Design and Development of Underwater Vehicle: ANAHITA

Technical Design Report: Team AUV-IITK

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***Abstract*— Anahita is an autonomous underwater vehicle which is currently being developed by interdisciplinary team of students at Indian Institute of Technology(IIT) Kanpur with aim to provide a platform for research in AUV to undergraduate students. This is the second vehicle which is being designed by AUV-IITK team to participate in 22nd Robosub 2019 competition organized by AUVSI. The Vehicle has been completely redesigned with the major improvements in modularity and ease of access of all the components, keeping the design very compact and efficient. New advancements in the vehicle include a new acoustic localisation system, navigation system using Doppler Velocity Log and IMU, new electrical circuit boards, using Deep Learning for computer vision tasks, as well as increased autonomy for the system using State Machines.**

I. COMPETITION STRATEGY

Being debutants at the competiton, our main aim was to specifically focus on some of the tasks which we were most confident in completing successfully. Since this is our second vehicle, we already had an existing framework for the three subsystems, but we decided to completely overhaul these and designed a new vehicle, mainly focusing on the modularity and robustness of the system. We designed a completely new software stack, taking full advantage of the recent upgrades in the Mechanical and Electrical designs. We tested our new controls and planning system through regular in-water testings as well as Gazebo simulations. Stress tests were performed on the circuit board by making the system run at the highest load over an extended period of time. A completely new acoustic and actuation were designed and implemented for torpedo and manipulators.

Since a lot of changes were being made at a rapid rate, we had to make sure that the testing time was being used at the maximum efficiency. Since the software stack was written completely new, everything including the low-level controllers, tasks and mission planner had to be tested. The pre-qualification task was the main point of our focus. After this, the the tasks were divided into three main categories, visual servoing using front and bottom cameras, interfacing the various hardware dependant tasks with the software, and testing waypoint navigation and the mission planner. The task, *Slaying the buoys* required us to identify the vampires and move towards them, for which object detection and simple motion were used. *Stake through Heart* will be attempted using our newly designed actuation system. The Acoustic system will allow us to navigate to the *Stake through Heart* and *Expose to Sunlight* and help the vehicle resurface.

Anahita is an improvement over AUV-IITK's previous vehicle Varun in terms of its modularity, robustness, ease of manufacturing and assembly. Rigorous Finite Element Analysis(FEA) is done to improve the robustness and use of Computer Numeric Control(CNC) machining has been increased. Some components are interchangeable and work specific parts increases the vehicle's modularity significantly. The vehicle is designed to perform complex space-constrained tasks and at the same time, not compromising on the maneuverability.

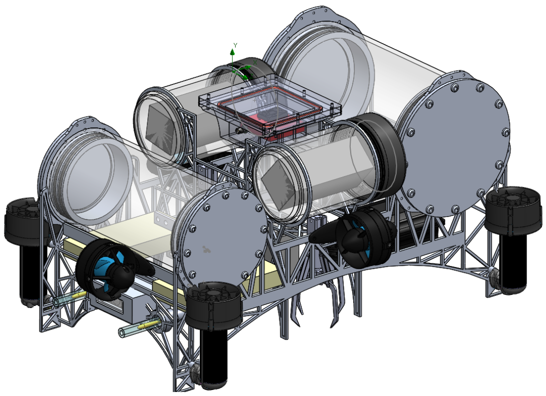


Fig. 1: Anahita Vehicle

II. VEHICLE DESIGN

Separate watertight casings have been made for individual components namely Cameras, IMU, Batteries, Acoustic Module and the main Electronics rack. Rigorous stress tests were made in designing the frame of the vehicle. All the enclosures and the frame has been designed in a way to keep the drag of the vehicle to a minimum. Acrylic and Aluminium 6061-T6 has been used for most of the Vehicle components. A new grabbing mechanism has been designed to suit for the Robosub‘s grabbing task. The buoyancy of the vehicle is being controlled by proper placing of dead weights and buoyancy foams.

