Design and Development of an Autonomous Underwater Vehicle: NUST-PNEC

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Abstract – This Autonomous Underwater vehicle has been designed and developed by undergrad students from PNEC, a constituent college of the National University of Sciences and Technology (NUST) in Pakistan. This is the team's first venture into RoboSub and also its first international grade competition. By entering RoboSub the team aims to learn and further develop this technology for AUV enthusiasts in its home country. This paper discusses the mechanical design of a low-cost Autonomous Underwater Vehicle (AUV), and presents the design of an efficient control system for stabilization and path-following of the AUV using image processing techniques implemented through OpenCV. For the purpose of execution of a prescribed underwater task, it is desirable to stabilize the vehicle's movement and implement a suitable strategy so as to accomplish navigation on a pre-defined path. This is achieved using a set of sensors such as high-rate Inertial Measurement Unit (IMU) consisting of accelerometers and gyroscopes, and a depth sensor, along with underwater cameras to capture images for image processing. Then, the data obtained from these sensors is processed in real-time to compute the control signals required for stabilization of the vehicle and to achieve the desired path-following with required accuracy.

I. INTRODUCTION

NUST-PNEC is a team of 3 undergrad students and 2 doctorate professors, the team has developed an Autonomous Underwater Vehicle (AUV) for participating in RoboSub 2015. The team aims to gain hands-on experience and learn to tackle real-scenario based missions using AUV technology.

II. MECHANICAL DESIGN

While designing an autonomous underwater vehicle, one has to take the additional challenging task of providing protection against water pressure, as the vessel has to withstand immense water pressure and ensure that the connections to sensors and actuators external to the AUV hull are watertight. Forces acting on a forward moving submerged body are thrust, drag, buoyancy and weight.

This AUV constitutes the main hull (a waterproof vessel), to box in the electrical components, actuators and the AUV frame, to attach each system.

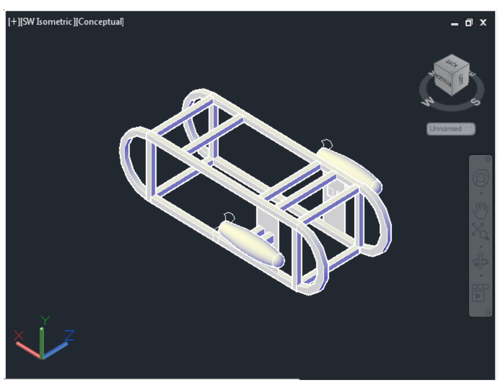
The criteria that were taken into account while designing are as follows:

1- The structure is kept simple so that common machining tools can be used to construct it.
2- To ensure waterproofing for electronic devices and electrical connection, rotating mechanical devices (rudders and bow planes) were avoided.
3- Cost effective (Due to low budget) - by the use of materials and components that are available locally and readily at low cost.

4- By eliminating ballast tank, software control implementation becomes relatively easy.
5- The structure is kept modular- giving ease with which the different systems can be attached to the skeletal frame.

Paramount to this selection was the capability of the material to withstand water pressure and the weight of all equipment it had to sustain. The material found most suitable for this purpose was acrylic. A frame for the vehicle was designed in AutoCAD and laser-cut from acrylic sheets, keeping in mind modularity and price of construction.

The most important aspect when designing an AUV is the consideration of Buoyancy, which allows a submersible body to float, this force is simply due to the lifting power of water. The vehicle is designed such that centre of mass is situated directly below the centre of buoyancy, which is critical in maintaining stability.



1. AutoCAD Design

The hull encloses the electrical components such as the computer, microcontroller, power distribution system and motor speed control circuit.

2. AUV Hull

III. POWER SYSTEM

The team's AUV is driven by two 6s configuration Lithium Polymer Batteries. These batteries are connected to a power supply unit (PSU) which is responsible for regulating power supply to the entire circuitry and devices, voltage monitoring and switching.

The batteries used are ZIPPY Compact 5800mAh 6S 25C Lipo Pac. Their specifications are given below:

Capacity (mAh)	5800
Configuration (s)	6
Discharge (c)	25
Weight (g)	913
Max Charge Rate (C)	5
Length-A(mm)	160
Height-B(mm)	46
Width-C(mm)	57

Unlike conventional NiCad or NiMH battery cells that have a voltage of 1.2 volts per cell, LiPo battery cells are rated at 3.7 volts per cell. The primary advantage is that fewer cells can be used to make up a battery pack.

The vehicle is equipped with ATX power supply, which is powered by LiPo batteries discussed above. Its primary purpose is to provide different voltages that are required by the wide array of electrical devices and modules. It also provides protection against voltage surge. The power supply has the capability to handle power up to 300W.

3. Power Supply Unit

IV. NAVIGATION

Two thrusters are placed at both sides of the AUV to provide thrust for moving the vehicle along the X-axis and the Y-axis. For turning the AUV in a particular direction the speed of rotation (rpms) of one thruster will be regulated through a computer program such that the AUV begins to turn in the desired direction. For instance, if the vehicle needs to be turned right then the thruster installed on one side of the AUV will be either slowed down or stopped until the vehicle has made the desired turn, this is controlled via a PID loop.

The two thrusters used for this purpose are BLDC type thrusters from Singapore. They operate on a voltage range of 12-18vDC and a maximum current of 1A.

Movement along the Z-axis will allow the AUV to submerge in and resurface out of water. Our AUV design utilizes Bilge pumps (used as motors) for movement along this axis. Bilge pumps are a feasible alternate solution to thrusters and are easily available at low cost. A configuration of four bilge pumps used as thrusters is implemented in our vehicle design, each is installed on the lower part of the structure such that the overall geometry is symmetrical.

