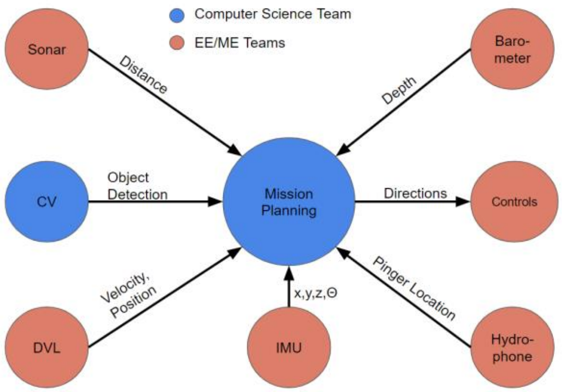

Fig. 5. High level diagram of the software modules on Lanturn

A Python API sends information from the sensor hardware to the submarine motherboard, where the mission planning software is running. The mission planning software contains several state machines for each competition task. Data is transferred among these state machines through ROS publishers and subscribers, and the mission planning module's output is sent to the submarine's controls module. The controls module computes the necessary stabilization motor commands, and then sends both the computed stabilization commands and the movement commands from mission planning to the motors to both stabilize and move the submarine.

The decision-making process is based on previous states and current sensor information. Each state has several subscribers. To increase the efficiency of message passing, the team created custom message types to send larger packets of information in one message. Computer vision collects data from an image stream using OpenCV, where the data is then processed by YOLO. The detected objects are then published to mission planning by the computer vision module.

2.2. Donphan

2.2.1. Mechanical

Donphan was inspired by the Deep Trekker DTG3, shown in Figure 6, combined with Robosub's design goals of simple efficiency at a reasonable cost.

Fig. 6. Deep Trekker DTG3 [1]

Donphan consists of a single 8-inch diameter acrylic tube, which houses all electrical components; two machined aluminum side plates, for mounting the majority of external components; an additional base plate for mounting the downward facing camera and other equipment; two side mounts for the vertical thrusters; and a rear mount for the back-facing thrusters.

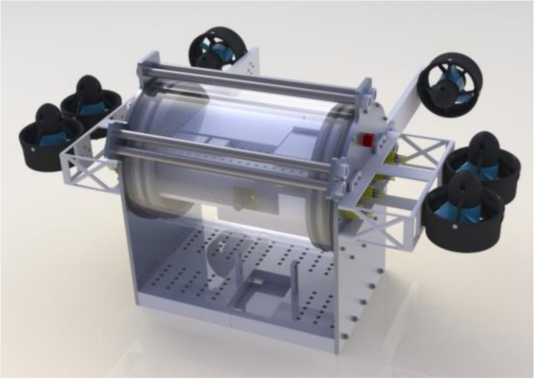

Fig. 7. Solidworks rendering of Donphan

Learning from the subs of previous years, a central design goal was to ensure easy access to all of the sub's internals. In Donphan's final design, six nuts on the half-inch diameter threaded rods can be removed to quickly access all of the internal electrical components. The screws at the bottom have their threads filed off at the end so that they can slot into the base plate as pegs, while still being easily replaceable.

Another objective of this design was to minimize the effect of drag in the water. The surface area perpendicular to forward motion was minimized to achieve this. Whenever forward-facing curved surfaces could be used, they were. When flat surfaces had to face forward, their profile in that direction was made as small as possible.

2.2.2. Electrical

The electrical system on Donphan consists of a Raspberry Pi, a thruster signal routing board, a buck converter, and a sensor suite, all powered by a single 14.8V, 10Ah LiPo battery. Its sensor suite includes:

- Inertial measurement unit (IMU)
- Barometer
- Cameras

Donphan's electrical system is extremely compact, as all of its data acquisition, processing, and decision making is done on a single Raspberry Pi, as compared to most systems which use intermediate microcontrollers for data collection.

2.2.3. Software

Akin to Lanturn's, Donphan's software architecture is split into modules. The mission planning module is responsible for monitoring data from all of the sensors as well as the computer vision module. It then decides the actions the submarine will take, depending on what objects it has seen as well as what tasks it has yet to complete, and sends the appropriate commands to the controls system.