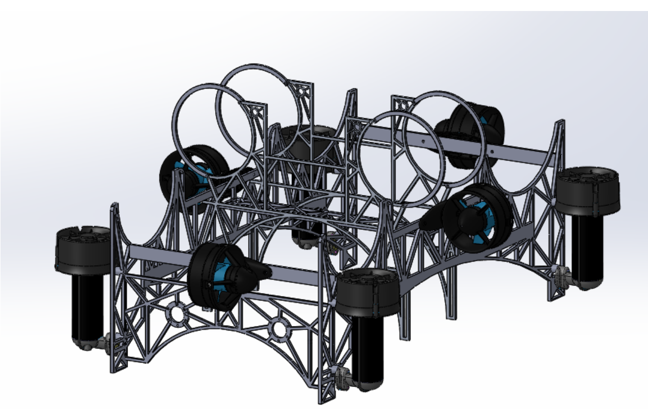


Fig. 2: Frame of Anahita

Major achievements in the electrical subsystem are custom design and fabrication of on board electrical circuit boards. A significant improvement in the electronics has been made by implementing modular design, which helps in debugging the system a lot faster. Detachable Arduino board and Mouser connectors were used to make the PCB more modular. The power board distributes the power coming from the battery after changing the voltage as required by the individual components. A full kit of inertial, visual and acoustic sensors are being used for data collection and navigation. The vehicle is powered by two lithium-ion polymer batteries, which have higher specific energy.

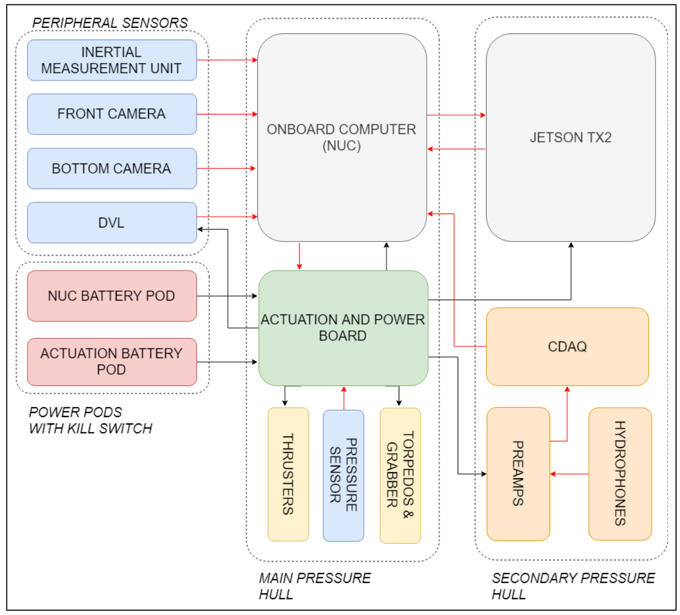


Fig. 3: Electrical Flowchart

Acoustic Signal Processing has been introduced for the first time in our Vehicle. A set of 4 Aquarian Audio AS-1 hydrophones are used and each signal received by the hydrophones is passed through its individual amplifiers. The amplified signals are fed into NI-9223 board through a C-DAQ, which is later fed into the LabView software through the NUC. All the processing is done inside the software. A cross-correlation algorithm is used to calculate the heading. This data is passed on to the Navigation Layer as a control variable for vehicle motion.

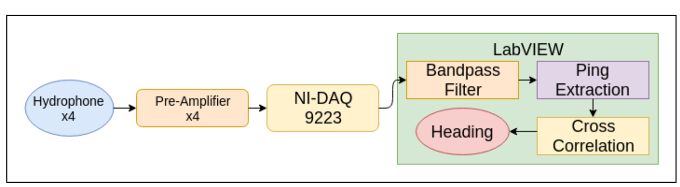


Fig. 4: Acoustic Processing

Another important challenge was to develop low level controllers which will be capable of

