Delhi College of Engineering

DCE-AUV

Abstract

VARUN is an Autonomous Underwater Vehicle (AUV) developed by a team of undergraduate students from Delhi College of Engineering (DCE) to compete in the 12th International Autonomous Underwater Vehicle Competition organized by Association for Unmanned Vehicle Systems International (AUVSI) and U.S Office of Naval Research (ONR) at the U.S. Navy's Space and Naval Warfare Systems Centre (SPAWAR) TRANSDEC Facility in San Diego, California, USA. Team DCE-AUV has pursued this endeavor for over two years and has brought about many improvements in technology with time. This Journal Paper presents the various architectural, software and design changes made to the third generation vehicle.

v.a.r.u.n

Vehicle for Automation Research and Underwater Navigation

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Introduction

The 12th Annual International Autonomous Underwater Vehicle Competition hosted by AUVSI and ONR is to be held in San Diego, California at the SPAWAR TRANSDEC Facility from July 26th to August 2nd 2009. The competition involves automated robots in an underwater arena carrying out pre-programmed tasks in a dynamic environment. It provides a platform for international academic interaction and gives a chance for the students to showcase their skills and intellect.

The DCE-AUV model has been designed with a view to achieve maximum operational standards and reliability with minimal payload and power requirements. The mechanical design focuses on stability and robustness, thus reducing dependence on automated control. Six onboard thrusters are controlled by six Syren10 motor drivers in communication with an on onboard computer encased in a waterproof hull. Lithium polymer batteries form the power supply of the vehicle.

The sensor array features four hydrophones, a pressure transducer, an inertial measurement unit and two cameras, all of which are interfaced to the onboard computer. Programs to implement image processing, acoustics, control systems and mission control have been developed. GUIs have been developed for getting data from all sensors, implementing individual codes as well as for the mission control. Addition of wireless access system enables the access of data on onboard computer to an off-board computer while the AUV is underwater.

Mechanical Design

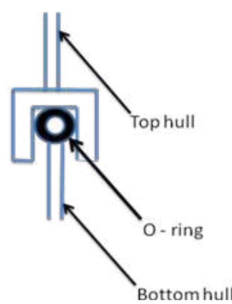
The new mechanical model is designed to be hydro dynamically stable. The vehicle features a seamless, smooth contoured ellipsoidal body. The shape of the vehicle has been decided after calculations, keeping various hydrodynamic parameters in mind to improve the overall performance of the robot. The mechanical body is designed to be propelled by 6 thrusters and has net positive buoyancy of 1kgf. The fabrication material is chosen to be FRP (Fibre Reinforced Plastic) because it is light and strong while being easily workable. The compressive strength of the material allows a working depth of approximately 10 metres for the design thickness of 4mm throughout.

CAD Model

The thrusters can be utilized to control three degrees of freedom, i.e.,
(i) translation along x-axis
(ii) translation along z-axis
(iii) rotation about z-axis

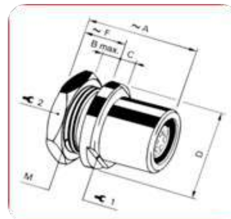
The other three degrees of freedom (roll, pitch and strafe) are stabilized without any external thrust application, by virtue of the mechanical design. The profile of the vehicle makes it easily maneuverable. The vehicle is even capable of rotating about central axis of the body. Two additional thrusters are being used to control the sideways motion of the underwater vehicle i.e. strafe.

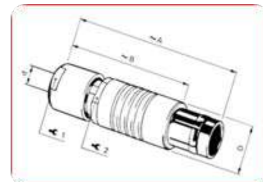
Electronic Hull and Waterproofing



The main hull is split into two symmetrical halves by a plane parallel to its longest side, and equidistant from the edges. A 'Y' shaped protrusion arises out of the edges, running along the complete perimeter. All the electronic components are housed inside the electronic hull, which holds a volume of 21 liters. Sandwiched between the arms of the 'Y' attachment and the edge of the lower half of the hull is a custom made silicon rubber 'o' ring. When the two halves are pressed into each other, the rubber ring is slightly compressed, thus acting as a physical block to prevent water leakage. One of the arms of the 'Y' attachment forms a skirt like structure around the entire periphery of the joint. This structure traps an air bubble around the entire joint, thus preventing water from even reaching the 'o' ring. This acts as the primary line of defense against the leakage.