V. SENSORS

To navigate in an underwater environment and successfully resurface after completion of a given mission an AUV gathers real-time data from its environment. This data is imparted to the vehicle's computer system from different sensors. The type and number of sensing devices depends on the mission or purpose of an AUV. To meet our purpose the team has incorporated the following sensor devices:

- Inertial Measurement Unit
    - 3-Axis Gyroscope
    - 3-Axis Accelerometer
- Depth Sensor
- Hydrophones

The IMU device used in our AUV is the MPU6050 6DOF IMU by Invensense. It has a 3-Axis accelerometer and a 3-Axis Gyroscope. The depth sensor used is the MS5803 14BA sensor module with waterproof gel covering.

4. MS5803 Depth Sensor and MPU6050 IMU

Data from IMU is used to determine the YAW angle of the vehicle and maintain the vehicle's balance through ROLL and PITCH values. Depth is regulated independently through the depth sensor. All these parameters are controlled through a PID control system.

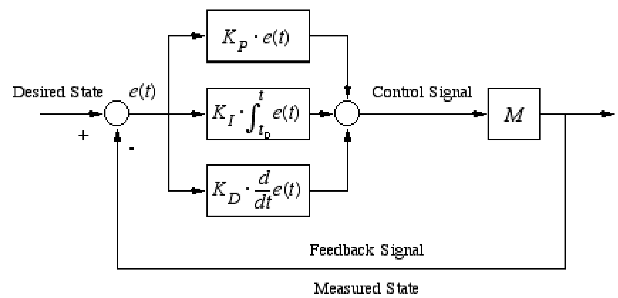
VI. COMPUTER SYSTEM

Our computer architecture constitutes a set of two computers, each of which is dedicated to perform specific functions. Such a distributed form of computer topology allows for better performance, designation of tasks and a robust computer system. The computer topology adopted constitutes a processor and a microcontroller, Raspberry Pi and Arduino respectively. Raspberry Pi is responsible for performing more process-intensive tasks like running image processing algorithms while Arduino will only perform simple actuation based on sensor data or commands from Raspberry Pi.

The Arduino board used is the Mega2560, it is interfaced with the depth sensor, hydrophones and thrusters. It will also take commands from Raspberry Pi through a USB interface.

Raspberry Pi Model B+ is interfaced with underwater cameras and it will forward actuation commands to the Arduino board after processing data from cameras. It will run image processing algorithms and compute results.

Image processing results and depth regulation, both are maintained through a PID feedback control loop system.



5. PID feedback loop

VII. IMAGE PROCESSING

For the detection of objects and alignment with guide markers the team implemented OpenCV algorithms for image recognition tasks. HD Raspberry Pi compatible cameras are used for the purpose of taking photos underwater. The camera is enclosed in a waterproof casing.

Object Detection involves Image Processing operations such as segmentation, edge detection and clustering. Once the object has been detected the iterative process of tracking takes place with minimum deviation from the desired path using a PID Controller.

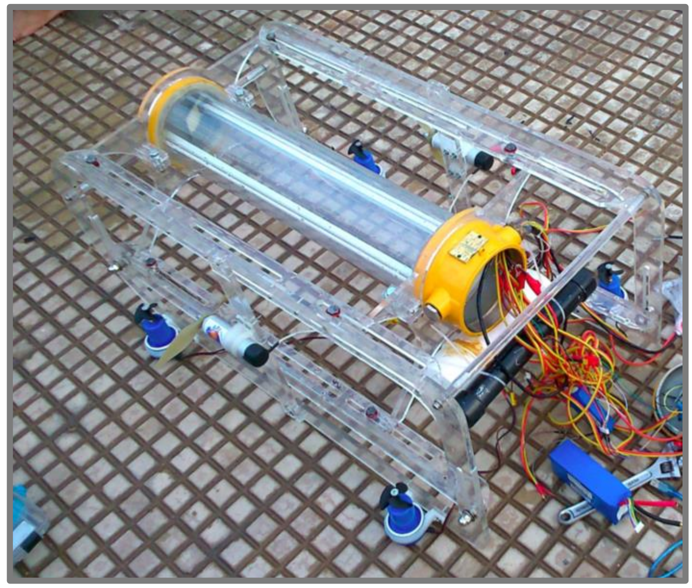
The algorithm used for detecting objects occurs in the following steps. The image is first filtered, it is then converted to greyscale and then the image is traced. In the RGB colour model, that we are using, a value of 255 would represent a complete white colour while a value of 0 would represent black. After filtering, the first thing that the algorithm finds is the range of the RGB value that we are going to deal with in the picture.

The algorithm then sets an arbitrary threshold value from which every pixel value will be compared. Based on the result of comparison the colour of the pixel is set to either black (0,0,0) or white (255,255,255) and saved in a new array.

Finally after the completion of comparison of each and every pixel in image, a new image is redrawn from the modified list of pixels.

After conversion to greyscale or detection of a coloured object the following steps are followed for completing a particular task which involves object detection:

1. Get the size of the image.
2. Sweep along the horizontal axis of all the pixels at the top of the image
3. Detect the change in the RGB values of the pixels along the x axis as compared to the threshold value.
4. The value of the x-axis where the change in RGB value of pixels is detected has to be stored
5. Find the midpoint of the line at the top of image
6. Now transverse through the x-axis at the bottom of the image and store the value where change in RGB value occurs
7. Find the midpoint of the line at the bottom of the image.
8. Now find the slope of the line using slope/intercept formula.
9. Manoeuver AUV using a PID controller.



6. AUV on pool deck with hull open

VIII. REFERENCES

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