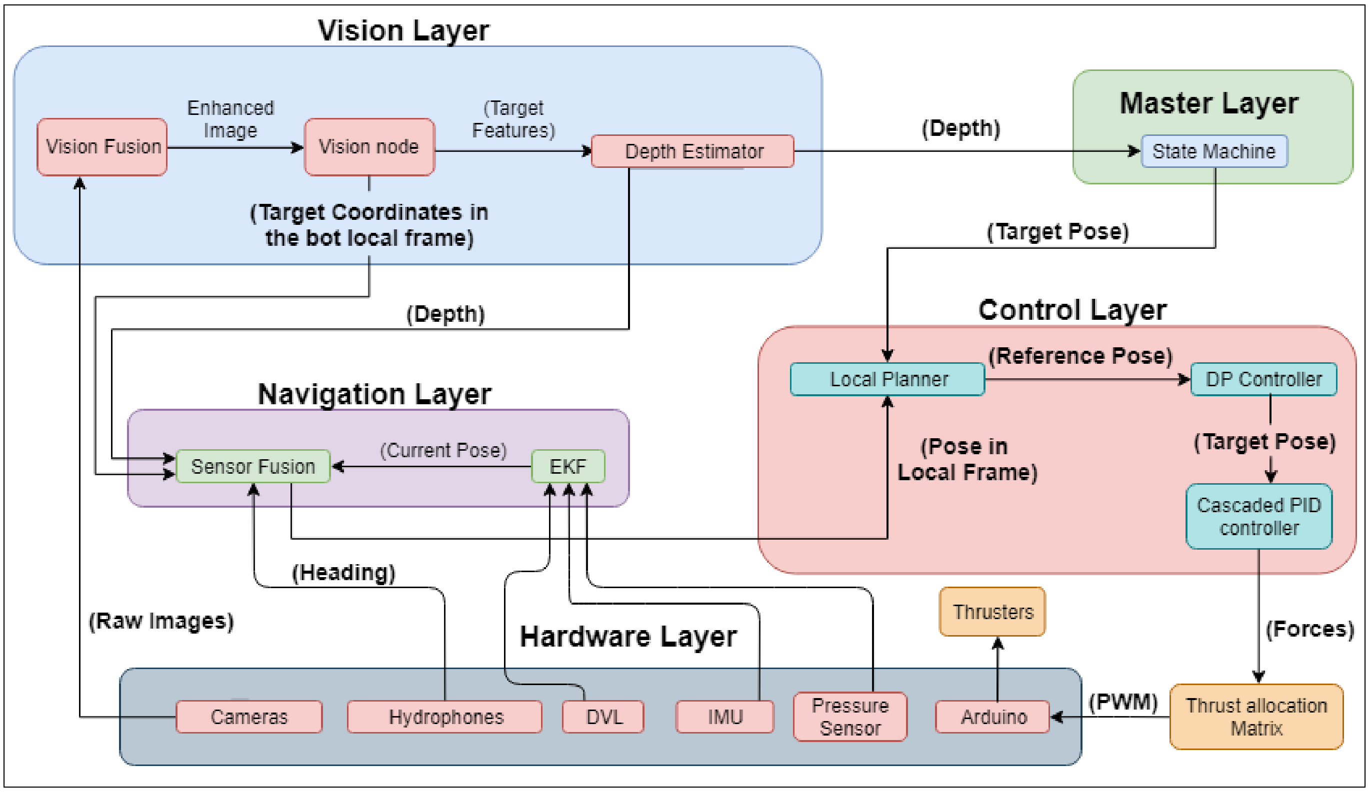


Fig. 5: Software Flowchart

producing stable motion along all the degrees of freedom that our vehicle provides, so that we can have strong base upon which we can build our motion layer for the vehicle. This time, we implemented a Cascaded PID Controller, which took into account both the error in position as well as velocity for calculating the force required. This force is divided for the various thrusters using a Thruster Allocation Matrix, and these values are mapped to PWMs using the official thrust-to-PWM mapping present on the website.

There have been some major changes in the vision layer as well. We implemented a image preprocessing pipeline based on the fusion framework, which was used to enhance the camera feeds before working on calculating the coordinates of the object in the frame.

Taking advantage of the newly acquired Teledyne Doppler Velocity Log (DVL) and Inertial Measurement Unit (IMU), we incorporated a new navigation layer, which allows us to perform waypoint navigation. The velocity measurements from the DVL along with the orientation inputs from the IMU are feeded to an Extended Kalman Filter, through which we estimate a 13-dimensional state vector of the vehicle.