Underwater Connectors and cables





The peripherals include professionally built underwater connectors, provided by Fischer Connectors. The connectors and cables provide effective water proofing and are easy to install.

Clamping System

An efficient clamping system provides the compressive force to compress the ‘o’ ring and hold the two halves of the hull together. The clamps are easy to handle and are used for opening and closing of the hull.

Vehicle Dynamics

Thrusters

Six strap-on BTD150 thrusters from Seabotix Inc are used to maneuver the vehicle. Two thrusters facilitate the horizontal motion, while the other two facilitate the vertical motion and the remaining two strafe motion . They were chosen because of their high thrust to weight ratio and safeguards for power surges and ground shifts. These thrusters provide a two blade bollard thrust of 2.9 kgf and require a power of 80-110 watts.

Metal Frame and Wings

The metal frame helps to lower the centre of gravity of the vehicle and is also used for easy mounting of thrusters and other components like dropper and grabber. The wings provide hydro dynamic stability to the vehicle.

Mechanical Subsystems

Dropper Mechanism

A marker dropper mechanism is made using a 12V DC motor. The mechanism is controlled using vision and control system modules, and is instructed to drop the markers into the designated bins.

Grabber Mechanism

A simple polycarbonate arm is used which is meant to trap the briefcase in its hooks. The location of the briefcase is obtained using sound and control system modules.

Hardware and Embedded Systems

Sensors

Inertial Measurement Unit (IMU

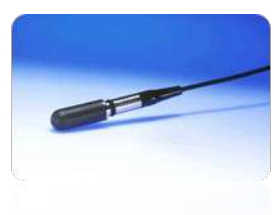
We are using MTi-28A (Motion Tracker-inertial) manufactured by XSens. The MTi is a miniature, gyro-enhanced Attitude and Heading Reference System (AHRS). It provides us with calibrated 3D linear acceleration, rate of turn, orientation data (yaw, pitch and roll), as well as earth magnetic field data.

Pressure Sensor

A full digital temperature and linearity compensation accurate pressure sensor from Desert Star (Desert Star SSP1/100) has been used to gauge the pressure, and hence, the depth of the AUV below the water surface. It sends output to the computer via RS-232 port, and has user configurable sample rate and pressure units. It yields an accuracy of 0.2% and a repeatability of 0.02%.

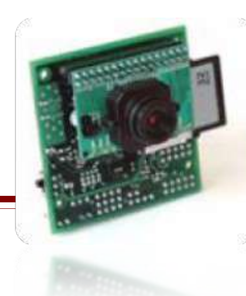
Hydrophone

Four Reson TC4013 hydrophones are used as acoustic sensors. They have high sensitivity and provide uniform omni-directional sensitivities in both horizontal and vertical planes up to high frequencies (ultrasonic), and can be calibrated individually.



