AUV Amogh

Preliminary Design Report
IIT Madras

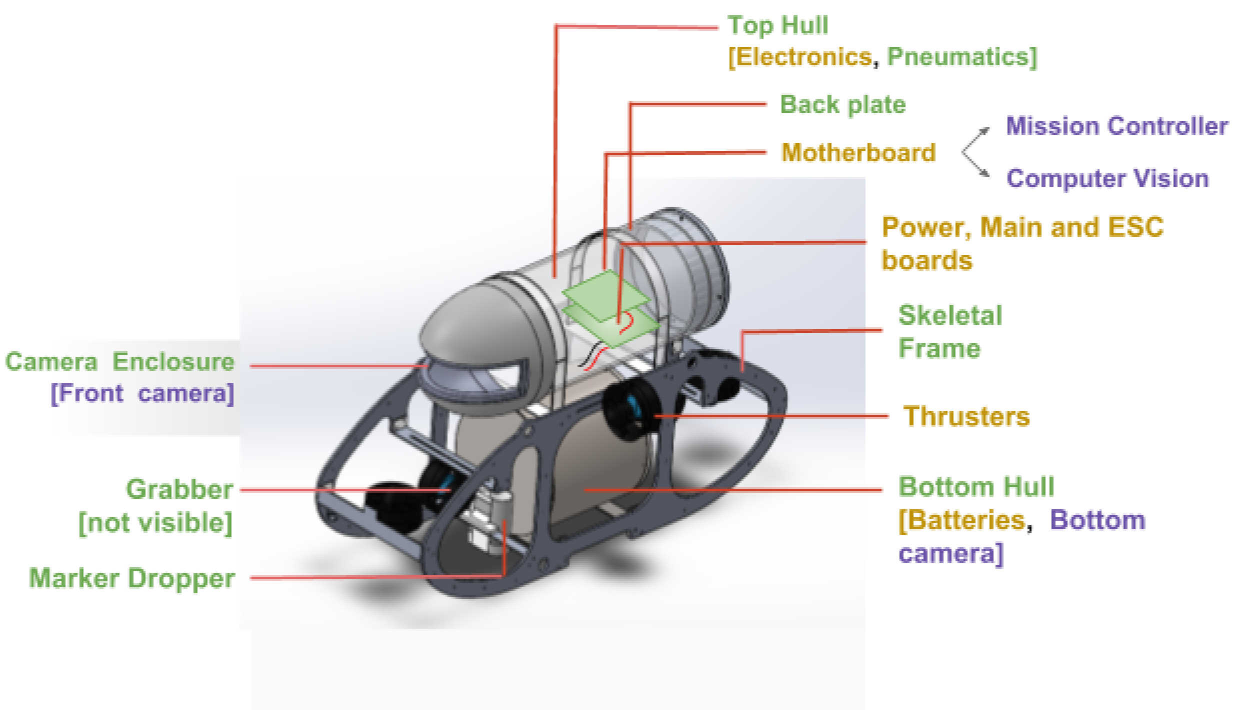
NIOT - SAVe

Abstract

Exploring the seafloor is quite a challenging task. Sparsity of light, depth and cold temperatures are just a few of the factors that make it such a daunting environment. ROVs (Remotely Operated Vehicles) are well suited to operate between moderate and deep depths underwater, but are fundamentally constrained by the requirement for continuous communication/feedback with the on-ground controller. Thus has emerged a new paradigm for performing tasks at extreme depths - that of Autonomous Underwater Vehicles (AUVs). AUVs are designed such that there is no requirement for communication with an on-ground operator and are intelligently *pre-programmed* to carry out tasks underwater that may not be feasible to deploy ROVs for. Amogh is an attempt at designing an AUV template that can be specialized to perform various tasks with minimal effort.

Amogh has designed been designed with the objective of performing data collection via the various on-board sensors and deliver/collect small volume underwater samples. It is equipped with cameras for feature identification underwater and a grabber mechanism that can be used to collect payloads. It also has a dropper mechanism that can be used to deliver small payloads to the target location(s).

Key design focal points were mechanical and operational robustness to withstand the adverse underwater conditions and tolerance to unpredictability in the environment. Modularity in design and maximizing efficiency were also crucial factors in the design process. Amogh is currently being prototyped and tested for shallow depth waters as a proof of concept with the ultimate goal of deployment at greater depths. A use case for Amogh can be the survey of interoceanic pipelines/cables. Amogh can be pre-programmed to identify and follow the pipeline underwater, and evaluate potential fault locations. The collected data can be analysed post resurfacing to devise remedies.



