SRM UNIVERSITY

AUTONOMOUS UNDERWATER VEHICLE

CONCEPT AND DESIGN OF AUV ALPHEUS

Website: www.srmauv.com
Dipesh Jain, Vedant Sanil, Mrigank Tiwari, Rohan Tiwari,
Rachit Bhargava, Varun Bhargava, Parth Natu, Nupur Tandon

***Abstract*— Alpheus is 6th iteration of Team SRM AUV and an enhancement to its previous versions and has been provided with upgraded features as compared to those of its successors. Improved designs and performance coupled with a new structure has raised the Alpheus a step above its previous versions. The materials used in this vehicle are lightweight and compact making the design structurally superior. The end caps in this vehicle are made up of polypropylene with the enclosure of Aluminum compared to the previous vehicles. The thrusters are cascaded in a square arrangement with hydrophones. An acrylic hull is used which contains all the electronic components of the vehicles**

The development of Autonomous Underwater Vehicles has gained a momentum with the advancement of the field of robotics. The need for rapidly deployable underwater vehicles that can be used in challenging environments is on the rise. Well-designed AUV's can provide a reconfigurable platform for various industries such as ocean research, oil and natural gas and many more.

The SRM Autonomous Underwater Vehicle Team consists of undergraduates from across various engineering disciplines studying at SRM University, Chennai. The goal of the team is to develop AUVs for the purpose of research and participating in the annual Autonomous Unmanned Vehicle System International (AUVSI) and the Office of Naval Research (ONR) RoboSub Competition at San Diego competing in many competitions. The AUV Alpheus is an improved version of the previously built Sedna 1.0. The vehicle comprises of many new equipment such as two vision cameras, numerous hydrophones and a pair of pressure sensors to name a few. With the limits of mankind extending to deep waters and oceans, the applications of vehicles of this type have increased in the past few years. Some of its general applications use mines clearing, feature tracking, cable or pipeline tracking and deep ocean exploration. For each of these operations, the design specifications and mechanical configuration can be altered to better suit the respective application. For example, manipulators must be used for tasks dealing with the nearby environment like mine clearing. For explorations or underwater environment detection, the vehicle must be made as compact as possible but not at the expense of its functions. For operations dealing with speed, the body can be made streamlined**.**

MECHANICAL DESIGN

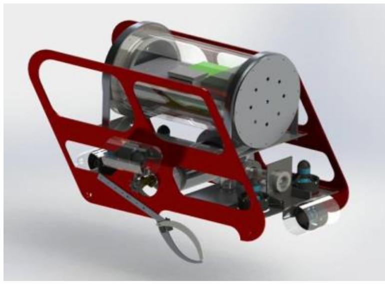


Fig: 1 Alpheus

DESIGN OVERVIEW

The ability of working in unpredicted circumstances was kept in mind while designing the vehicle. In order to make sure that the vehicles find use in the operations like shipwrecks, pipe inspection, submerged cave systems and many more, the AUV is designed as such that it can maneuver in overhead environments. The AUV is made as compact as possible acknowledging the area constraints in some of its operations. The hull contains sliding deck mechanism ensuring removal and centralized access to electronic components. The frame is designed in a modular way keeping in mind any future modifications to be made into the vehicle can be accomplished with minimal effort. SolidWorks and ANSYS have been used for modeling and analysis of the vehicle.

IMPOSED DESIGN REQUIREMENT

Many preliminary designs have been analyzed to bring the vehicle to its current operating form. The design of AUV is made streamlined to make sure the vehicle fulfills the environmental requirements. It is able to spin about an axis within its own body and is capable to move/spin in all directions. The design has to offer pressure resistance, streamlining, neutral buoyancy and speed. The speed depends upon two factors, the minimum drag coefficient and the power supply.

MECHANICS OF AUV

The design of SRMAUV, ALPHEUS was made in a modular way. Initially different rough sketches are made in order to make the drill patterns over the side plate. All the patterns are created in such way that 4 thrusters and other components are placed in a perfect way.