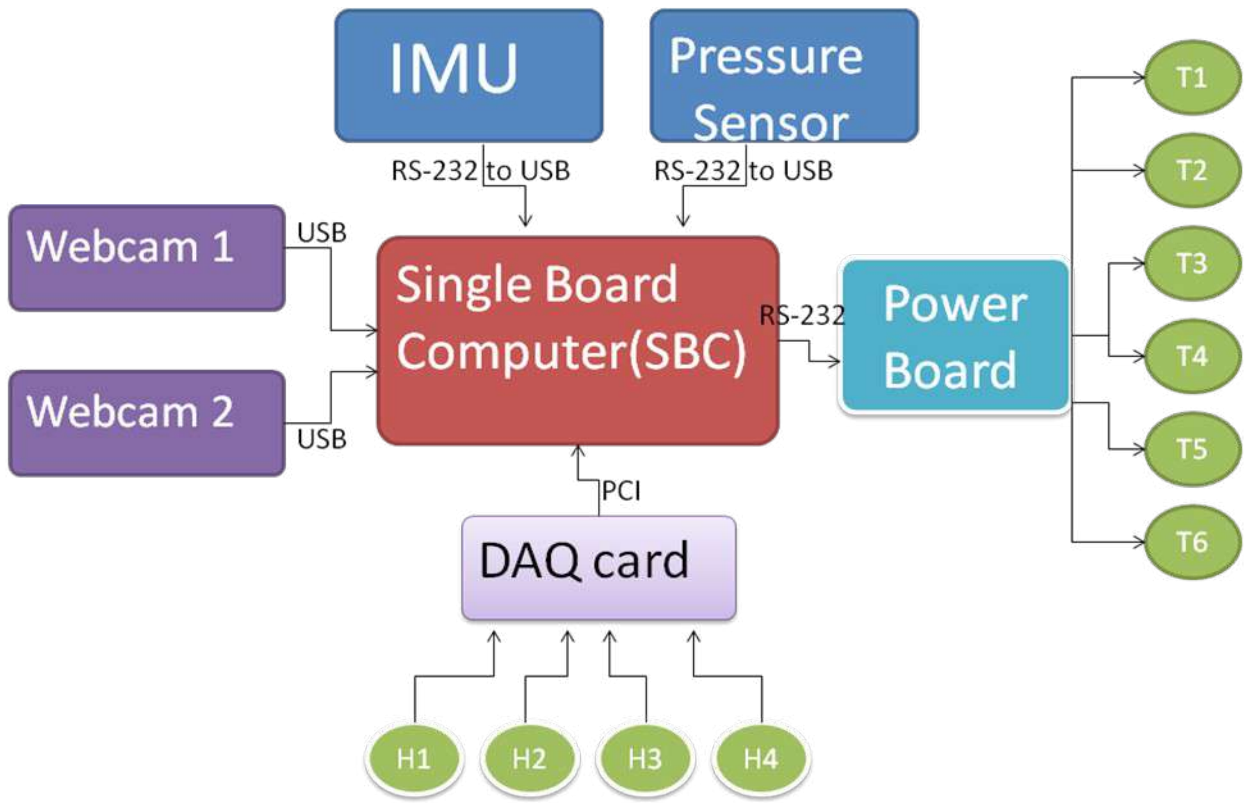
Cameras

Two Logitech Quick Cam 5000 USB webcams are used for vision sensing. These webcams have user configurable vision settings and low power requirements. One points straight ahead, another points



straight down. The cameras are internally mounted, thereby not interfering with the streamline motion of the body. The vehicle is capable of switching between cameras to perform different tasks.

Hardware Architecture



Onboard Single Board Computer (SBC)

A light and sturdy SBC (Single Board Computer) is made to fit in the electronic compartment of AUV. SBCs are preferred over laptops as we can customize their configuration according to our requirements and add additional Data Acquisition (DAQ) cards if needed. The Kontron 986 LCDMTiX SBC is the core electronic unit of the vehicle.

Sensor Interfacing

All sensors are interfaced either through USB or RS-232 method of interfacing. Serial communication is done using UART module. A 12-bit analog to digital conversion is done when required. NI PCI 4462 is a Data Acquisition (DAQ) card manufactured by National Instruments. It has 24-bit resolution

ADCs with 118dB dynamic range and is used to interface the
hydrophones for acoustic navigation.

Thrusters and Motor Control

Brushed thrusters and simple dc motors have been used for providing locomotion. A Syren10 motor driver have been used to control the speed of thrusters at 255 different levels. These motor driver are reliable, fast and compact.

Power Systems

The power system used is a simple compilation of batteries, DC/DC converters and underwater switches to get different voltages required to drive various systems in the AUV.

Lithium Polymer Battery

Custom made LiPo batteries having light weight and high energy density are used.

The Drive System

A single battery of 27.4V, 22 Ah provides power to the drive systems. The thrusters have electrical rating as (28 ± 10%, 4.5 amps). In forward motion, the thrusters require 4.25 amps of current and 4.10 amps when moving backwards, as against a potential difference of 24.8V applied at full power. The runtime in this case would be 2 hours approximately.

