Research and Development of Matsya 5, Autonomous Underwater Vehicle

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***Abstract*—Matsya, stands for a fish in Sanskrit, is a series of Autonomous Underwater Vehicles (AUVs) being developed at Indian Institute of Technology(IIT) Bombay with the aim of delivering a research platform in the field of underwater robotics and to promote autonomous systems. AUV-IITB is a forum for students and faculty to pursue their interests in underwater robotics. AUV-IITB team has developed five vehicles each one more advanced as well as more capable than it's predecessor. Major architectural changes have been made to the subsystems by designing them from the perspective to handle tasks in real time.**

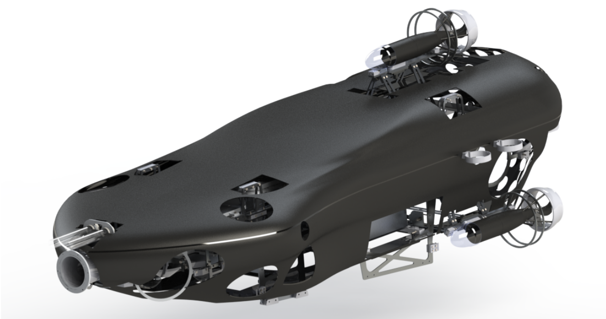


Fig. 1: Matsya 5

I. INTRODUCTION

Matsya 5 is an AUV developed by a multidisciplinary student-faculty group at IIT Bombay to facilitate research and development in Underwater Robotics as well as to participate in the International Robosub Competition. With integration of a robust Acoustic Localization System and improved control system, this year's vehicle is capable of performing majority of the tasks and addressing the challenges defined by the competition. AUV-IITB is a group of 23 students from different specializations having a strong motivation to explore the field of Underwater Robotics. It has three divisions namely Mechanical, Electronics, and Software. Matsya 5 has seen a two year-long development cycle with majority of components, underwater connectors, software stack and electronics boards designed in-house by the team members.

II. DESIGN STRATEGY

The designing of Matsya 5 kicked off two years ago when team decided to build a completely new vehicle from scratch, starting with a blank sheet of paper. Initially 7 rough sketches of Matsya were proposed and after thorough discussion, the best technologically and aesthetically designed was singled out. Having experience of building 4 vehicles, we listed down the drawbacks and scope of improvement that could be made. On the basis of this list, electronics and software sub-divisions were planning and doing experiments that would be implemented in the vehicle. Once the preliminary designs were ready for both electronics and mechanical, considerable amount of time was devoted in visualizing mechanical-electronics stack integration and placement of connectors on different hulls. This resulted in less cumbersome wiring both inside and outside of hulls. Whole process was visualized in solidworks. In parallel the software team would test their algorithms in simulator to foresee any bug before going to actual pool testing.

III. VEHICLE DESIGN

MECHANICAL

Matsya's mechanical subsystem consists of four specialized sub-divisions namely: Frame, Hulls, Pneumatic System and Surface. Every sub-division undergoes predefined design flow (Figure 2) to deliver reliable and optimized components.

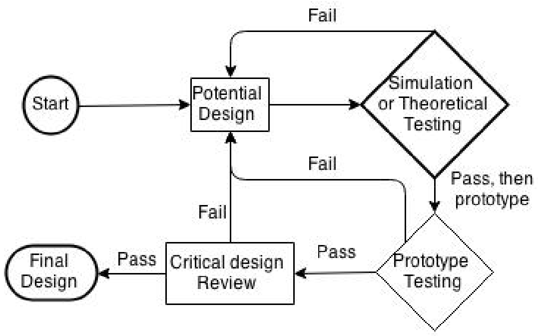


Fig. 2: Design Flow

A. HULLS

Hulls are the pressure chambers of the AUV meant to provide a waterproof region for the electronics and other water-sensitive components of Matsya. To incorporate various needs like accessibility to inner component(s), field of sensing, provide modularity, etc., Matsya houses four types of hulls: battery hull, camera hull, main hull and the sensor hulls. For ensuring rugged waterproofing, all the hulls have undergone vacuum impregnation - an industrial porosity sealing technique. Apart from this the other design objectives include ease of assembly and disassembly and efficient heat circulation. Each hull has a fully removable endcap which mechanically squeezes a Nitrile O-ring fitted on the flange to achieve waterproofing of the hulls. This is achieved through the use of latches in main hull and nuts-bolts in the other hulls.

a) Battery Hull: This year Matsya has two battery hulls each of which contains 2 batteries and a BMS board. One of the battery hulls is used by Matsya, and the second is used when the batteries in the first hull is discharged. Easy installation and uninstallation of battery pods allows to change the batteries in less than a minute with hot swappable power supply feature to power the vehicle. The design objective was to achieve robust waterproofing and efficient placing of the 2 batteries and the BMS board. The battery hull comprises of four sections: endcap, flange, walls and baseplate. The endcap is made of polycarbonate, is fully removable and is fastened to the hull through a set of 20 nuts and bolts. This helps to get a view inside the hull for diagnostic purposes. The baseplate and flange are made of high strength Al-6061-T6 alloy. The walls are made of the more ductile Al-5052(O) alloy. To reduce the welded zones the walls are bent from a sheet to form two C-shaped structures. This results in improved strength and lesser probability of water seepage.