Structural Design of AUV Amogh

Mechanical Design

Dual Hull Design

Amogh is designed with two hulls placed symmetrically one below the other, with the batteries and other heavy components housed inside the lower hull and electronics housed in the top hull. The heavy bottom provides greater stability by lowering the Centre of Gravity (CM) and increasing the vertical separation between the CM and Centre of Buoyancy (CB). Mass is concentrated as much as possible at the centre of the bottom hull to achieve damping to cancel roll motion. Resistance to pitch motion is achieved by distributing weight symmetrically about the longitudinal central axis of the AUV. This ensures that the CM and CB are aligned vertically. Isolating batteries in the lower hull also protects other delicate electronics under abnormal circumstances.

Both hulls were designed as cylinders because it provides the right balance between reducing drag, maximizing internal space for mounting components and ease of manufacturing, without compromising on the ability to withstand hydrostatic pressure. The AUV is designed to be **positively buoyant** to allow it to float to the surface if the use of inbuilt kill-switch is necessitated.

Top Hull

The top hull is designed to be transparent to make it possible to keep a watch on the electronic sub-assemblies inside the top hull for debugging purposes. It is constructed using acrylic, being transparent, strong and extremely lightweight.

Bottom Hull

To make the bottom hull heavy for more stability, mild steel was chosen. A camera is enclosed in the bottom part of battery hull with an acrylic window to view outside.

Skeletal Frame

A skeletal frame is used to mount both the hulls along with other mechanical modules including thrusters and the grabber mechanism. It accounts for mechanical strength both in and out of water. It also adds to the modularity of the AUV. Readily available Al-Strut channels in addition to being lightweight provide enough structural integrity for use in the skeletal frame. The profile of the frame was determined based on that with the optimal CFD profile and surface area to attach the grabber and dropper mechanism.

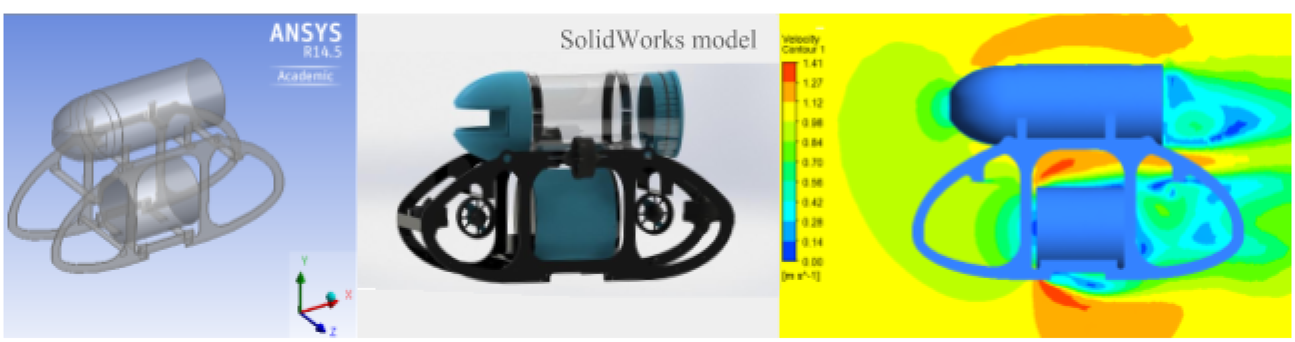


Figure 1. SolidWorks CAD Model and CFD profile

Hydrodynamic Performance

To inhibit susceptibility to cavitation and hydrodynamic resistance at higher depths, a front nose satisfying the laws of hydrodynamics is important. Four different profiles - cone, stubbed nose, spherical and elliptical, were considered and analysed for drag and dynamic pressure distribution.

From the results of the CFD analysis, it was inferred that an ellipsoidal profile is best suited for imparting improved hydrodynamic performance to the vehicle as it experiences minimum drag. The ideal major to minor axis ratio was observed to be 1.6. The front nose was modelled using Polypropylene (PP).The diameter of the top hull is 195mm and the front nose extends out 310mm.

While performing analysis, the complex geometry of the vehicle is simplified by neglecting thrusters and other payloads [refer figure 1]. Tubes and wires were also neglected in order to study the total drag on the hulls and frame. The comparison of estimated resistance for different versions of the vehicles and power requirements shows that there is reduction of power required by 35% at a velocity of 1m/s with respect to previous designs.