The movement controls system is a standard multi-PID control system, with separate PID controllers for yaw, roll, pitch, depth, and forward/backward distance.

The state machine is responsible for the monitoring of sensors, tracking of specified tasks, and execution of task related activities. It is based on a loop of searching for an uncompleted task, approaching the task, executing the task, and disengaging/tracking completed tasks. Each state is responsible for obtaining relevant data from the sensor modules, as well as controlling the submarine. Each approach and execution state is unique to the task, allowing the programming and testing of a specific task without the need to have the entire state machine running. It also allows for setting a time limit on tasks, allowing the submarine to move on if the task takes too long to complete. The modularity of this system will allow for greater reuse of code, as well as faster modifications without disturbing the function of other task states.

3. Experimental Results

3.1. Lanturn

To evaluate the efficacy of the welded AL 6061 design of the hull in withstanding the stress produced as a result of latching and unlatching the lid latches, static and fatigue stress analysis was conducted. SolidWorks' built-in weld size calculator, which leverages static stress analysis data, was used to calculate a first-order estimate of required weld bead size.

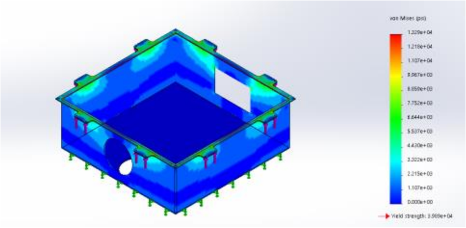

Fig. 8. Determination of required weld-bead size via stress analysis

These results were then further verified through fatigue stress analysis in ANSYS. For this study, symmetry was leveraged and a ⅛ model of the loading condition was simulated, which allowed for a more refined mesh and higher fidelity results.

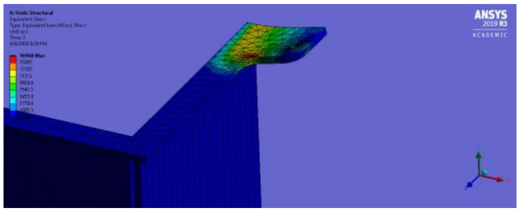

Fig. 9. Fatigue stress analysis in ANSYS

To determine the accuracy to which the developed hydrophones system could determine the heading angle of a high frequency sound, the hydrophones system was tested in a body of water by placing a pinger a few yards away from the hydrophone array and recording the calculated angles while the approximate "theoretical" angle was known. The array was tested at "theoretical" angles incremented by 45^{o}. The system was able to consistently produce the correct heading angle of the pinger.

Lanturn's computer vision system was also trained on several of the competition images, and its accuracy was found to be sufficient for detecting these images underwater. A preliminary version of Lanturn's ROS architecture showed its functionality in cooperation with the other systems on the submarine.

3.2. Donphan

While lack of access to manufacturing facilities led to an inability to manufacture a full-scale sub, multiple smaller-scale test fits were performed with 3D printed pieces. These were done during the design and prototyping phase and had favorable results for the viability of the final product.

Testing of the stabilization controller was done in a small pool on one of the 2019 vehicles to determine the k values for the PIDs. The controller successfully stabilized the submarine once the correct PID values were determined, verifying the functionality of the code.

4. Acknowledgements

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5. References

[1] Deep Trekker. (n.d.). Underwater Remote Operated Vehicles and Robots. Retrieved July 30, 2020, from https://www.deeptrekker.com/?utm_source=unmannedsystemstechnology.com