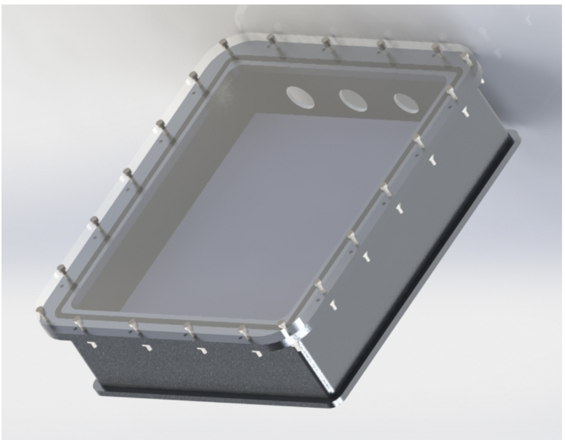


Fig. 3: Battery Hull

b) Camera Hull: This year Matsya has two camera hulls: Front camera hull and Bottom camera hull. The bottom camera hull is integrated with the main hull by welding them together. Because of modular design philosophy, the camera hull has similar design to that of Matsya 4A. Accurate mounting and enough field of view for cameras are the primary objectives that the hull must meet. The camera hull comprises of six sections: endcap, 3 flanges, main body and a baseplate. The main body of the camera hull is made of Al-1060 alloy since it is easier to machine along with providing strength. The endcap is made of polycarbonate for the camera to have clear view. The flanges are made of Al-6061-T6 alloy and used for fastening the endcap and baseplate to the hull. The camera is mounted on an adjustable ABS mount which is press fit inside the hull.

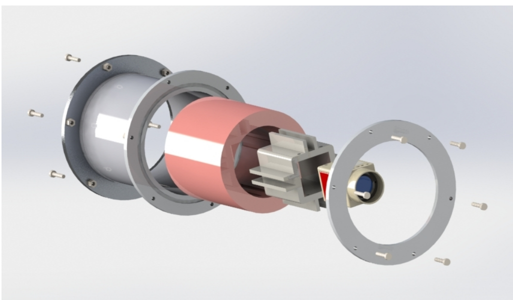
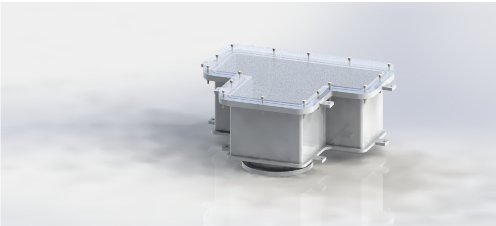


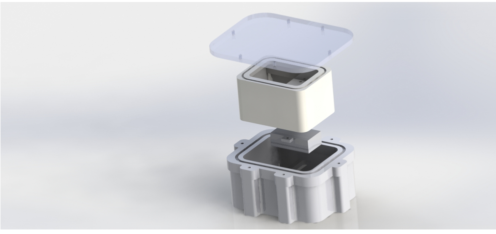
Fig. 4: Exploded View: Camera hull

c) Sensor Hulls:

Doppler Velocity Log (DVL) Hull: The design of the DVL hull is similar to that of the battery hull. For early detection of water leaks, this hull has been designed to allow maximum visibility to the inner parts. The design objectives are accurate mounting and electromagnetic shielding.



(a) DVL Hull



(b) IMU Exploded View

Fig. 5: Sensor Hulls

Inertial Measurement Unit (IMU) Hull: For maximum visibility and reducing weight, the IMU hull is made entirely of acrylic. Similar to the DVL hull, IMU hull has electromagnetic shielding.

d) Main Hull: Main hull houses all the electronics of Matsya 5 and includes features like layered and backplane electrical stacking, and good heat dissipation qualities. The height of the main hull is reduced and length is increased proportionately to accommodate both, the backplane and the stack. The main hull comprises of four sections: endcap, flange, walls and baseplate. The endcap has two parts - a frame made of Al-6061-T6 and an acrylic plate. The acrylic plate is press fit into the frame and the whole endcap is fastened to the hull through 10 180° latches. The acrylic plate provides a transparent interface for visual detection of water seepage as well as electronic displays and indicators. Similar to the battery hull, walls of the main hull are made of Al-5052(O) and bent into two C-sections for welding. The flange is made of Al-6061-T6 and designed to avoid accumulation of water on the top surface and to ensure that no water seeps inside during disassembly. The baseplate is made of Al-6061-T6 which has more strength since the main hull also provides structural strength to Matsya.