At a pressure of 2.2Mpa, the top hull with a yield strength of 45 Mpa attains Von Mises stress of 44.2 Mpa. This gives 208 meters as the theoretical depth before failure for the top hull and the AUV.

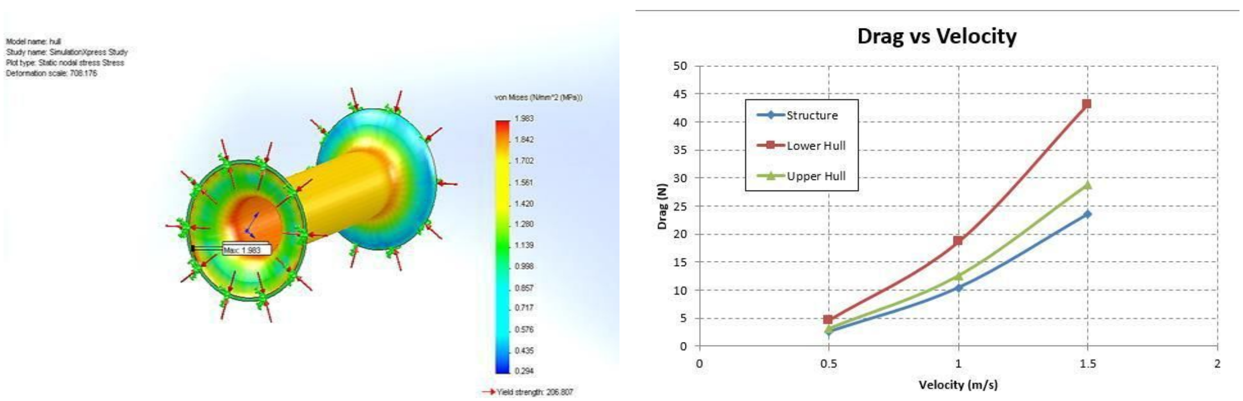


Fig. 2. (a) Simulations to analyze structure (b) Estimated drag breakup from CFD analysis

Fig. 3. Velocity contour plot for the flow around the AUV

Thruster Configuration

Amogh Version uses 6 thrusters for achieving control in **4 degrees of freedom**.
Their configuration is as follows [refer to figure 2]:

1. Two thrusters placed on either side provide surge and yaw motions differentially.
2. Two thrusters placed in the front and back differentially provide Heave and Pitch motions
3. Two thrusters mounted between the two hulls facilitates sway motion. They lie on either side of CM and CB to achieve yaw motion when operated differentially.

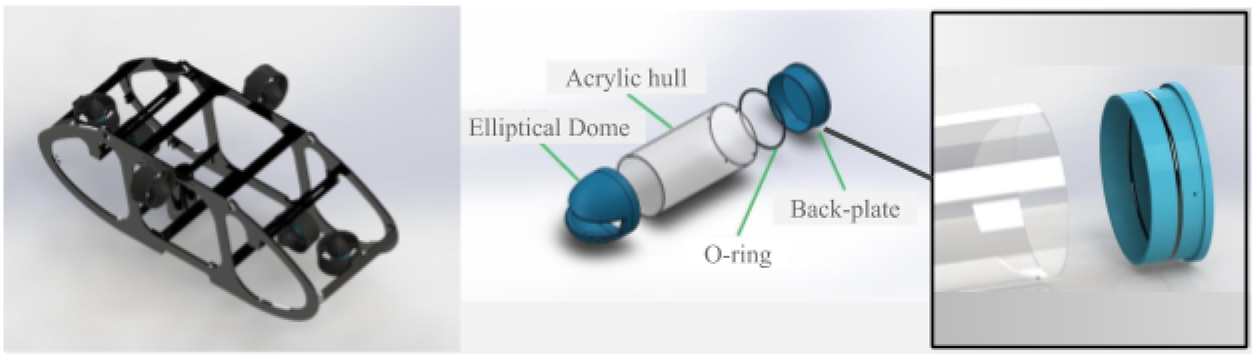


Fig 4. Exploded view of thruster configuration and top hull

Grabber

The grabber is a mechanical arm capable of hoisting small and medium weight payloads. It has a two-claw design that uses a double acting piston as actuation. The claw is positioned at the bottom of the AUV and is actuated via solenoid valves directed by the main board and which are placed in the top hull.