Appendix A: Component Specifications for Lanturn

Component	Vendor	Model/Type	Specs	Cost (if new)
Buoyancy Control	Blue Robotics	Buoyancy foam	12” x 6” x 1”	Re-used
Frame	McMaster Carr	Aluminum t-slot	6061-t6	Re-used
Waterproof Housing	McMaster Carr	Various aluminum, acrylic, bolts etc		$1388.84
Waterproof Connectors	Seacon	Wetcon	3-pin and 8-pin connectors	$895.23
Thrusters	Blue Robotics	T200 thrusters		$805.83
Motor Control	Blue Robotics, Digikey + other	ESCs, custom PCBs and components		$174.80
Actuators	Amazon	Servo motors	Various	$150.00
Battery	Turnigy	LiPo battery	14.8V, 20Ah	$175.00
Converter	Amazon	Buck converters	14.8V to 5V, 5A max output	Re-used
Motherboard	Nvidia	Jetson TX2		$0
External Comm Interface	RobotShop	Tether interface Fathom X board	7-28V, long distance ethernet	$186.32
Programming Language 1		Python 3		
Programming Language 2		C++		
Inertial Measurement Unit (IMU)	Vectornav	VN-100 IMU/AHRS	32bit processor, 3-axis accel, gyro, mag	Re-used
Doppler Velocity Log (DVL)	Teledyne	Pathfinder	600kHz	Re-used
Camera(s)	Blue Robotics	Low-light HD USB camera	2MP, 1080p	Re-used
Hydrophones	Aquarian	AS-1	1-100k Hz	Re-used
Algorithms: vision		OpenCV and YOLO v3		
Algorithms: acoustics		Custom cross-correlation alg		
Algorithms: localization and mapping		Custom PID and DVL algs		
Algorithms: autonomy		Custom ROS SMACH-based alg		
Team size (number of people)		40		
HW/SW expertise ratio		50/50		
Testing time: simulation		20hr		
Testing time: in water		10hr		

Appendix B: Component Specifications for Donphan

Component	Vendor	Model/Type	Specs	Cost (if new)
Buoyancy Control	Blue Robotics	Buoyancy Foam	12” x 6” x 1”	Re-used
Frame	McMaster Carr	Aluminum sheets and bolts	Various	~$300
Waterproof Housing	Blue Robotics	Acrylic tube and flanges	8” diameter	$312
Waterproof Connectors	Seacon	Wetcon	3-pin and 8-pin	Re-used
Thrusters	Blue Robotics	T200 Thrusters		Re-used
Motor Control	Blue Robotics, Digikey + other	ESCs, custom PCBs and components		$170.80
Actuators	Progressive automations	Linear actuator	12V, 6” shaft	$117.11
Battery	HobbyKing	MultiStar	14.8V, 10Ah	Re-used
Converter	Amazon	Buck converters	14.8V to 5V, 5A max output	Re-used
Motherboard	Amazon	Raspberry Pi	4GB RAM	$95.98
External Comm Interface	RobotShop	Tether interface Fathom X board	7-28V, long distance ethernet	Re-used
Programming Language 1		Python 3		
Programming Language 2		C++		
Inertial Measurement Unit (IMU)	Adafruit	Bosch BNO055	9-DOF, integrated dev board	Re-used
Camera(s)	Blue Robotics	Low-light HD USB camera	2MP, 1080p	$89.00
Algorithms: vision		OpenCV		
Algorithms: localization and mapping		Custom PID algs		
Algorithms: autonomy		Custom ROS SMACH-based alg		
Team size (number of people)		40		
HW/SW expertise ratio		50/50		
Testing time: simulation		20hr		
Testing time: in water		10hr		

Appendix C: Outreach Activities

During Fall semester, the team hosted various workshops for CSULA students to teach skills such as CAD modelling, PCB design, Arduino programming, and 3D printing. The team also participated in several department-organized outreach activities, which include teaching local high school students about the RoboSub project, a welcome buffet event where student organizations recruit members on campus, and tabling events on the campus walkway to recruit members and inform students who are interested.

Since the school’s format for courses and extracurriculars was transitioned to online only, the team has made considerable effort to reach out to students interested in the RoboSub project (or engineering in general) through presentations in online engineering classes, remote workshops for students to learn new skills, and mini-lectures and info sessions to spread knowledge about the project. These were carried out through the remainder of the Spring semester. Since then, the team has redesigned our website to be more informative and interactive, with detailed information about the submarines and interactive resources for students to access from home. The team is now focusing on organizing online activities to begin recruiting next year’s team of RoboSub students.