III. EXPERIMENTAL RESULTS

A lot of drastic and important changes were introduced in the vehicle, and this required us to test the vehicle in-water, in simulation as well as on-bench. Since there were different enclosures and a number of connectors running through them, a lot of leakage testing had to be made so as to ensure the reliability on the watertight casings. Software code was tested in a simulator for basic sanity checks before being deployed in the vehicle. A complete simulation environment was set up on Gazebo which included hydrodynamics, was modifying an open-source simulator ‘uuv-simulator‘ to our needs. Every testing had to be recorded, so we worked on creating an interface which would help us replay bag files and find errors. This would also help at the Robosub, since we would get short slots, and would need to extrapolate the data from the runs at TRANSDEC. We also ensured that we get to record camera feeds for varied conditions of weather, by mixing testings during the day and night times. We needed a large amount of data for implementing object detection and made sure we had camera feeds recorded for those tasks, even though we were not testing the code for them.

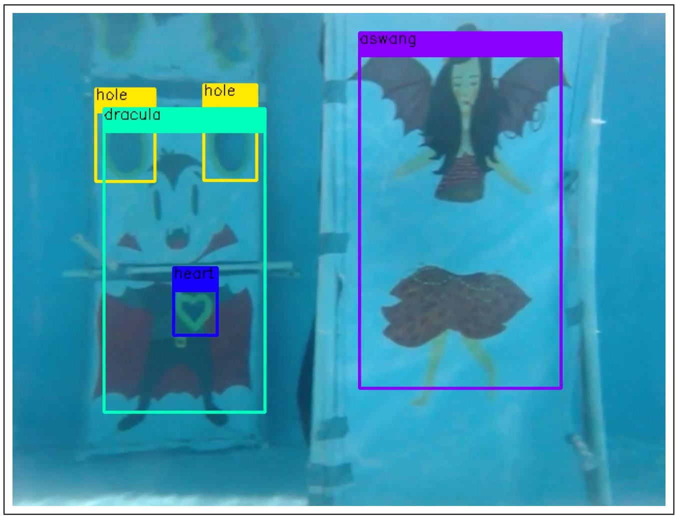
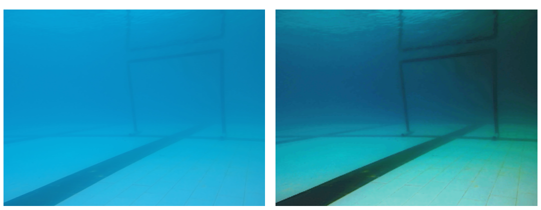


Fig. 6: Deep Learning Predictions



(a) Raw image (b) Prepossessed

Fig. 7: Pre-processing Pipeline

Our team once had faced a setback when a short-circuit occured in the vehicle electronics rack. As we were testing our controller that included a barrel roll, due to a slight leakage there were traces of water found inside the mail pressure hull. This caused a fire inside the hull and melted a few of our Electronic Speed Control (ESCs) and melted a part of the acrylic tube. This caused a severe blow to our testing time, but we were able to resolve all the issues and got back into testing phase in only a couple of days. We had learned a very important lesson to perform a regular check on leakage before pulling off such maneuvers, install leakage sensors, and fix all electrical equipment inside the hull. We are also introducing an acoustic localization system in the vehicle this year. Complete Localization program was made on LabVIEW software. We tested the hydrophones for months but werent able to get a right heading so we tried the same program but with a portion of the signal. We got a bearing with the error of about 10-20 degrees so we extracted that part of a signal which contains the ping by putting a threshold control on the signal being processed which reduced the error to 5 degrees.

ACKNOWLEDGMENT

We would like to thank DoRD, IIT Kanpur for funding our project. This project would not have been possible without the support of the staff at 4i Lab, Central Workshop and Tinkering Lab at our institute in manufacturing several of our components.
The team would also like to extend our gratitude towards the Institute administration and numerous staff members at the swimming pool who supported us during our extended phase of development and testing. We would also like to thank the following sponsors for making the design and fabrication of the AUV possible: ANSYS, Solidworks, Sparton and Mathworks, Xsens, and iDS Imaging Systems.