Marker dropper Mechanism

The marker dropper mechanism is capable of holding and releasing small payloads on command. It consists of two holders for two different payloads, each with a double acting cylinder holding the payload in place. Pistons are triggered individually by a solenoid valve as directed by the main board. The piston pulls in to drop the payload into the water. The marker dropper mechanism is displayed in Figure 4 (a).

Top hull nose

Polypropylene is selected for the front end cap of top hull for ease of manufacturing. The surface finish is polished for hydrodynamics. It has a wide FoV aperture in the front where cameras will be facing.

Back-plate

The rear end cap is made of aluminium because it is a better option for attaching connectors, via welding. It also has an undue advantage of acting as a heat sink for dissipating heat produced by electronics inside the top hull.

Bulk-head connectors

Male and female connectors of required diameters are fitted to the back-plate of both hulls. Chloroprene rubber based SubConn connectors were used for easy integration with systems. The female end is attached to the back plate, and the male end connects to different sub-assemblies. SubConn connectors are easy to install, are modular because there is no need for any adhesive and have high depth rating.

Waterproofing

The back-plate on the bottom hull is sealed using face sealing while the on the top hull is sealed laterally. The circumferential gap between the back-plate and the hull is sealed additionally using silicone grease.

Lateral Sealing Mechanism

As shown in figure 2, the back-plate is grooved sideways for the O-ring which fits into the slot with some portion projecting out. As the plate is fit, the O-ring gets compressed and ensures water tightness.

Sealant

After carefully studying the various options for sealants, araldite was chosen due to the strong waterproof joint it creates that can withstand high pressure. AUV Amogh uses araldite at the following sites:

1. Between acrylic hull and polypropylene end cap of top hull.
2. Front cap join with the aluminium bottom hull.
3. Rear cap join of the bottom hull.

Fig. 5. (a) Marker Dropper Mechanism (b) Battery enclosure (mild steel)

Electrical Design

Power consumption is one of the major concerns while designing an AUV as it is powered by on-board batteries. Mechanical as well as electrical design factors decide the power rating of the AUV. To survive long underwater missions, the allowed loading capacity of the AUV has been minimized as far as possible. Amogh uses custom electronics and sensors designed in-house, that have undergone rigorous testing, to **half the cost** of commercial counterparts. By removing redundancy in off-the-shelf boards, efficiency is improved. Flexibility, upgradability and compactness were the major focal points of electrical design. Below is illustrated a breakup of the electrical subsystem design:

Printed Circuit Board (PCB) Design

Where mentioned, electronic devices discussed below are integrated together compactly as custom PCBs. The EAGLE tool from AutoDesk was used to design circuit boards for Amogh. Due to tight space constraints, maximum focus was laid on designing compact boards, which saw the utilization of *Surface Mount Devices* (SMDs). Building PCBs significantly improves system reliability.