The acrylic hull is placed over the upper base plate. The side frame, base plate, and the thruster plate are made of Al-6061T6. The base part is also made with different pattern convenient for all cables. In the main acrylic hull, all the electronic components of the AUV are mounted onto the two plates of aluminum in between stand of 40mm is made.

.As the works related to electronics are performed frequently at the time of competition, it is difficult and time consuming to take out the both racks. In order to overcome this, frequently used components are placed over the upper plate of the hull.

Two lower base plates are made for the placement of thruster which is to be placed at the front and back of the frame. The lower base plate is placed in such a way that the upper base plate and other components don't obstruct the thrust provided by the thruster. On the frontal lower base plate, small camera enclosure plate is welded. Batteries and its components are placed on the lower plate of the hull.

The thrusters are positioned in such a way that the vehicle possess six degrees of freedom. Six thrusters are used to move/spin the vehicles. Out of six thrusters, 4 are placed at the bottom plate which help in adjusting the depth of the vehicle. These four thrusters are placed along the vertical axis to provide a high downward thrust. Two thrusters are used for controlling the yaw of

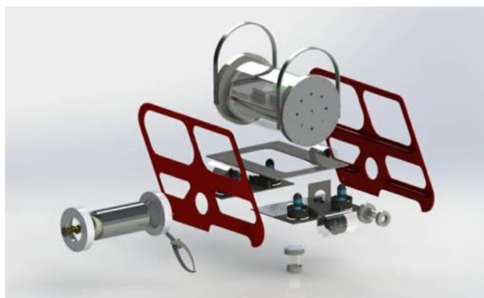


Fig: 2 Exploded view of Alpheus

the vehicle and these thrusters are among the six thrusters that is situated in the bottom plate. Each of the side frame consist of a thruster that is used controlling the surge of the vehicle. Hence in total there are eight thrusters used for assisting the six degrees of freedom.

VEHICLE SPECIFICATIONS

Specifications	
Depth rating	25ft
Length	649 mm
Height	596 mm
Width	420 mm
Cable Penetrator Holes	(2*9) *13mm
Constructions	Aluminum frame/end cap and acrylic tubes
Watertight Enclosure Inner Diameter	290mm
Watertight Enclosure inner length	540mm
Net buoyancy	773.967N
Weight in air (with ballast)	45kg (estimated value)
Weight in air (without ballast)	38kg (estimated value)

COMPONENTS OF THE VEHICLE

a. EXTERNAL FRAME

Fig: 3 Frame

The frame is made up of hard anodized Aluminum for structural stability and drill pattern is applied to make it modular. The designs make sure that the total deformation, von mission stress and strains are minimized. The components like thrusters, hull among others are directly secured by the frame and the design is such that it provides unobstructed flow for the thrusters. ANSYS is used to analysis structural rigidity.

Fig: 4 Side Frame

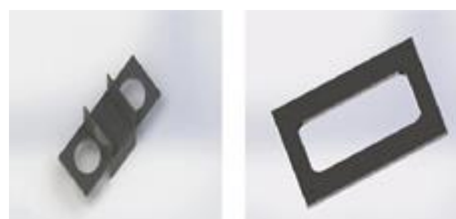


Fig: 5 Base Plate

The frame has 2 AI-6061 side plates each 6mm thick and having dimensions of **649mm x 6mm x 596mm**. The frame houses 8 thrusters for surge, heave, yaw and pitch control. The handles ensure easy transportation of the AUV.

Aluminum grade Al-6061-T6: It is an alloy of aluminum along with magnesium and other similar metals. It is used at two different thicknesses: 6mm and 4mm. It is used for fabricating frame, rack, thruster placements and other smaller components like holdings and end caps.