The Embedded Systems

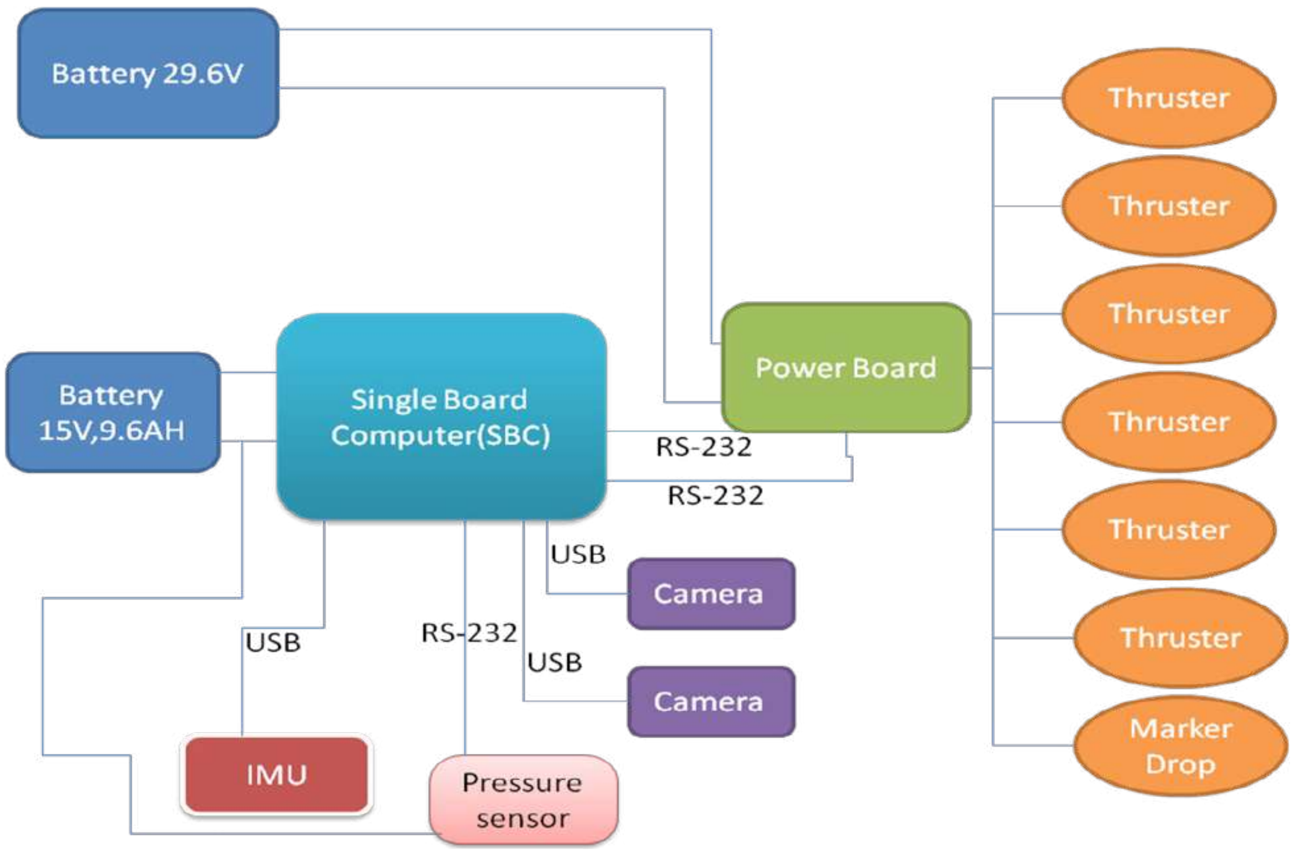
To drive the embedded components and ICs, another battery of 14.8V, 9.6Ah is used. However, if the battery supplying current to the thrusters fails, the battery used for embedded systems can be used as a substitute and is capable of powering all the components.

Kill Switch

A generic double pole single throw switch is mounted on the vehicle which is fully Submersible in water and placed outside the main body of the hull. The switch is used to

Activate and deactivate the power circuitry of the vehicle.