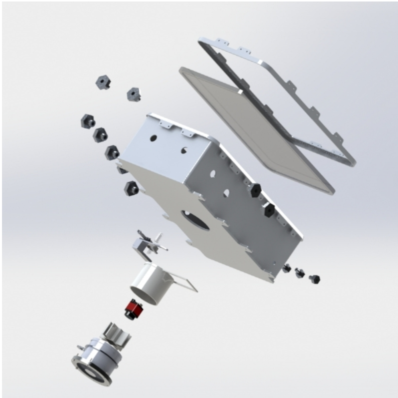


Fig. 6: Main hull exploded view

e) Connectors: The team has fabricated in-house dry mate-able two pin underwater connectors to route connections between main hull and battery hull. The plug and play nature of these connectors makes it convenient to integrate additional components in Matsya and eases the phase of disassembly and replacement. Since these connectors are custom made, their manufacturing cost is 20 times cheaper as compared to the alternative option available in the market.

f) Penetrators: Penetrators are designed to route cables out of hulls for direct connection to the sensors for which simple plug and play connectors cannot be used as they cause data loss and impedance matching problems.

g) Underwater Switches: Matsya 5 has 4 underwater switches at the back end of the vehicle- two on both sides. This year rotatory switches have been designed for the ease of use by the diver. They contain magnets and reed switch for their operation.

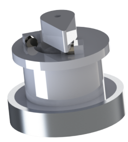


Fig. 7: Underwater Switch

h) Latches: For sealing main hull, pull action toggle latches are fixed on top of the end cap to squeeze the O-ring sandwiched between end cap and flange of main hull. They also incorporate a custom designed lock to prevent accidental opening.

B. FRAME

The frame of Matsya 5 has been designed to achieve a more hydrodynamic vehicle and to bring more stability than before. To engineer this, the length of the vehicle is increased and its height is reduced. A skeleton type internal structure has been designed to reduce weight without compromising on the strength. The cage-like structure is made up of water-jetted aluminum 6061 alloy with an external coating to prevent its corrosion. The corners and the angles have been joined by nylock nuts (SS), bolts (SS) & CNC-machined delrin parts acting as a support to prevent relative motion. The structure of frame has been provided with handles, at front and rear end, to transport the vehicle by hand, and a horizontal rod at the rear end, as a handle for the diver.

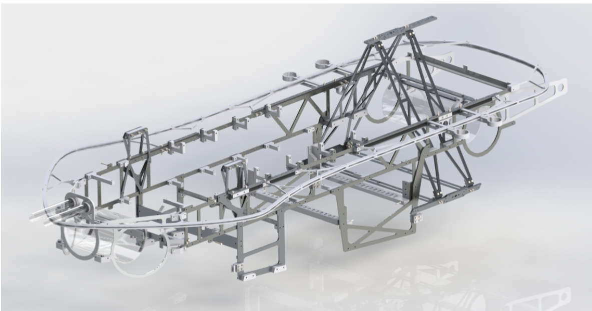


Fig. 8: Internal Frame

a) Component Positioning: Every component and hull of Matsya 5 has been positioned to make the vehicle stable (static) in Roll, Pitch and Yaw. The positively buoyant hulls, Main Hull & DVL Hull, have been kept above the negatively buoyant components, Battery Hull, Pneumatic valves & pressurized CO_2 tank. The hydrophones have been attached to the studs of the vehicle to receive clear signals.
A total of 8 thrusters have been used in Matsya to provide all possible degrees of freedom to the vehicle. The surge thrusters of Matsya 5 have been kept on the vertices of an equilateral triangle. The surge thrusters hence can also be used for pitch and yaw control. The line joining the centroid of the equilateral triangle and CG (Center of Gravity) of the vehicle is along the surge axis of the vehicle. This was done to provide maximum stability during surge.