The 6061-T6 temper of aluminum is chosen over other metals and alloys because it shows the most favorable properties when it comes to fabrication and application. It has an ultimate tensile strength of 290Mpa (42,000psi) and yield strength of 240MPa(35,000psi) which make it highly resistant to underwater pressure while carrying a considerable amount of load. The shear modulus or bending modulus of aluminum alloy is higher than other similar alloys and metals which are considered which makes it the best choice. Also, aluminum alloys take a longer time to rust when compared to iron based alloys.

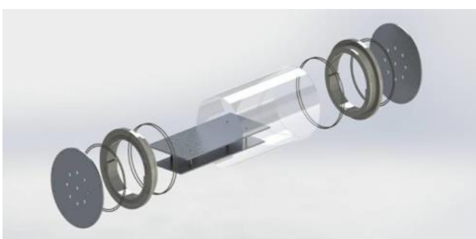


Fig: 8 Exploded View of hull

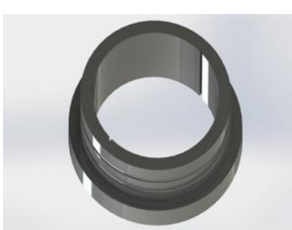


Fig 9: Neck of Hull

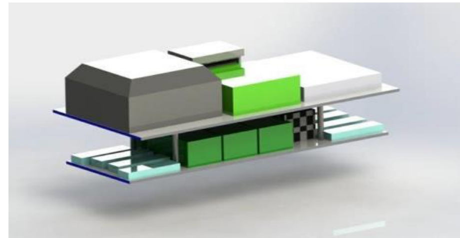
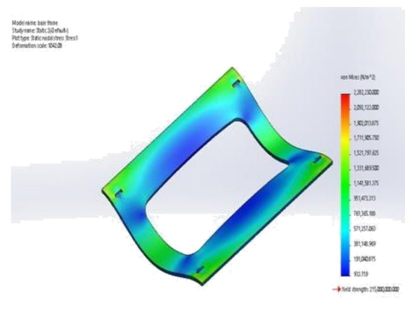


Fig: 10 Electronics Rack



base frame-Static 2-Stress-Stress1

Hull is made of Acrylic tube of thickness 5mm with the enclosure of the polypropylene and aluminum. Alpheus is enhanced with the radial sealing. The polypropylene enclosure contains groove on its upper and side face for the O-ring. The hull is closed by using the aluminum plate. The aluminum plate contains holes for connectors which connect all the component to the hull.

Acrylic tube provides good impact strength and rigidity to hull. It also provides excellent dimensional stability and low mound shrinkage as well as optical clarity.

Polypropylene plastic is considered a “tough” material because it exhibits elasticity over a certain range of deflections and experiences plastic deformation early in the process. The material also has excellent fatigue resistance. It is also a good option for use around electrical components as it is a very good insulator**.**

In order to verify the safety of the hull up to 25m in depth, Ansys of the hull was done and results were found to be positive which can be verified by the diagrams.

Dimensions (metric) Length: 540 mm
Internal Diameter: 290mm
External Diameter: 330mm
Volume: 78.896L
Buoyancy: 773.9697N
Centre of Mass: X=202.26mm, Y=219.33, Z=397.56mm

