# SubjuGator 2022: Design and Implementation of a Modular, High-Performance AUV

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***Abstract*** **– Here we present SubjuGator 2022, the eighth and ninth generations of SubjuGator. SubjuGator was made by talented and diverse individuals who consist mostly of undergraduate students in UF's Machine Intelligence Laboratory (MIL). The current version of our autonomous underwater vehicle (AUV) focuses on adaptive control, hardware improvements, and software innovations. This model includes a controller area network (CAN) bus, onboard general-purpose graphics processing unit (GPGPU), deep learning for computer vision, and other challenge-specific designs. Additionally, the design changes, testing, competition, and teamwork strategies discussed were adapted based on previous experience, changes to the competition rules, and the structure of our team.**

## I. Competition Strategy

Leveraging 25 years of autonomous underwater vehicle (AUV) development experience at the University of Florida, which has produced seven prior individual platform designs, the SubjuGator family of AUVs has progressed to accommodate advances in sensors, computing, and mission requirements leading to the design of the new generation SubjuGator 8 vehicle (shown in Figure 1) and SubjuGator 9, presently under construction.

SubjuGator 8 has recently served as the flagship autonomous submarine for MIL for the past four years. For the 25th annual

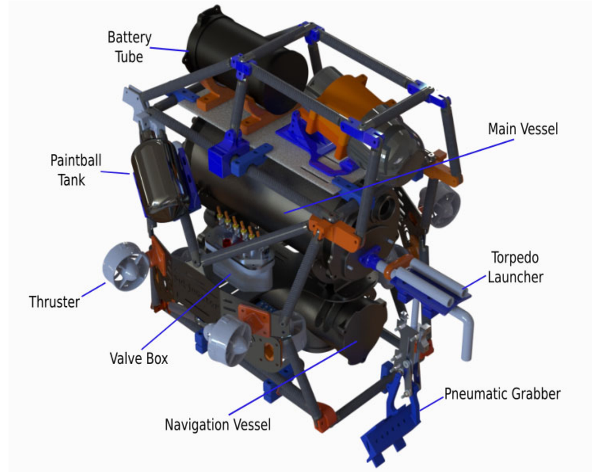


**Figure 1: Sub-systems of SubjuGator 8**

competition; SubjuGator 8 will once again join the previous iterations of autonomous underwater vehicles to solve novel tasks in a competition environment. Reusing SubjuGator 8 for the 25th annual competition provides our team with the benefit of reliable electrical and mechanical systems. Nevertheless, we continued to innovate on these systems, in order to provide the vehicle with the ability to perform all possible tasks in the competition, which includes identifying and classifying images using computer vision and deep learning, detecting and localizing acoustic pingers, shoot torpedoes, drop balls, and manipulate PVC structures.

SubjuGator 9 is still in development and therefore will not be used in the RoboSub 2022 competition. Major progress has made, which will be explored in section II D.

Finally, since the team this year consists of predominantly new members or members who will attend their first in-person competition, we prioritized mastering a select number of feasible tasks while maximizing test time. Thus, many of the design strategies took into account team capabilities and experience, while working on top of the infrastructure left behind from previous teams.

### A. Mechanical

SubjuGator 8's pneumatic system will be leveraged to perform all actuation tasks in a reliable manner. SubjuGator 8 also has the ability to sustain operation after a failure has occurred, whether the failure is of mechanical, electrical, or software origin. As an example, the redundant eight thruster design allows for the vehicle to maintain full six degrees of freedom control if on-board software detects a thruster failure. The submarine can continue to function with full motion capacities even if both a vertical and non-vertical thruster fails.

## B. Software

The submarine employs a heavy use of computer vision techniques to identify distinct objects and also provides our vehicle with an understanding of its environment through depth estimation. The passive sonar system (a hydrophone array) and cameras are used to locate regions of interest that contain a pinger. Upon correct discovery, the vehicle performs defined maneuvers to utilize each of the pneumatic actuators, depending on the specific task. Our modularized mission system allows developers to quickly construct and change mission plans in accordance with the sub's performance and goal.