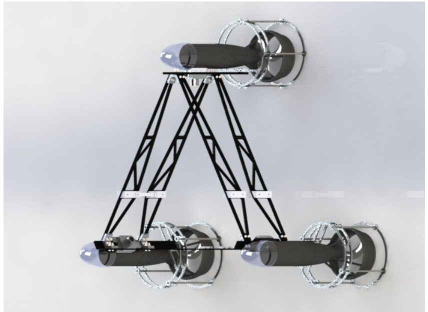


Fig. 9: Surge Mount

In Matsya 5, three heave thrusters have been used and are kept at the vertices's of an isosceles triangle, two at the front and one at the rear. This allows to operate these thrusters for pitch and roll control as well. The two sway thrusters, one near the front end and the other at the rear end, have ducts around them to ensure symmetric unobstructed flow of the wake. The centroid of the isosceles triangle of heave thrusters, the midpoint of the sway thrusters and the CG of the vehicle have been made collinear for maximum overall stability.

b) Analysis: Each of the structural elements of the frame has undergone static analysis using the Finite Element Method (FEM) on ANSYS Workbench. The analysis was done on the designs before fabrication to ensure that the components can handle the realistic situations like:
The frame of the vehicle should be able to withstand the weight of the hulls and the force of the thrusters in air and underwater. The hulls of the vehicle should be able to withstand the hydrostatic pressure at atleast 50 meter depth. The stresses and deflections were considered for each case and a safety factor of atleast 1.3 was achieved everywhere.

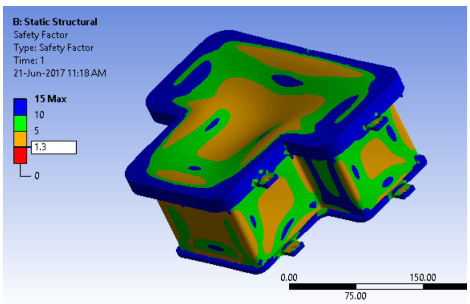


Fig. 10: ANSYS of DVL Hull at 50m depth

C. ACTUATORS

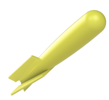
Matsya 5 has several actuators mounted on its frame to make it capable of accomplishing several tasks at RoboSub. All the actuators have been connected to pneumatic valves which are driven by a CO_2 gas tank.

a) Gripper: Matsya has a gripper mounted on the right side of the frame. They have been designed in such a way that they require less ground clearance but when actuated, provide large gripping area. The gripper was designed using Genetic Algorithm as an optimization tool.

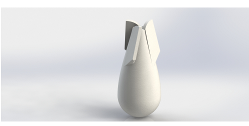
Fig. 11: Gripper

b) Torpedo: Matsya 5 has 2 torpedoes just above the front camera hull. The torpedoes have twisted fins at the and to provide gyroscopic stability allowing torpedoes to travel in a straight line for 1 meter with deviation of 10 cm or less.

c) Marker Dropper: Matsya 5 has two marker droppers and the actuation system has been optimized to use only one pneumatic piston as opposed to two in Matsya 4A. The design principle of the markers is same as that of the torpedoes, with the only difference being markers are heavier.



(a) Torpedo



(b) Marker

(c) Marker Dropper

Fig. 12: Torpedo & Marker System

D. SURFACE

The previous series of AUVs had open frame structure which considerably hindered the hydrodynamic characteristics of the vehicle. An enclosure was conceptualized, in order to direct the incoming fluid, and therefore improve the drag characteristics of the vehicle.

The design objective is to heighten hydrodynamic performance and aesthetics. The initial design was developed in collaboration with IDC, IIT Bombay. To permit easier access to the components of the vehicle, the surface is split into 6 parts, each of which is detachable. The surface is mounted on the vehicle by using a press-fit mechanism, ensuring a faster opening and closing of the surface.

Acrylonitrile Butadiene Styrene (ABS) has been used for making the surface, due to its relatively good strength and impact characteristics (Izod values), among thermoplastics. The manufacturing process involved CNC-machining a stack of MDF plywoods for the surface mould, heating the ABS sheet to 80^{o}C and vacuum suctioning it over positive moulds (Vacuum Forming). Each part was mounted on the vehicle using custom 3D printed mounts.

Fig. 13: Surface

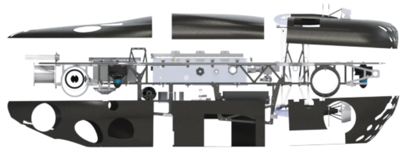


Fig. 14: Surface Exploded View

ELECTRONICS

Electronics framework is the main element for interface between the mechanical and software systems It also serves for better endurance and safe operation of the vehicle in real time.