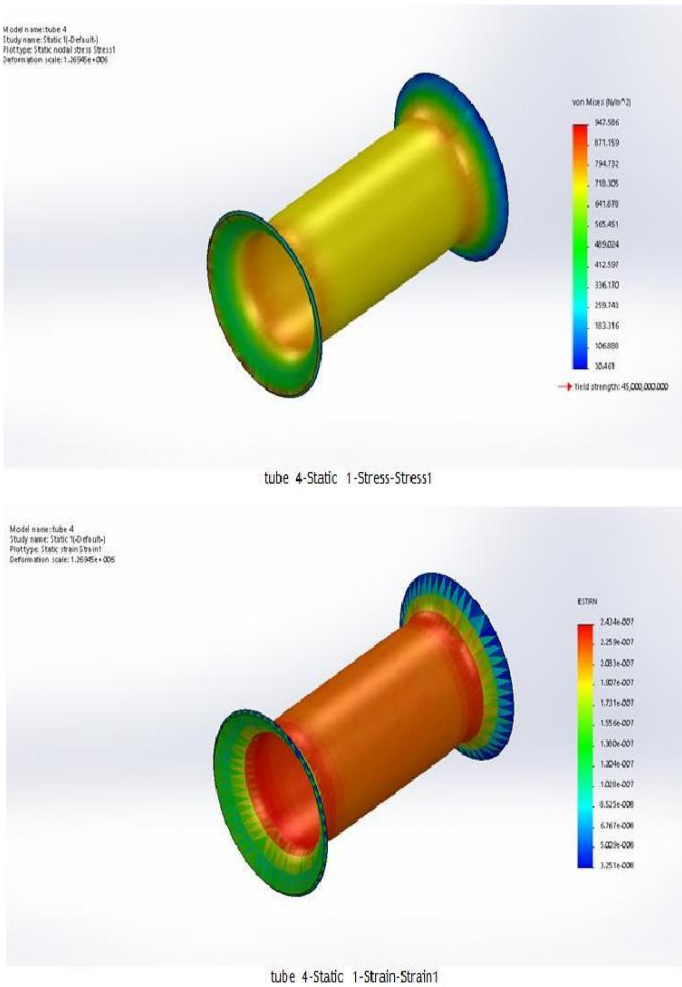


Fig: 11 Stress test of the hull

CAMERA POD

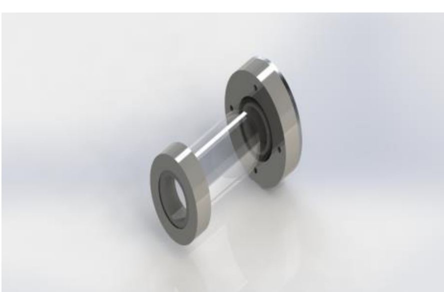


Fig: 12 Camera pod

Two custom camera enclosures have been fabricated for the front and bottom vision cameras. Clear acrylic front panels provide an unrestricted field of view.

GRABBER MECHANISM

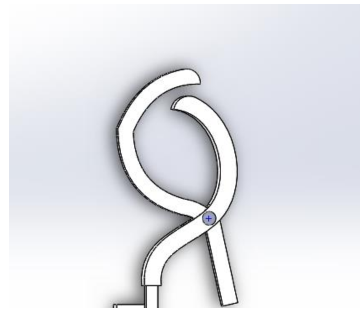


Fig: 13 Grabber

The grabber mechanism is an important component of the AUV system. The grabber is placed to pick up objects and target items Underwater and deposit them in the specified area. The task to be performed and it's regulations are kept in mind while designing the grabber. It consists of two arm like extrusions that are usually curved. The arms are operated using servo motors.

The arms have a curved shape to facilitate maximum coverage of the object surface while also being less harmful to the object. One of the grabber arm is kept stationary at a pre-meditated angle while the other arm is coupled to an underwater servo motor that gives it 180degree motion. Using this mechanism, the grabber arms are opened and closed. The object placed in the pool is detected and picked up using the grabber and is deposited in the designated area.

DROPPER MECHANISM

Fig: 14 Dropper object

Dropper provides to deliver an object, usually a ball, to a designated bin placed underwater in competition. The dropper is mounted at the bottom of the AUV to provide unhindered access to the bin. The dropper is made from acrylic and PP.

A servo motor is used to hold the ball in place within the dropper cylinder. Once the vehicle has detected the bin, the dropper is positioned directly above the bin and the servo motor operates to let the ball drop directly into the bin. This provides a simple and efficient mechanism dependent solely on the weight of the ball rather than an external force to direct it into the bin.