## C. Electrical

The goal for the electrical team during the 2022 season was to improve and refine the overall electrical architecture of the sub. Many student-designed PCB boards on the sub were redesigned to provide better reliability and provide more data back to the main computer. The team accomplished this by expanding the CAN bus network to more boards allowing for better exchange of information between subsystems. One significant improvement was the introduction of a pair of battery management boards. These boards provide the rest of the sub with voltage and current outputs from the batteries. That information is then sent via the CAN bus to the main CPU, which can use the data to develop a more sophisticated power plan and protect the lifespan of the batteries.

# II. Vehicle Design

## A. Mechanical

SubjuGator 8 integrates three types of independently operated pneumatic mechanisms into its design (grabber, torpedo launcher, and marker dropper). The mechanisms are used to complete mission specific tasks and are controlled via the six pneumatic solenoid valves which are housed in a separate, compact pressure vessel shown in Figure 2.

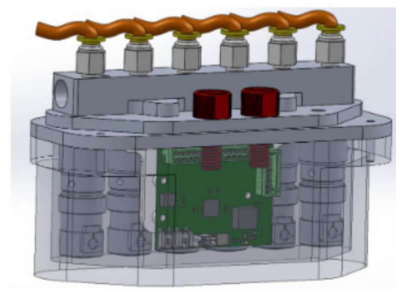

**Figure 2: Pneumatic Valve Box**

This design allows for quick-disconnect fittings to facilitate easy addition or removal of pneumatic subsystems.

The entire system is powered by an air tank, which is regulated down to a working pressure of 100 psi via two in-line regulators. The grabber is powered by a linear pneumatic cylinder mounted to plates. The cylinder actuates a 3D printed ABS gripper designed specifically to manipulate PVC from various angles and shapes.

Moreover, the space-frame type chassis, made from carbon fiber tubes and three aluminum sheet sections provides protection for delicate components of the sub, while providing for the flexibility to add additional components.

## B. Electrical

SubjuGator 8 consists of a robust set of industry standard as well as student designed electronic components. Peripheral to the main processing unit is a suite of devices to aid in navigation, safety, and communication. A water cooling system keeps SubjuGator 8 running at optimal thermal efficiency. The navigation system includes a Doppler Velocity Log (DVL) and inertial measurement unit (IMU). The tether allows an Ethernet interface that is leveraged when a hard-wired connection with SubjuGator 8 is necessary during testing.

The safety system incorporates both battery monitoring and emergency shut-off components. The battery monitoring module allows SubjuGator 8 to monitor power consumption. This is important when deciding when to safely change batteries on the robot. Furthermore, the thrust/kill board is another student designed board that allows the robot to control thrusters as well as cut power to them, creating a safe shut-down feature. If all else fails, there is also a manual shut-off feature that can be triggered by placing a magnet on the appropriate location of the vehicle, thereby cutting power to the thrusters. This action is facilitated by Hall effect sensors and relays.

Other student designed boards include a power merge board and a system status board. The power merge board safely combines the power of two 24 V batteries to create one 24 V power source that is routed throughout the rest of the system. The system status board provides real-time diagnostics of SubjuGator 8 through CAN and wireless interfaces.

The system also includes a passive sonar (hydrophone array) device that gives the vehicle the capacity to accurately track a point source of sound in an aquatic environment.

## C. Software

SubjuGator 8's software stack is built on the Melodic version of the Robot Operating System (ROS). Our stack has grown to over 60+ ROS packages, all of which are open-source[1], allowing other teams to share the benefits from our work. Many of our packages feature extensive documentation, and we are constantly improving their documentation and features.

[1] All code is located at https://github.com/uf-mil

### 1. State Estimator

The state estimator uses an inertial navigation system (INS) and an unscented Kalman filter [1]. The INS integrates inertial measurements from the IMU, producing an orientation, velocity, and position prediction. The Kalman filter estimates the state by comparing the output of the INS prediction against the reference sensors, which are a magnetometer, depth sensor, and Doppler Velocity Log (DVL).