A. Architecture

The whole of electronics can be broadly divided into the 3 parts viz. Main Stack, SBC and

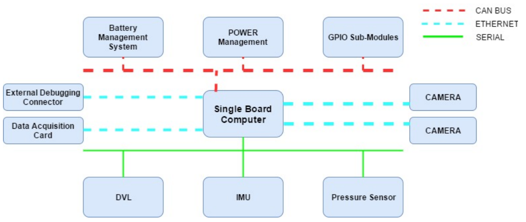


Fig. 15: Electronics System Communication Diagram

the Battery Management system. The SBC does the higher level processing such as vision, Mission planner and controller. It reads/publishes data from various sensors(IMU, DVL and Pressure sensor) and electronics stack on serial and CAN bus respectively. The Main stack features a custom designed backplane system for ease of accessibility , increased modularity and enhanced ease of replace-ability in case of failure in one of the components. The backplane has slots for Power, GPIO and Motor Driver modules with connectors for thrusters, Sensors, Power and kill switches placed on the periphery for easy accessibility and removal. It serves as the interface between different boards and the SBC.

Fig. 16: Electronic Hardware Stack

B. Controller Area Network

The communication over different subsystems occurs over CAN. Higher level communication protocols are designed in a way to have a highly robust system considering the cases of failures and their solution. The CAN bus serves as a single point of I/O for the main processor i.e. SBC from the electronics stack. All the messages from different subsystems are published on CAN bus which may be accessed by all other subsystems. Unconcerned data can be easily filtered by subsystems thus reducing the processing time on the subsystem. The data traffic consists of information about speed of thrusters, state of actuators, Ping messages from different subsystems, Battery SOC as well as the interrupt messages published when any of the external switches are used.

C. GPIO Board

Integrates the sub-modules for generating PWM, Digital I/O and ADCs. The PWM signal are generated for thrusters. Digital Outputs are used to control power to actuators. The pressure sensor reading are recorded by 12 bit dedicated ADC which is sent to SBC on serial. Different reference voltage line is used to keep the pressure sensor signal unaffected by noise or fluctuations in GND used for power lines.

D. Power Management System

Takes input power from BMS and converts them into different power rails needed by sensors, SBC, Data Acquisition Card and cameras. All the power rails are controlled by Atmega328P which ensures proper powering up sequence and communicates with SBC via CAN. In this way any device's power can be rebooted in case needed without powering off the entire system. A soft kill signal can also be generated for switching off thruster upon message from SBC which is sent to BMS for implementation.

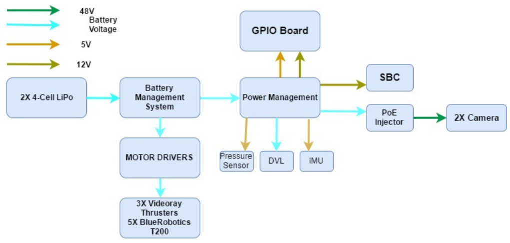


Fig. 17: Power Distribution Diagram

E. Battery Management system

It is designed to ensure maximum endurance for Matsya. The BMS takes power from two 16000mAh 4 cell lipo batteries, check the battery with higher SOC along with kill switch and software commands to channel power to thrusters. If any of the three criteria fails, power will not be channeled to thruster ensuring the safety of battery, vehicle and diver swimming near the vehicle. The battery voltage is measured at a time when current is not being drawn to get accurate voltage. It is done alternately so that power supplied to electronics is not affected. It periodically sends the SOC left to mission planner to estimate run time available. If SOC drops below certain threshold, such message is also published on CAN bus to warn the mission planner. If SOC further drops below another threshold, BMS shuts of all the power to electronics to prevent batteries from over discharging.

F. Motor Driver Board

The Motor Driver Board integrates all 8 BlueESC from BlueRobotics on two identical custom designed boards and provides ease of replaceability and safety features. With a current rating of 30A, each of these motor drivers are capable of efficiently driving both Videoray brushless as well as Blue Robotics T200 thrusters. The power to this board is controlled by MOSFET switches independently by kill switches as well as command from SBC.

G. Acoustic Localization System

Acoustic localization unit of Matsya uses four hydrophones to localize with respect to an active sound source. A custom board is designed to condition the signal coming from the hydrophones. This conditioned analog signal is converted to digital signal using DAQ NI 9223 from National Instruments and saved & processed on SBC to estimate the Direction Of Arrival (DOA). The entire system execution is divided into following stages:

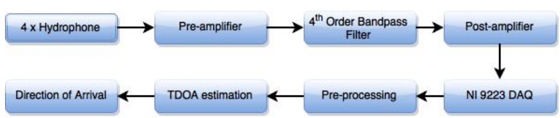


Fig. 18: Acoustic Localization Flow

- Pre-Amplification: This stage involves pre-amplification of raw hydrophone signals that intrinsically have very low peak to peak voltages. The gain is controlled in order to compensate for voltage compatibility with Analog to Digital Converter (ADC) levels and improve sensitivity.
- Filtering: Elliptic band pass filter is used to remove noise from the amplified signal and passes them to the post amplification unit. Two second order active elliptic filters are cascaded for each hydrophone in order to provide high roll-off factor.
- Post-Amplification: The filtered signal is again passed through a post amplification phase with a fixed gain to make it compatible with the ADC's voltage levels.
- Sampling: Signals from all hydrophones are sampled using NI 9223 data acquisition board. The digital signals are then transferred to SBC through ethernet for further processing and direction of arrival (DOA) estimation.
- Digital Signal Processing: Digital Signals of all hydrophones are processed on SBC to estimate position of pinger relative to the vehicle. After implementing the Fast Fourier and Inverse Transform, the signals are then pre-processed to discard noise and to make envelope of the signals uniform. The DOA is finally estimated from the processed signals using hyperbolic positioning.

H. Batteries

Matsya's entire system is powered by two 4-cell 16Ah Lithium Polymer batteries. Both the batteries are merged so as to maximize the endurance. Special provision is made to charge the batteries without having to open the enclosure. Safety measures are also taken for the gases leaking out during charging.

I. Sensors

Various on board sensors are used to get feedback for control and underwater navigation.

1) Cameras: There is a significant jump in terms of quality of images we used to get in matsya 4.0. This year we are using Mako G-234 camera along with Kowa LM6HC lens. The camera is operated at 14 fps and 405x645 resolution. The cameras are PoE compliant and communicate directly to SBC via Ethernet. Power is provided through through a PoE injector in intermediate path.

2) Inertial Measurement Unit: For low-drift and precise orientation measurements, Matsya uses GX4 Attitude Heading Reference System (AHRS) from Lord Microstrain Sensing Systems as its primary navigator. Based on MEMS sensor technology, this device fuses data from its triaxial accelerometer, triaxial gyroscope, triaxial magnetometer and temperature sensors using an on-board processor and provides very accurate inertial measurements. It is directly interfaced to the SBC via RS-232 protocol. The sensor is mounted so as to be least affected by the electromagnetic interference caused by high current consuming components.

3) Pressure Sensor: US300 pressure sensor manufactured by Measurement Specialties Inc., is used for the vehicle's depth measurements. It is a voltage based pressure sensor and is used to calculate depth from surface. The analog output of the sensor is fed directly to ADC which is sent to SBC via serial communication.

4) Doppler Velocity Log: Teledyne RDI's Explorer Doppler Velocity Log (DVL) has helped significantly in improvising the navigation and localization framework of Matsya. By fusing data from an onboard inertial sensor and depth sensor, this device provides high precision velocity data useful for real-time underwater navigation using the Doppler effect of sound waves. Rated at depths up to 1000m, it communicates directly with the SBC using RS-232 serial protocol.

5) Water Seepage sensor: An in-house water seepage sensor was developed to alert us when water seeps inside hulls and becomes danger to electronics. The current conducted by the small amount of water is processed to work within TTL level and programmed to generate interrupt when water seeps inside

6) Hydrophones: Four Reson TC 4013 hydrophones are used as an input array to receive the pings of an active sound source emitting at regular intervals. With an input sensitivity of -211dB $\pm$ 3dB re 1V/uPa and usable frequency range of 1 Hz to 170 kHz, these hydrophones provide an optimal solution for a passive acoustic localization system.

Fig. 19: CAD rendering of thruster profiling setup

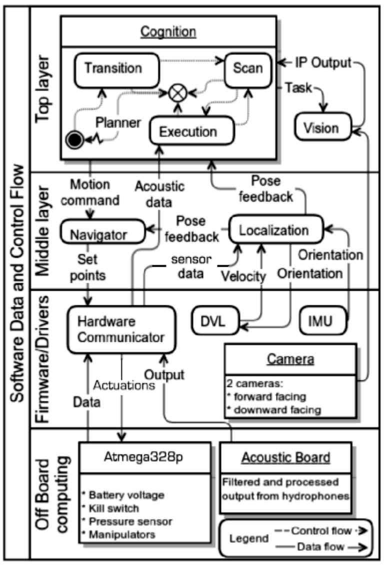


Fig. 20: Software Data and Control Flow

SOFTWARE

The Software Stack of Matsya 5 has been developed on top of Robot Operating System (ROS), developed at Willow Garage.