TORPEDO MECHANISM

Fig: 15 Torpedo

The torpedo mechanism refers to underwater rockets that are fired to fulfill the prescribed task. The torpedoes are produced using 3-D modelling and can be made using plastic or metal pieces. The torpedo is fired using a pneumatically actuated cylinder. The torpedo is placed within the acrylic tube. Compressed gas is released at high pressure which propels the torpedo out of the tube towards the sheet to be pierced. The torpedo is provided with adequate weight and cross section to have perfect aerodynamics

ELECTRICAL DESIGN

OVERVIEW

The electrical infrastructure consists of Power Management Systems, Acoustic Signal Processing and Sensor Payload Electronics, so as to cater the needs of constantly evolving software and mechanical components. The design ensures modularity in the electrical system for allowing boards to be reused through multiple design iterations and provides support for future unforeseen requirements. The Mini-ITX motherboard, microcontroller carrier board, Batteries and Power Supply Units are the main electrical components which are enclosed within the hull. In addition, a number of sensors and protection circuits have also been incorporated to make the system robust.

POWER MANAGEMENT SYSTEM

A dedicated Power Management System is developed to support the onboard electronics and sensor payload. A Battery Management System is developed for optimal power distribution among various boards such as the onboard CPU, thrusters and the microcontroller board. A Battery Management and Protection board is custom designed to provide even discharge of Lithium Polymer (Li-Po) batteries. A visual feedback system to provide battery level information for thrusters and electronic peripherals is developed. Special care has been taken to ensure water leakage detection and overheating. Each component is protected with resettable fuses. Sedna is powered by two 14.8V (4S), 10Ah Lithium Polymer batteries in parallel.

POWER MONITORING

A custom board has been designed to monitor the power level of each battery which is also provided with a Hall Effect current sensor to continuously measure the current. A point contact temperature sensor is placed on each battery to continuously measure the temperature. A graphic LCD displays the status of the batteries, power lines and hull temperature. LED strip lighting provides visual feedback for software debugging.

POWER DISTRIBUTION

A M4-ATX (250W) power supply unit provides power to the mainboard computer which is equipped with features like programmable voltage output and time out auto shutdown features. A DC-DC boost converter receives the raw voltage from batteries and converts it to different levels of voltage (5v, 12v, 18v) required by microcontrollers, actuators and sensor payloads. These channels are monitored and displayed on the LCD and protected in case of an overcurrent or overvoltage.

Components	Avg. Power Required(w)	Quantity	Total(w)
Thrusters	350	8	2800
Computing Unit	55	1	55
Display Unit	10	1	10
Total Power Required			2865

ONBOARD COMPUTER

Computer design for Alpheus is governed by the vehicle's need to perform complex computer vision and machine learning in real time in spite of restrictive space requirements. The software system is powered by an Intel Haswell CPU Core i7-4785T quad core processor with a maximum Thermal Dissipation Power (TDP) of 35W on a Gigabyte GA-Z97NWIFi motherboard along with a 256 GB SATA Solid State Drive (SSD). The Motherboard requires a non-fluctuating and uninterrupted DC power supply to deliver optimum performance, and it is provided by M4-ATX (250W) PSU. A USB hub interfaces the embedded sensors and actuators as well as other serial devices, i.e. Battery Management System (BMS), AHRS-8 and cameras. The main purpose of the Arduino board is interfacing Alpheus' various sensors and thruster.

Fig: 16 Gigabyte GA-Z97N-WIFi Mini-ITX Motherboard

Fig: 17 Arduino Mega 2560

SENSORS

Alpheus is equipped with a suite of sensors used for sensing the environment and providing orientation feedback as well as odometry information. Sensors for current, temperature, inertia, angular velocity, pressure and leakage are used in Sedna. Two vision cameras are provided for driving the image processing software stack. The sensor suite provides 6 degrees of freedom state space solution. A brief description of the sensors is given below:

a. Pressure Sensor

The vehicle uses UltraStable™ US300 Series submersible pressure transducer to obtain analog pressure data. The sensor returns the pressure exerted by the mass of water above the vehicle. Using Pascal's Law, the depth of the vehicle is extrapolated.