Power Distribution Diagram

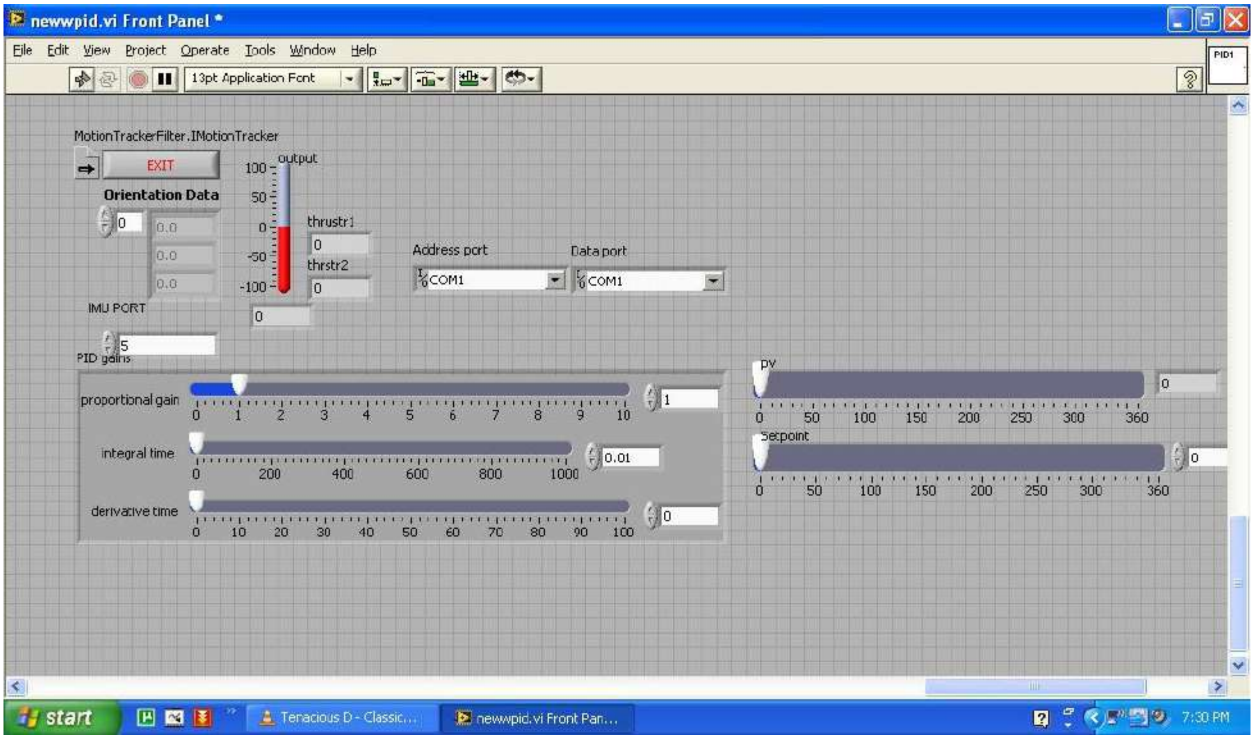


Software

The use of Labview, developed by National Instruments, has been made to develop our software framework. The software is designed to run in decentralized multi-threaded agent architecture, with the threads handling pressure sensor, acoustics, cameras, control system, IMU, each performing input and output operations in continuous loops.

Control System

Control parameters are acquired for control of thrusters by PID method of motor control. PID algorithm processes data from various sensors ,vis a vis IMU and Pressure sensor, and according to parameters sent by PID control, the speed and direction of the thrusters is controlled using Syren10 motor driver . The PID control algorithm has been coded in Labview. This method has proven to be more efficient, less processor intensive and easy to use.



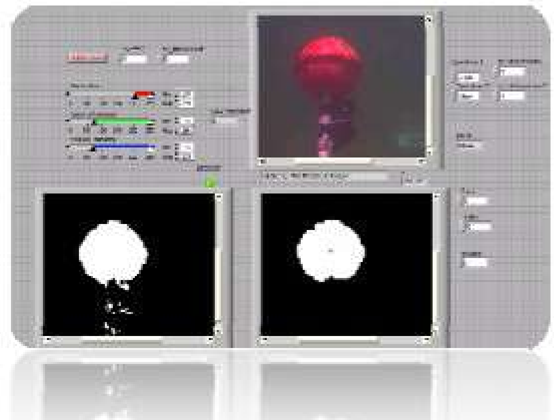
The control system follows simple motion control algorithms using PID feedback. It relies on the mechanical stabilization for both roll and pitch, and thus, only the yaw, depth and horizontal movement is controlled by the vehicle control system. The system attempts to maintain its state using dynamic feedback from the IMU, pressure sensor and the acoustic and vision modules. The control system receives its vector coordinates from all the modules and it undertakes priority tasking as programmed. User interfaces are specifically developed to tune and adjust the PID parameters. These interfaces facilitate easy and quick tuning to determine the values of Kp, Ki and Kd wirelessly.