The software system is implemented as one stack with different packages representing various modules like vision, navigation, controls, firmware and mission planning. The design specifications of the stack ensured that it is extendable, independent and generic. ROS helped in meeting these design goals and keeping the software modular with different tasks compartmentalized into various processes called nodes. ROS handles all the Inter Process Communication between the nodes via messages and services. The software can scale with respect to the tasks or missions that can be accomplished. It is also generic enough to be plugged into other robotic frameworks. The broad division of the software stack into different levels is as follows:

- Off-Board Computing: This layer consists of specialized hardware like filters, amplifiers, ADC, GPIO, PWM, etc. The communication with SBC is over TCP/IP, UDP, as well as CAN protocols.
- Firmware/Driver Layer: Responsible for all of the Hardware Abstraction, this layer helps abstract data from the sensors and present them as processes to the SBC. This layer also consist of communication modules required for handling GPIO, PWM and ADC. Each hardware peripheral connected to the SBC is abstracted out as a ROS node.

- Middle layer: This layer is responsible for processing information from sensors such as IMU, DVL and Cameras and presenting it to the higher level logic nodes.
- Top layer: This layer uses information from the middle layer to generate actuation commands. It also provides a real-time interface to monitor Matsya's performance and as well as to implement individual missions.

A. Localization

The localization module targets clear segmentation of upper layers of cognition and lower layers which consist of different sensors and controller driver modules.

It is responsible for filtering and fusing data from inertial and acoustic sensors to provide the top layer with a single source of all relevant localization data. At all points of time, Matsya uses the localization data to localize itself in the belief map.

B. Controls

This year Matsya's Motion Control System has been redesigned to provide precise control for six degrees of freedom, namely, surge, sway, heave, pitch, roll and yaw. The control loop runs at a frequency of 10 Hz, acquiring localization data from the DVL and IMU and generating appropriate PWM signals for each of the eight thrusters. A single loop modified PID control architecture has been developed which comprises of a kinematic controller and a dynamics controller. The kinematic and dynamic controller pair is able to achieve global position and velocity reference tracking.

A 3D motion simulation tool has also been developed to analyze the performance of the motion controller. This tool is also used to test our motion planning and navigation techniques.

C. Navigation

The Navigation system is responsible for converting motion primitives generated by the Top layer to set points understandable by the lower layers. It handles the generation of set-points for intermediate locations on the trajectory generated for motion from point A to point B. Based on a state machine architecture, it chooses the motion to be performed based on checks on the localization data with respect to the desired set point.

D. Mission Planner

The mission planner controls active behavior of Matsya. Its main goal is to schedule tasks depending upon the active state of the system to maximize the score in the competition. To achieve its objective, it runs a state machine which consists of 3 states for each task:

- Transition State: When the currently active task is not in the range of Matsya's sensors, Matsya navigates to the optimum point using a user-fed belief map. As soon as Matsya has the task within range of its sensors, it switches to the Scan State.
- Scan State: When the currently active task is in the range of Matsya's sensors, Matsya tries to search around itself using a combination of its history and user-fed scan plans. Using its sensors, it tries to cover the most probable region for the currently active tasks till it receives an acceptable amount of sensor feedback. On reaching an acceptable position to perform the task, it switches to the Execution State. If it fails to find the location of the task within pre-specified time it aborts the current mission
- Execution State: When Matsya enters the Execution State from Scan State, there is a very high probability that the task can be completed. In this state, Matsya performs the required motions to complete the task, and moves onto the next task on successful completion. On losing track of the task, it switches to scan state so as to position itself properly again.

  Figure 20 describes the state machine and the various transitions.

E. Vision

The vision subsystem provides crucial information about the target object which is used for navigating Matsya to the target location and performing the desired mission. Software modules for image processing and computer vision are built using Intel's OpenCV 2.4 library.

- Framework: The image processing code is implemented as a library employing object oriented philosophy for different processing techniques. Since the other software elements are entirely based on ROS architecture, a single vision node in ROS environment is used to handle the communication between vision and other software elements.

This helps in reducing the inter-process communication delays which might occur in ROS and thus complex algorithms can be used in the vision subsystem.

- Camera control and pre-processing: To account for the varying environmental conditions such as illumination variation, brightness artifacts, sunlight reflection, etc., auto exposure and gain control algorithms have been implemented which update the camera parameters in real-time. Also, several localized and adaptive pre-processing techniques have been developed to handle water color cast, poor contrast, and reduced color quality underwater.
- Processing techniques: The major processing modules include color detection, shape based validation, region growing, contour analysis and machine learning based object detection and classification. A modular framework has been developed for video-based object training and model generation. Each task object is detected by a combination of aforementioned processing techniques. The final output of the processing module gives generic information about the target such as its location, orientation, dimension, distance-to-camera estimate and some task specific information. This information is communicated to other software elements via the Vision ROS node.
- Parameter tuning: Some of the image processing techniques require some tuning of parameters for better performance. Thus, an easy-to-use text file based parameter tuning interface has been prepared which can be used for the live update of the parameters.

One major addition in Matsya 5 is a generic process architecture which enables breaking algorithms in modular pieces, reducing lines of code as well as increasing test coverage.