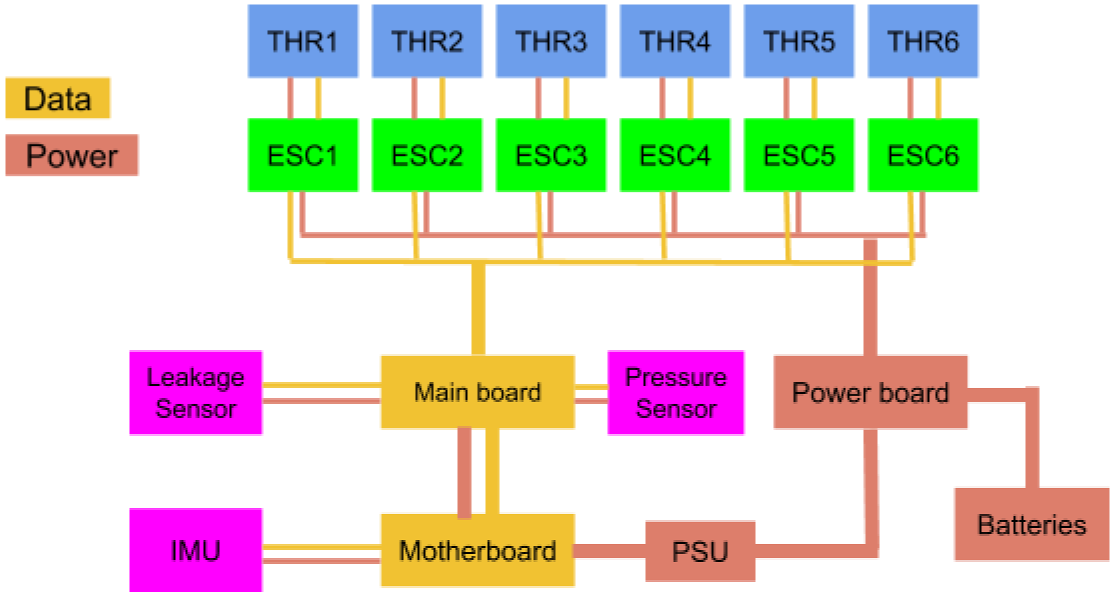


Fig 6. Structure of Electrical Subsystem

Motherboard

The motherboard burdens the brunt of the processing requirements of the AUV from both the image processing and mission control ends. The Intel I7-4770T is close to the ideal processor for the AUV under the subjected constraints which meets the processing requirement featuring a 4 core, 8 thread setup, and operates at 2.5 GHz with a 45W TDP. It is supported with 4GB of on-board DDR3 RAM. MSI-Z87i was chosen as the motherboard for the CPU. It fetches required power using an external 20 pin DC-ATX power supply converter, *picoPSU-120* from *Minibox*.

Electronic Speed Control Boards (ESC boards)

ESCs control speed and provide tri-phase AC power to the low-impedance brushless thrusters from the on-board DC power input. On Amogh, custom designed PCBs were used as ESCs built around an Atmega8 microcontroller. The boards can handle power in compliance with the peak power and current ratings of 12.5A and 135W respectively for the Blue robotics T100 thrusters. A PWM signal from the main board to the ESC controls the thruster RPM. The ESCs provide short-circuit, overheating and over/under voltage protection. Heat sinks are installed on all the 6 ESCs for heat dissipation and sensor-less feedback is used to affirm the RPM of the thrusters, which is calculated using the motor back-emf generated. It communicates over an I2C bus with the main board and are equipped with a safety fuse, separate I/O port and current sensor across it for logging.

Fig. 7. ESC board

Thrusters

The thrusters used in the AUV are Blue Robotics T100 thrusters. These are brushless thrusters powered by 3-phase AC from the ESC boards. These operate using a voltage supply of 22V with a peak power rating of 135W. The max forward thrust that they generate is 2.36kgf and reverse thrust is 1.85kgf. The thruster is speed control is given via PWM signal with an allowed pulse width from 1100μs to 1900μs with 1500μs being the OFF pulse width. Amogh is fitted with 6 thrusters as described in the mechanical section.

Main Board

To interface the various component boards with the motherboard, we use a central controller [Arduino Mega2560] which has adequate number of pins for external I/O. This offloads the data serialization problem from multiple peripherals. The abundance of Arduino libraries simplifies the process of writing custom firmware. The main board interfaces with the motherboard via USB and communicates with the CPU over a strictly defined protocol, continuously relaying AUV state parameters (orientation, speed, heading, depth and sensor data) over a serial line. This data is processed by the CPU and instructions are directed back to the main board to update thruster PWM values.

Sensors

Inertial Measurement Unit (IMU)

AUV localization is very significant problem under water. It requires precise heading, pitch and roll measurement. The IMU is extremely crucial in this aspect providing orientation velocity and gyroscope data. Amogh uses a low power (330mW), high performance (±1.0°RMS error) IMU (Inertial Measurement Unit) - Sparton AHRS 8p which accurately provides attitude, position and orientation sensing with in-field calibration.

Fig. 8. Sparton AHRS-8p IMU

Pressure Sensor

A submersible pressure sensor is used in the AUV which is placed directly in water and is screwed into female threading in the back-plate of the top hull. The PX-319 gauge pressure sensor from Omega Engineering used, can go up to 2 bars of pressure (20.5m), with an accuracy of 0.25% FSR.

Leak Detection Sensor

A leak detection circuit is employed to detect if water accidentally seeps into the hull. Two circular probes mounted near the back-plate of the hulls monitor the intrusion of water inside. Due to water, conductivity would be amplified and the voltage feedback is provided as an input to the main board.

Power Management System & Electronic Safety

The key components of Amogh's power management and electronic safety system are the Lithium-Polymer battery bank, current and voltage sensors, and kill switch.