Artificial Vision and Image Processing

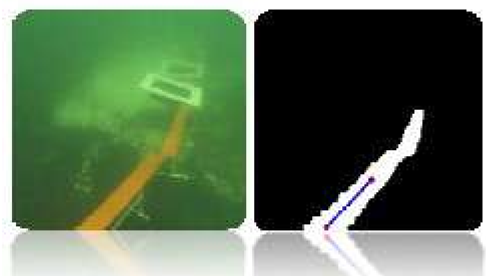
The Computer Vision module was developed using the “NI Vision” library in NI LabView. The high parallelism during execution of programs on multi-core CPUs in LabView gives the vision module the required real-time computational power. The module incorporates concepts involving image processing, particle analysis, image segmentation, binary morphology and machine vision. The major change this year is that the navigation system works on absolute yaw (angle) control. The previous gen vehicles had a less accurate navigation system partly based on heuristics

Validation Gate: The forward facing camera is used in this task. The image is segmented for the specific color (green). An edge filter is then applied to the binary image thus formed. The Center of Symmetry of vertical edges thus gives the correct heading (in degrees) to the vehicle.

Flare (blob) detection: The algorithm segments out the red color, giving a binary image. The HSV color space is used for all segmentation based operations.The binary image is then eroded and dilated suitably to remove any errors present. The particles in the binary image are then analyzed and the center of the largest particle gives the current heading. The vehicle tries to approach the flare keeping the center at 0 degrees.



Path Detection and Orientation calculation: The camera angled at 45 degrees is used for this task. The color segmentation is used to separate out the specific color (orange) from the captured image. After conversion into binary image, the pipeline detection algorithm checks whether the data in the image is accurate enough, and any information available is extracted. The orientation of the largest particle in the binary image with the horizontal axis of the camera is the orientation of the pipeline.



Bin identification: The downward facing camera is used for bin identification. The algorithm implements concepts of pattern recognition and is able to differentiate between the given geometrical patterns. The center of the bins is found by calculating the centre of symmetry of the edges found in the captured image of the bin. (The white-black edges are only considered). The marker is then dropped after the vehicle aligns according to the center given by the algorithm.

Underwater Acoustics

The SONAR system uses 4 hydrophones as signal receivers which are connected to a NI PCI 4462 Data Acquisition Card (DAQ). The DAQ features 24-bit resolution ADCs with 118dB dynamic range, 6 gain settings, variable anti-aliasing filters and 4 simultaneously sampled inputs at up to 204.8kS/s. Multilateration technique for pinger detection has been employed for accurately homing on to the acoustic source. National Instruments LabVIEW software is used for data acquisition, processing and decision making. Once the coordinates of the acoustic pinger are determined, the processing is passed on to the control system to manoeuvre the vehicle towards the target.

Graphical User Interface (GUI)