### 2. Trajectory Generator and Controller

The trajectory generator is based on a nonlinear filter that produces 3rd-order continuous trajectories given vehicle constraints on velocity, acceleration, and jerk [2]. Our trajectory tracking controller implements a proportional-integral-derivative (PID) controller with feed-forward velocity and acceleration terms to estimate drag and buoyancy.

### 3. Mission Planner

The vehicle's mission planner is responsible for high level autonomy and completing the competition tasks by enabling asynchronous support in Python. This library has been developed and used for the past ten years, and is continually being augmented and improved (including this year, with a move towards supporting Python 3).

### 4. Vision Processing

Traditional techniques, namely image segmentation via adaptive thresholding, followed by contour analysis, are used to find many of the competition elements.

Deep neural networks are also used to assist traditional computer vision techniques. In particular, the architecture known as *You Only Look Once* (YOLO) [3] is used, which is trained by using transfer learning and with the darknet YOLOv4-tiny model [4]. After the feedforward step, YOLO returns bounding boxes and object classifications. The training data is labeled by the team using a collaborative labeling tool for machine learning called *LabelBox* [5].

Additionally, by modeling object motion, a dynamic scene can be reconstructed by an unsupervised learning technique [6] which enables monocular depth predication and serves as an initial guess for object pose prediction. Using one Point Grey Chameleon camera and one e-con See3CAM CU20, we generate robust 3-D information of our world when operating in favorable conditions. Internal camera calibration and distortion parameters are obtained using [7].

### D. SubjuGator 9

Limitations caused by the pandemic, significantly delayed the manufacturing of the SubjuGator 9 (Figure 3) chassis, making the ninth generation SubjuGator unavailable for RoboSub 2022.

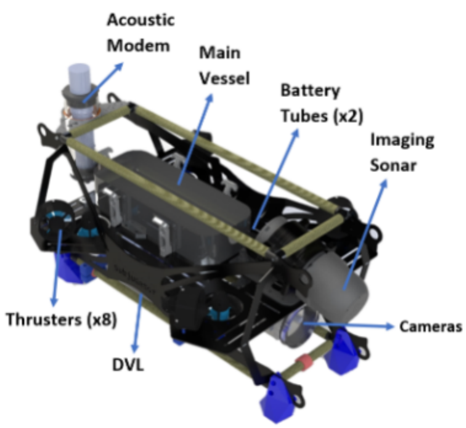


**Figure 3: Sub-systems of SubjuGator 9**

However, significant progress has been made in the manufacture of the complete aluminum chassis (Figure 4) as well as the main electronics hull (not shown).

**Figure 4: SubjuGator 9 Aluminum Chassis**

## III. Experimental Results

Before the competition, our submarine was rigorously tested, both in simulated and physical environments. Due to the COVID-19 pandemic, our team was unable to test the submarine throughout the 2020 and 2021 seasons. As a result, we prioritized having an extensive 2022 testing schedule to ensure that new members gained an understanding of how the sub performs in a physical environment.

### A. Mechanical

The main testing goals for this iteration was to have a pneumatic system and the hardware kill system working reliably, and to make sure the submarine moves and floats in a stable manner by adjusting the weight distribution on the current configuration.

### B. Electrical

Physical testing was done to refine the electrical architecture. Each board was tested using laboratory tools, such as oscilloscopes, microprocessor development boards, and computers, to ensure each board worked as functioned. Back-up PCBs were assembled as replacements, if necessary. Through this process, the team ensured the electrical systems functioned and communicated properly between the boards and the computer.

### C. Software

Our software systems were dually tested in a physical environment (using a university pool) and a simulated environment (using the Gazebo simulation software). The simulation environment allowed for rapid development of various SubjuGator components, while testing in a real-world environment ensured that our systems were operating as expected in a true environment.

## IV. ACKNOWLEDGMENTS

The SubjuGator team, at the Machine Intelligence Laboratory (MIL) at the University of Florida (UF), would like to thank everyone who has supported us throughout the year, including the University of Florida's Electrical and Computer Engineering (ECE) Department, Mechanical and Aerospace Engineering (MAE) Department, and the students and faculty in our sister laboratory, UF's Center for Intelligent Machines and Robotics (CIMAR).