Batteries

An added constraint of not having a tether to the surface of the water is that Amogh must be powered from a set of on-board Lithium-Polymer (Li-Po) batteries. The optimal power-to-weight ratio was found to peak using four 8Ah Lithium Polymer batteries in parallel. Current and Voltage across batteries, thrusters and other electrical components are continually monitored through using voltage and current sensors. This data is logged for monitoring the health and performance of the components as well as for predicting faults. Faults during a mission are dealt by the mission controller, and later the logged data can be used for debugging purposes At full load, the bot can endure 45 minutes of underwater activity. However under real conditions, the bot is is estimated to stay submerged for about 80-90 minutes at a stretch.

Power Board

The Power board interfaces with all the batteries individually and connects them in a parallel fashion. It takes care of power distribution to thrusters, motherboard and peripherals. DC-DC converters are incorporated in the board for conversion of battery 24V to 12V, 5V and 3.3V, which provides the regulated output to the 6 thrusters, main and ESC boards and other sensors respectively. Heat sinks are included for the 24 to 12V converter due to the high power it supplies. The power board also features under-voltage protection for the battery using MOSFET switching under critical threshold voltages.

Kill Switch

Kill switch, when activated, immediately disables the AUV and is only for use during emergency circumstances; being positively buoyant the AUV would eventually rise to the surface.

Mission Controller

The Mission controller is the central control unit and interface for all systems on board. It is a set of processes which perform metabolistic and bookkeeping operations. The underlying intention was to create a highly modular API that abstracts away the control algorithms and low level interactions with the various peripherals that can be used to program the AUV to perform virtually any kind of task with minimal effort.

- It is centered around a shared memory block described below that holds the real time state information of the AUV (orientation, velocity, depth, current, voltage) and is updated by the various sensors (IMU, pressure sensor etc.) and processed camera feed continuously.
- PID control is used to generate PWM targets that are passed on to the main board that interfaces with the thrusters.
- The data logger continuously logs the shared memory state in a structured manner for future analysis and debugging.

Shared Memory

The mission controller allocates a portion of memory as a shared memory space. Every program can access data stored in this block and it has been designed in such a way that makes it extremely easy to modify. Programs can read data from and write data to these locations independently which reduces latency. Data integrity is automatically ensured as all read/write operations are atomic. Implementation is done using inbuilt C++ libraries.

Image Processing Sub-system

Image processing sub-system is responsible for surveying the environment around the AUV, recognize objects of interest and provide their coordinates. These coordinates are written into the shared memory block as polar coordinates. Underwater environments present several challenges for Image Processing algorithms. Primarily:

1. Color distortion. Salt and fresh water absorb wavelengths near the red-end more than at the blue end, whereas water with organic colloids (such as marshes) absorb blue-end wavelengths more.

2. Poor illumination. Natural sunlight attenuates very quickly and cameras are unable to perceive colors and shapes accurately in deep water. At shallow depths, strong sunlight can also create uneven patterns of light on objects which significantly interferes with normal algorithms.

Keeping these in mind, we have designed a two pronged approach to object detections:

1. Image preprocessing to vastly reduce the complexity of images, followed by
2. task specific operations depending on the nature of the object to be detected.

The Python-OpenCV library was used for implementations of all commonly used algorithms.

Image Preprocessing

Pick channel of interest

Different channels of the image contain different objects of interest in varying prominence. Depending on the task, either a single channel or a weighted average is considered.

High Pass Filter

This is used to extract edges and their prominence from the image. The HPF is applied as a simple Gaussian filter with fixed parameters the result of which is then subtracted from the original image.

Noise removal

Since noise pixels have a high gradient around them, the filter responds to these as well. These can be removed by standard noise removal filters such as a median blur.