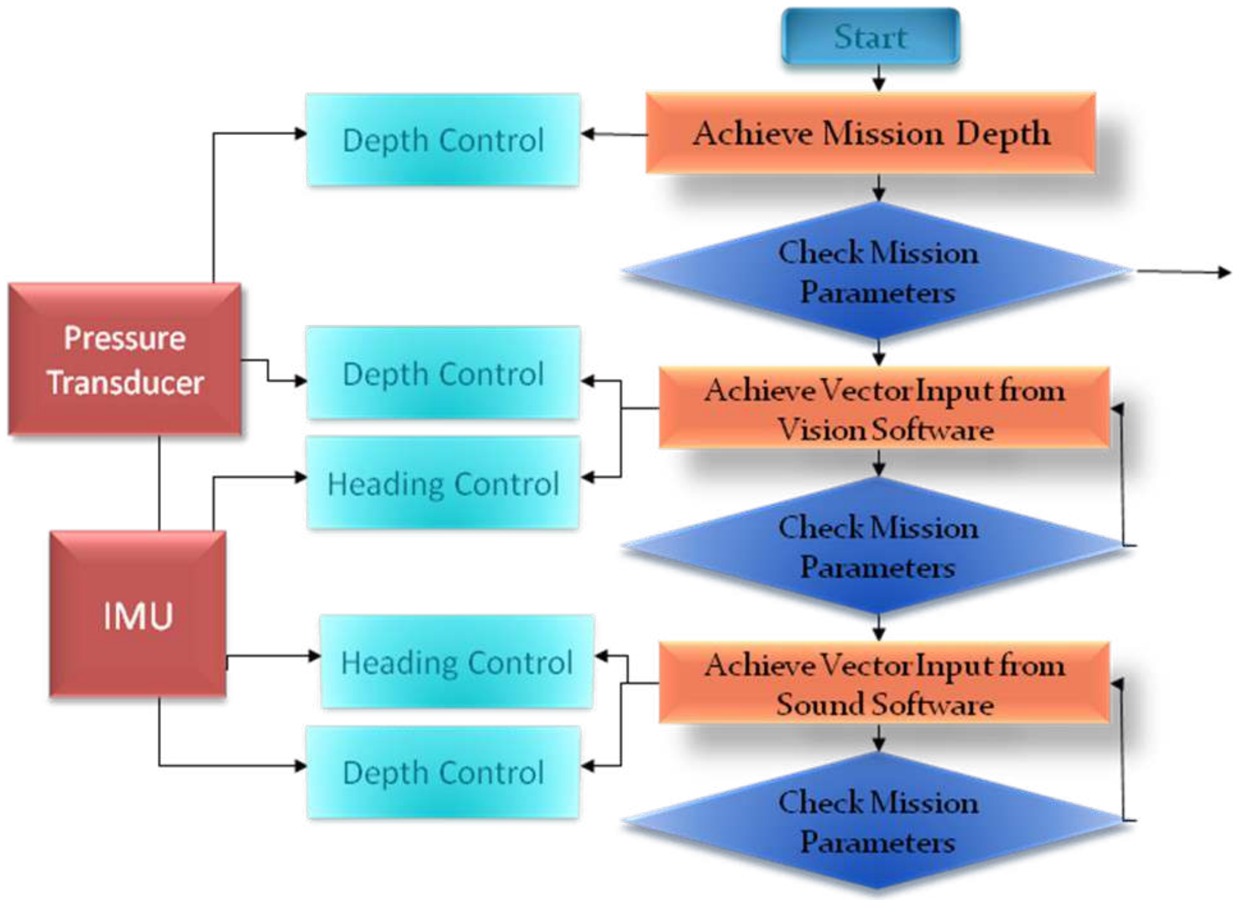
Graphical User Interfaces (GUIs) have been developed for acquiring data from all sensors, adjusting control parameters, implementing individual codes, as well as for the mission control. All codes of individual mission statements can be accessed from one main interface while
testing of the vehicle, thereby enhancing debugging and reliability.

Wireless Access

The SBC present inside the AUV is the client to which the offshore client connects remotely through a server. It is achieved by using Windows Remote Desktop Connection application which establishes a wireless Ethernet (802.11g) connection. A router is configured as a DHCP server. It leases out private IP addresses to clients that connect to it.
Remote access helps in parallel code development, debugging and data logging. It plays a key role in testing of the vehicle. By viewing the real-time sensor data, we can tune most aspects of the submarine's intelligence and control. In addition, the main control program can be remotely modified and recompiled. All of this is possible while the submarine is submerged and operational.

Mission Strategy

A separate mission code is developed for the final run in autonomous mode. The mission code is responsible for the artificial intelligence of the vehicle.
Mission control is at the highest level in the software hierarchy, coordinating the global state of the submarine and the state of each subsystem. It makes calls to vision, sound and control modules to dictate how each portion of the course is carried out and to determine where to go. The mission control server coordinates the state of the submarine as it goes through the entire course. Once the AUV determines where it needs to go, it calls the control module which commands the actuators to function accordingly.



Acknowledgements

Team DCE-AUV extends its warmest thanks to Dr. Shailesh Nayak (Secretary, Ministry of Earth Sciences) and his team of extremely talented people who have supported this endeavour with both technical and financial assistance.

We are indebted to the National Institute of Ocean Technology (NIOT) for the guided backing they have provided us at all times during the project.

We would like to thank Delhi College of Engineering for its unflinching support. We sincerely thank our faculty advisors, Prof.P.B.Sharma and Prof.R. K. Sinha, who have helped us in completing this project.

We are grateful to our sponsors who have provided us with resources and made our participation possible: Fischer Connectors, National Instruments, Kontron, Xsens and Igus.

We thank AUVSI and ONR for organizing this competition and giving us an international platform of learning and showcasing our efforts.

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