IV. Experimental results

An apparatus was developed for profiling of thruster current and thrust vs PWM values. This would give the controller data which would help it to optimize its performance. The output given by controller is in terms of force, so the force to PWM map aids in optimal control of the vehicle. The setup consists of Load cell attached to a frame which is rigidly attached to ground so as to get the most accurate result. The thruster is attached to load such that the thrust from it produces a torque. The setup is calibrated and its parameters are calculated from known values of force and used to calculate thrust. Also attached in series of current path given to thruster a sense resistor to measure current consumed for given thrust. The profiling results of thruster gave the the non-linear relation between PWM and thrust. This greatly helped in optimizing controller.

As the theoretical testing of controller was being done in parallel with mechanical and electronic fabrication time, the real testing of controller was reduced to tuning of parameters. This resulted in maintaining focus on the tasks in problem statement. Matsya 5 has observed 300 Hrs of rigorous testing comprising of testing of acoustic, vision and mission planner. It is now going to perform integrated testing of all tasks and will be optimized for time.

V. Conclusion

With much rigorous design, analysis and testing done by all the three subdivisions of the team, Matsya 5 has the ability to easily adapt and incorporate additional systems integration without major developmental changes. This will help the team to focus more on software testing and sorting out runtime issues efficiently in future. Innovative indigenous solutions like underwater connectors and switches provided unique insights into the team's design philosophy. Major advancements in software and electronics architecture achieve a reliable interface of software with mechanical end. Matsya 5 offers a great opportunity to the team to pursue further its research in Underwater and Autonomous Robotics.

VI. Acknowledgements

We would like to thank the Industrial Research and Consultancy Centre of IIT Bombay for continuous administrative and monetary support during the project. The support of the Dean R&D's office was essentially crucial in the successful execution of the project.

We sincerely appreciate the generous support from our sponsors. They played an instrumental role in helping us meet our goals within our budget constraints. Special thanks to our vendors such as Blue robotics, Teledyne RDI for their support in case of technical problems.

References

[1] Chan, Y. T. and Ho, K. C., *A simple and efficient estimator for hyperbolic location.* 1994.

[2] Quigley, Morgan and Conley, Ken and Gerkey, Brian and Faust, Josh and Foote, Tully B. and Leibs, Jeremy and Wheeler, Rob and Ng, Andrew Y., *ICRA Workshop on Open Source Software.* 2009.

[3] Ashok Kumar Tellakula, *Acoustic Source Localization Using Time Delay Estimation.* 2007.

[4] Welch, Greg and Bishop, Gary, *An Introduction to the Kalman Filter.* 1995.

[5] Zhen Cai, Jonathan Mohlenho, Cassondra Puklavage, *Acoustic Pinger Locator Subsystem.* 2009.

APPENDIX:Community outreach

The AUV-IITB Team, each year attends many workshops and/or exhibitions to reach the community. It is through these exhibits the team encourages young school as well as high school students to take up robotics. The team demonstrates working of the AUV followed by a detailed seminar and a questionnaire session to motivate students, and increase their knowledge about AUVs and robotics in general.

The Team last year participated in events such as TechFest- Asia Largest Technical Festival, organized by IIT Bombay; Nehru Science Centre Exhibition and MakerMela. Also, the team itself held many workshops in the campus, open for all, to have thought provoking discussions with the students and professors about the design strategy and the general working concept of the AUV. This not only helps the team get fresh ideas, but it also helps us ponder on a few details which the team might have missed.

Apart from this, the joy it brings to others, especially young enthusiastic school students (for example students of Witty International School shown in photo)is a rewarding experience and motivates the team further to work harder and continue to make more developments.

Fig. 21: School children at our lab

The research done by the team also helped several students in their Masters/ BTech projects on topics like Control of Overactuated Nonlinear Systems, Navigation of Unmanned Vehicles, Design of a 2-Link gripping mechanism, etc. This further fuels the team to work harder and deliver results.

Fig. 22: Matsya at exhibition at Techfest

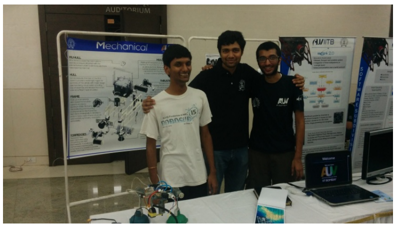


Fig. 23: Matsya at Tech and RnD expo

The team also mentors quite a few other teams from India, who are keen on making AUVs, like IEM Kolkata, Sahyadri College and VIT Pune. The team guides them through the overall procedure of making an AUV, importance of communication and documentation and the process of acquiring funds for making AUVs in their respective colleges.