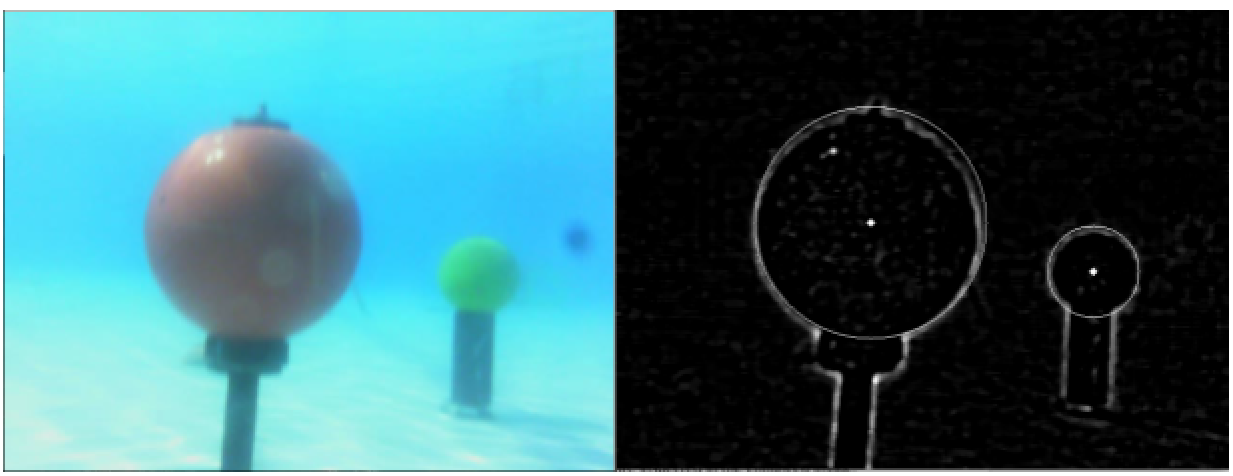


Fig. 9. Buoy detection made possible using edge map

Task specific steps

Depending on the task, openCV functions are used to locate circles and polygons in the image. More complicated shapes can be located using feature based techniques such as SURF. If numbers and alphabets are to be detected in the image, HP’s Tesseract library is used. For object classification, approaches based on neural networks are being tested. The benefit of using such approaches is the fact that the edge map generated usually is composed of an outline of the object over random noise - an image that can be synthesised artificially to train the neural network on.

Color Detection

If the task is color specific, contrast enhancing algorithms like Histogram equalization / normalization is applied. It recovers highly attenuated colors but also amplifies noise and makes the colors unnatural. Hence the image is preprocessed to get regions of interest and only those pixels are inspected in the enhanced image.

Web-based GUI (Web App)

The Web based GUI is an attempt at an interface capable of debugging the AUV, reading logs or taking manual control of the AUV for data-collection, all *while in operation*. The AUV is connected to a router on land via the ethernet port in the back plane. The AUV runs a Node.js server and serves a simple web page to another computer connected to the same router. The client only needs to have a web browser installed in order to operate the AUV. By design, a mobile phone with a web browser, connected to the router **can completely control the bot**.

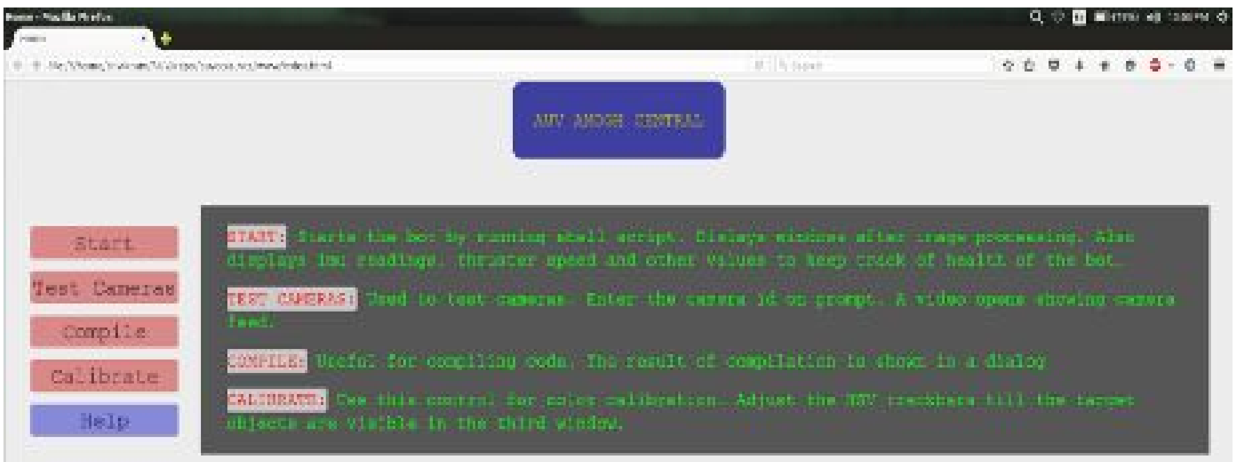


Fig 10. Home page of the web app

The following tasks can be performed from the webapp:

1. **Start/Stop**
2. **Camera feed video streaming**
3. **Data Logging**

References

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