We would also like to thank several former students who have contributed to our team with especially valuable advice.

Each of the following corporate and MIL alumni sponsors were gracious to assist with either (or both) monetary and product donations:

- Diamond Sponsor: L3Harris Corporation.
- Platinum: Erik de la Iglesia (MIL alumnus), Reid Harrison (MIL alumnus).
- Gold Sponsors: Texas Instruments, UF's Department of Electrical and Computer Engineering (ECE), UF's Department of Mechanical and Aerospace Engineering (MAE).
- Silver Sponsors: SolidWorks.
- Bronze: DigiKey.

The latest SubjuGator developments can be found on our web page [www.subjugator.org](www.subjugator.org) or by following us on twitter @SubjuGatorUF or on YouTube platform (SubjuGator AUV).

# VII. REFERENCES

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# APPENDIX A: COMPONENT SPECIFICATION

| Component | Vendor | Model/Type | Specs | Origin | Cost | Purchase Year |
|---|---|---|---|---|---|---|
| Buoyancy Control | No hardware - Positively buoyant (thrusters control depth) | | | | | |
| Frame | DragonPlate | Carbon fiber | Space frame | Custom | | |
| | Students | Aluminum | Frame core | Custom | | |
| Waterproof Housing | Students | Aluminum | Main vessel | Custom | | |
| | Students | Aluminum | Navigation vessel | Custom | | |
| | Students | Aluminum | Pneumatic vessel | Custom | | |
| | Blue Robotics | Aluminum | Downward camera vessel | Custom | | |
| | Students | Aluminum | Power Vessel | Custom | | |
| Waterproof Connectors | SubConn | Wet-connect | External wet-mate connectors | Custom | | |
| | SEACON | Wet-connect | External wet-mate connectors | Custom | | |
| Thrusters | Blue Robotics | T200 | | Purchased | $169 | |
| Motor Control | Blue Robotics | Basic ESC | 7-26v, 30amp, PWM | Purchased | $25 | |
| High Level Control | | | | Custom | | |
| Actuators | Clippard | | Double acting ½" bore, ½" stroke | Custom | | |
| Propellers | Blue Robotics | Stock | | Custom | | |
| Battery | MaxAmps | LiPo | LiPo 5450 6S, 22.2v | Custom | | |
| Converter | Students | | Power over Ethernet (POE) | Custom | | |
| Regulator | Various | | | Custom | | |
| CPU | ASRock | ASRock Z390M-ITX | mini-ITX motherboard | Purchased | $140 | |
| | Intel | i9-9900k | | Purchased | $500 | |
| GPGPU | Nvidia | RTX 2080 | | Purchased | $700 | |
| Internal Comm Interface | Students | | CAN | Custom | | |
| | Various | | USB | Custom | | |
| External Comm Interface | | | Ethernet | Custom | | |
| Compass | PNI | TCM MB | | Custom | | |
| IMU | Sensonar | STIM300 | 9-axis | Custom | | |

| **Component** | **Vendor** | **Model/Type** | **Specs** | **Origin** | **Cost** | **Purchase Year** |
|---|---|---|---|---|---|---|
| DVL | Teledyne | Explorer | 600kHz | Custom | | |
| Manipulator | Students | | | Custom | | |
| Algorithms | Rapidly-exploring random tree (navigation), Adaptive PID | | | | | |
| Vision | OpenCV (Canny Edge Detection, Thresholding, Optical Flow), RCNN (YOLOv4-tiny) | | | | | |
| Acoustics | Scipy, Numpy (Time of Arrival, Least Squares, Fast Fourier Transform) | | | | | |
| Localization + Mapping | Eigen (Unscented Kalman Filter) | | | | | |
| Autonomy | Robot Operating System (ROS) Melodic | | | | | |
| Open-Source Software | Most SubjuGator software is published under an open-source license; most libraries used by SubjuGator are open-source (OpenCV, Scipy, ROS, Numpy, PySerial, PyYAML) | | | | | |