Fig:18 US300 Pressure Sensor

b. Inertial Measurement Unit (IMU)

Alpheus is equipped with a MEMS based Sparton AHRS-8 system. It is fully temperature compensated and uses Advance sensing technology (3-axis magnetic, 3-axis MEMS acceleration, and 3-axis MEMS gyro) to compute yaw, pitch and roll measurements. It provides critical inertial data at a rapid rate of 100 Hz. The IMU is used to provide vehicle angular velocities and linear acceleration that is used to compute the pose of the vehicle.

Fig: 19 Sparton AHRS-8 IMU

c. Camera

Alpheus uses two Microsoft LifeCam cinema cameras, one forward and other at bottom. Cameras are used to drive the vision system of the vehicle and are housed in custom fabricated external enclosures that provide a clear field of view to the camera lenses.

Fig: 20 Microsoft LifeCam cinema

d. Current Sensor

A low noise producing current sensor is used in Alpheus. Hall Effect current sensors (ACS 709) are used by the power board to get a feedback of current being consumed from the batteries, It continuously monitors the current going in and out of the battery.

Fig: 21 ACS709 Hall Effect Current Sensor

e. Temperature Sensor

Alpheus utilizes a LM35 digital thermometer temperature sensor. The digital thermometer has the capability of deriving power directly from the data line, thus eliminating the need for an external power supply. The sensor monitors the temperature within the hull in areas where higher temperatures might be a cause of concern.

Fig: 22 LM35 Temperature Sensor

f. Leak Sensor

Alpheus has integrated leak sensors to detect possible water leaks. It consists of an array of wires. When these wires become wet, an electrical short occurs which is transmitted by a binary signal to the microcontroller and it is processed and desired action is taken. In addition, LED strips are integrated as state indicators. These indicators are especially useful during autonomous runs for understanding the vehicle's current state.

Fig: 23 Leak Sensor

BATTERIES

Lithium polymer batteries built with Li-Po Nano-technology substrate complex are used for providing power to Alpheus. The advantage of using these batteries is that there is less voltage sag and a higher discharge rate. The batteries are connected to a Battery Management System, which efficiently supplies power to the thrusters, microcontroller carrier board, CPU and other components used in the AUV. It can power the AUV for 120 minutes continuously.

Fig: 24 Multistar Li-Po 10000mAh

KILL SWITCH

Alpheus is provided with a kill switch which is used to shut down the entire AUV system, in an emergency. When the kill switch is activated, it stops power supply to electronic components completely and disables the thrusters. The kill switch minimizes the risk of the AUV getting damaged when an emergency is detected. Emergency situations include water leakage which may cause short circuiting, attacks caused by marine animals and destructive human activities which may inflict severe damage on the AUV.

DROPPING & TORPEDO CIRCUITRY

The vehicle uses a pneumatic cylinder assembly for dropping markers. The piston is actuated using a double acting cylinder, which is connected to a solenoid valve allowing the marker to fall into the bin. This design was chosen due to its low offset and high accuracy.

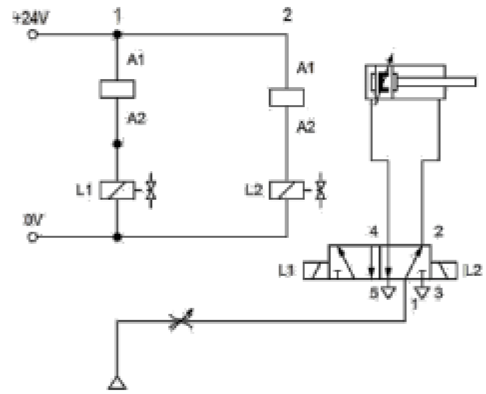


Fig: 25 Dropping & Torpedo Circuitry

THRUSTERS

Alpheus uses 8 Blue Robotics T200 series thrusters systemized in three main groups: Two horizontal thrusters for surge, four vertical thrusters for heave and two side thrusters for heading and sway control. Each of these thrusters are controlled using an independent motor driver. This enables uniform and accurate propulsion, since it allows for individual control of each thruster's rotation speed. The depth rating of the thrusters is 150 meters in fresh water.