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Appendix A: Expectations

Below is the scoring table showing the points associated with each task. Enter the points you **expect to score** with the vehicle(s) that you have designed and engineered. At the end of the competition, enter the points you **actually scored** in the last column.

Subjective Measures			
	Maximum Points	Expected Points	Points Scored
Utility of team website	50	30	
Technical Merit (from journal paper)	150	130	
Written Style (from journal paper)	50	45	
Capability for Autonomous Behavior (static judging)	100	90	
Creativity in System Design (static judging)	100	85	
Team Uniform (static judging)	10	10	
Team Video	50	50	
Pre-Qualifying Video	100	90	
Discretionary points (static judging)	40		
Total	650		
Performance Measures			
	Maximum Points		
Weight	See Table 1 / Vehicle	0	
Marker/Torpedo over weight or size by <10%	minus 500 / marker	0	
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	150	
Gate: Coin Flip	300	300	
Gate: Pass through 60% section	200	200	
Gate: Pass through 40% section	400		
Gate: Style	+100 (8x max)		
Collect Pickup: Crucifix, Garlic	400 / object		
Follow the "Path" (2 total)	100 / segment	200	
Slay Vampires: Any, Called	300, 600	300	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	700	
Drop Garlic: Move Arm	400		
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	800	
Stake through Heart: Move lever	400		
Stake through Heart: Bonus - Cover Oval, Sm Heart	500		
Expose to Sunlight: Surface in Area	1000	1000	
Expose to Sunlight: Surface with object	400 / object		
Expose to Sunlight: Open coffin	400		
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)		
Random Pinger first task	500		
Random Pinger second task	1500		
Inter-vehicle Communication	1000		
Finish the mission with T minutes (whole + factional)	Tx100		

Component	Vendor	Model/Type	Specs	Cost(If new)
Buoyancy Control	Blue Robotics	Buoyancy Foam	Density: 192 kg/m3, Specific Gravity: 0.19	119$
Frame		Designed, machined using waterjet	Aluminium 6061 T6	1,000$
Waterproof Housing		Flange and Hull machined	Acryllic	500$
Waterproof Connectors	Fisher Connectors	Bulkhead connectors		3,000$
Thrusters	Blue Robotics	T200		1,690$
Motor Control	Blue Robotics	Basic ESCs		25$
High level Control	Arduino	ATmega 2560		10$
Actuators	Hitec	HS-5086WP		200$
Battery	Tattu Lipos	Lithium-Polymer Batteries	10000MAH 6S 25C 22.2V LIPO	465$
Regulator		Buck Voltage Regulators	5V, 19V, 14V power rails	
CPU	Intel	NUC8i7BEH	Intel i7 Processor, 8 GB DDR4 RAM, 240 GB mSATA Mini SSD	570$
Internal Common Network	Open Source Robotics Foundation	ROS		
External Common Interface	Telda	Ethernet	5 Port-Network Switch	5$
Programming Language 1	Python			
Programming Language 2	C++			
Intertial Measurment Unit(IMU)	Xsens	MTi-300	RS232-Connection	Sponsored
Doppler Velocity Log(DVL)	Teledyne Marine	Pathfinder DVL	Bottom-Track Velocity	Sponsored
Camera(s)	Logitech	c930e Webcam	640x480, 15 FPS	150$
Hydrophones	Aquarian	AS-1 Hydrophones (x4)	STFT, cross-correlation	1,500$
Data Acquisition	National Instruments	cDAQ 9223	Simultaneous 1 MHz/channel sampling, 16-bit	1,800$
Manipulators		Designed and manufactured in-house	4-finger grabbers	
Algorithm:vision	Open-source (under BSD License)	OpenCV, Darknet	TinyYOLO on Darknet, Trackers, Fusion Framework for preprocessing images	
Algorithm:acoustic		Cross Correlation	Sampled at 300 kHz	
Algorithm:localization and maping		Extended Kalman Filter (EKF)	13 variable state estimator	
Algorithm:autonomy		State Machines	ROS Smach	
Open Source Software		DVL and IMU Drivers	Serial Protocols	
Team size(number of people)	13			
HW/SW expertise ratio	4:1			
Testing Time: Simulation	150 hrs			
Teasting time: In water	100 hrs			