Fig: 26 Thrusters (Bluerobotics T200)

HYDROPHONE ARRAY

The Acoustics System enables real-time detection and estimation of the Direction of Arrival (DoA) of underwater impulsive audio signals produced by the pinger. The main objective is to compute the angle and elevation of the source of signal. Signal Processing hardware from National Instrument and a 2-dimensional array of four Sparton PHOD-1 hydrophones are used for the acquisition and real-time processing of the signals. Once the event (impulsive signal) is detected, its DoA is estimated using Generalized Cross Correlation (GCC) with Phase Transform weights (PHAT) to measure the Time Difference of Arrival (TDoA) between pairs of hydrophones. Parameterized predictions of TDoA's are compared to actually measured TDoA's such that the parameter can be obtained by a Least-Squares minimization. Using realtime techniques, there is no loss of information from the environment for the processes of signal detection and DoA estimation occur in parallel.

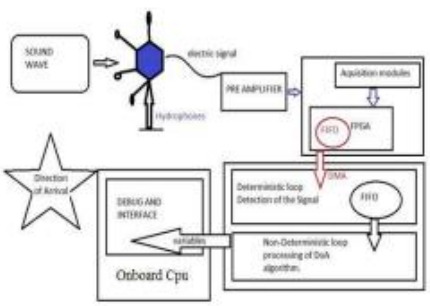


Fig: 27 Acoustic system

Fig: 28 Sparton PHOD-1 Hydrophone

SOFTWARE DESIGN

. The Software stack of Sedna is built on top of the **Robot Operating System** (ROS) by Willow Garage. ROS is installed on top of **Debian Linux** operating system, running on an Intel core i7 processor. A Mini-ITX on-board computer is provided inside the pressure hull.

The software stack has been designed from scratch this year and provides the following benefits:

- Modular design with optimal task distribution
- Abstract asynchronous inter-process communication mechanisms
- Redundancy in process life-cycles in case of crashes
- Shared memory system for vehicle parameter variables
- Improved front-end controls for easy debugging of missions

The Robot Operating System is an industrial-grade robotics framework which provides various services and tools that significantly reduce design cycle time. The software stack of Sedna is modularized into various processes that are completely independent of each other, yet are able to communicate using an asynchronous messaging protocol.

The software subsystems of Sedna are divided as such:

- Mission Planner
- Motor Controller
- Vision Server
- Action Server/ Action Client
- User Front End
- Telemetry

All these systems are integrated into the ROS infrastructure in the form of nodes with asynchronous communication among them. Topics provide data communication over TCP or UDP and Services provide an XML-RPC request-response call. The software team is mainly responsible for developing software for mission planning, computer vision and control system design.

The software architecture is divided into two parts:

- A **High-Level Architecture** which involves abstract planning algorithms like mission planners and direct waypoint navigation functions. It also includes the vision server which is responsible for image processing and object recognition on the camera images. Most of these algorithms run of the onboard computer.
- A **Low-Level Architecture** where the onboard sensors and actuators of the vehicle are interfaced to the microcontroller. The directives from the high-level software are fed to the microcontroller which controls the thrusters of the vehicle.

SYSTEMS INTEGRATION:

Sedna's architecture is a highly distributed and abstraction is achieved in the form on

"nodes" with asynchronous inter-process communication mechanisms between them.

The various subsystems are started all at once at runtime and are actively involved in asynchronous IPC once started. The system is fault tolerant with a node being immediately restarted if any system error causes its shutdown.

DESIGN METHODOLOGY

Sedna's software is developed in various layers of abstraction. The low-level software comprises the PID controllers, the microcontroller kernel and the communication protocols to interface the microcontroller with the on-board computer. The rest of the software is mostly the high-level architecture which sends commands to the low-level controllers, e.g. navigational commands. Sensor data is collected through various sensors

CONTROLLER DESIGN

Robust vehicle control is achieved in Sedna through a combination of 6 carefully Proportional Integral Derivative (PID) controllers. The autonomous operation of the AUV is brought about using set-point directives to the PID control loops. The microcontroller board is programmed with a custom kernel that constraints operating frequencies of the control loops along with loops for collecting sensor data and relaying information to the on-board computer.

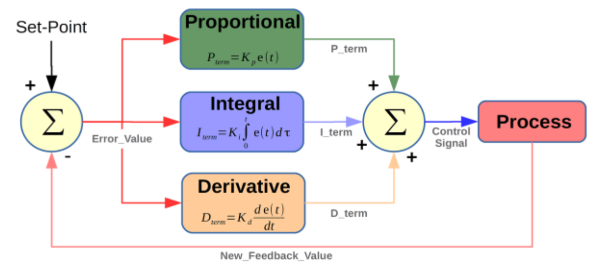


Fig: 29 PID Algorithm

Pose of the vehicle is determined from the inbound IMU data. Each PID controller maintains pose of the vehicle using set-point directives from the High-Level Software. The controller computes the error in each of the Yaw, Pitch, Roll, Surge and Sway Axis. A high frequency error minimization algorithm with average weighting of output corrects the pose error to achieve the target set-point.

MISSION PLANNER

The high-level planning software is developed using a State Machine implemented in Python using the SMACH (State Machine) library. The competition tasks are described using a set of states with a number of inputs and results associated with each state.

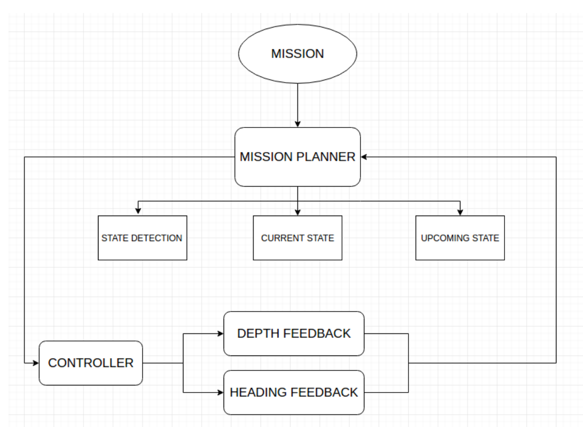


Fig: 30 Mission Planner

The state machine transitions with the successful completion of a task and failure to complete a task would be logged into the system. Each state also has a time-out feature which helps to transition onto the next state in case a task is taking too long to complete the competition tasks are divided into a set of states that are executed sequentially or iteratively. The design of mission planners is very rapid because of the high-level design approach used for developing the state machines. Also, the states of the state machines can be bundled in containers and be reused as abstract state machines inside another state machine. The main link between the High Level and the Low-Level architecture of Sedna is the Action Server and the Action Client interface. The Action server is used to send goals to the Action Client which executes them until completion. Benefits of using the action sever include execution of pre-emptive goals, active goal completion feedback and fault tolerance.

VISION SERVER

The vision server of Sedna is the main system for image processing. The images are obtained using a set of two cameras onboard the vehicle, one for forward and another for bottom vision.

Fig: 31 Vision Debugging Suite

The image processing software employs a series of algorithms to detect and segment underwater objects. The main task of the vision server is to compute the geometrical co-ordinates of various underwater objects and relay the information back to the vehicle controllers. An example image processing pipeline to detect a colored Buoy can be summarized as follows:

We white balance the input image to improve the contrast. For providing lighting invariance we make use of an appropriate color space. This is followed by segmentation of objects in the image using color thresholding. A set of erosion and dilation filters is implemented to smoothen out the resultant binary mask. Circular Hough Transform is applied on this binary image to detect circular contours. The biggest circular contour is then selected which corresponds to the target buoy. To this image we apply cvMoments to compute the inertial center of the buoy. Finally, the computed information is relayed over a ROS Topic so that other subsystems can utilize it.