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IIT Kharagpur Autonomous Underwater Vehicle: Conceptual Design Report of Kraken 4

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Abstract

Kraken 4 is the unmanned undersea vehicle being developed by AUV IITKGP, a team of 20 undergraduate students at IIT Kharagpur. Kraken 4 is an advanced version of our previous AUV, Kraken 3. This report describes the design and development of an AUV for the STUDENT autonomous underwater vehicle event, organized by NIOT, Chennai. This document discusses the general design methodology, modelling and simulation of the proposed conceptual design. With numerous improvements, this design presents a more agile vehicle with increased capabilities over previous vehicles. New advancements include a stronger frame, an improved electrical system and momentous software changes which affords improved mission reliability. The proposed model has 6 degrees of freedom with allowances for a robust navigational payload.

Keywords: IIT Kharagpur • Underwater • Electrical system

Introduction

Robotic system started to take place in human life in parallel with the development of robotic technology and artificial intelligence and applications through their acquisition. As the ocean is a magnet to a large number of environmental issues and resources as well as scientific tasks, the need for the use of an Autonomous Underwater Vehicle system has become more apparent.

The competition hosted by NIOT (National Institute of Ocean Technology) mandates the design of a robot submarine (AUV) and associated technologies for observation of physical properties in the coastal region. The AUV is expected to serve, assess and monitor the environmental conditions and marine activities of the coastal zone.

The robot also needs to be entirely autonomous in nature i.e. it needs to be piloted by an on-board computer to complete pre-programmed mission objectives. The AUV is expected to operate at an optimum depth of 25 m and have a maximum length of 2 meters and diameter of 0.5 m. Scalability, cost effectiveness and robustness were the guiding design principles in this project [1].

Mechanical Design

The body of the AUV is designed to implement a differential motion-based control with two heave, four surge and two sway thrusters. The vehicle consists of vehicle frame, two Hulls, DVL, 8 Thrusters and actuators all mounted onto an Aluminium Frame. The dimensions of the vehicle are 105 cm × 35 cm × 36 cm.

The Main Hull has a diameter of 20 cm, and it houses the various electronic components, and the batteries are placed externally in separate battery pods. The thrusters are placed so as to provide maximum control. All the thrusters have been accommodated as close as possible to the corresponding planes of centre of gravity so as to minimize the unbalanced roll, pitch and yaw moments generated due to thrusters. The frame is made up of aluminium plates to make it robust and lightweight (Figure 1).

The frame is implemented to provide rigidity and strength, and also to provide protection to the main hull in case the AUV collides with a wall in the arena. Enough clearance has been provided between the end cap and the sway thruster in order to accommodate water tight connectors to be attached to end cap. Other mechanical enclosures like DVL, battery pods, gripper, marker dropper, torpedo launcher, actuators have been integrated to the frame with high optimization.

All components are placed such that the centre of mass is at relative centre of AUV allowing for more stable vehicle control. While designing the vehicle, a lot of emphasis has been given on ease of accessibility of different enclosures. The vehicle also includes two actuator systems, Marker dropper and torpedo shooter for different tasks to be performed. The model has been designed on SOLIDWORKS 2016, Dynamic stability analysis, finite element analysis (to calculate stresses and displacements) and drag analysis

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of the vehicle and its different components has been done through ANSYS 18.1 (Table 1).

Component	Dimension (cm)
Main hull diameter	20
Hull length	60
AUV full length	105
AUV full width	35
AUV full height	45

Table 1. Vehicle dimensional data.

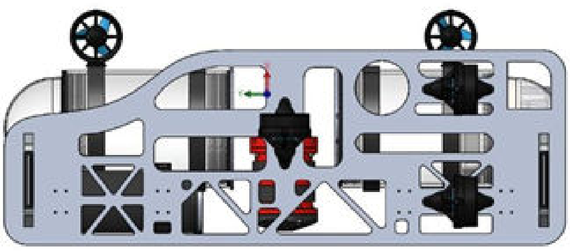

Figure 1. Side view of the vehicle.

Various Mechanical Components

Hull

Kraken 4 contains two hulls. It is pressurized and built to contain camera, processor in front hull and motherboard in rear hull. This is the major part of the AUV where all the processing and controlling of the AUV is done. Here we are using an acrylic pipe of thickness 6.35mm such that we could get enough strength to withstand the hydraulic pressure at around 25m depth inside water. FEM analysis of pressure hull was carried out to ensure its capability (Table 2). The transparent acrylic pipe also helps us to see the LED's attached to the electronic circuits, by which we can identify whether the circuits are properly working or not. The length of both pipes is 43 cm and inner diameter 20.32 cm so that we can get enough space to accommodate the various electronic equipment's inside [2].

Component	Number	Weight (kg)
On-Board Processor	1	2
Depth Sensor	1	0.1
IMU	2	0.3

Table 2. Various main components inside the hull.

Frame

To assemble all parts main hull, thrusters we are going to make aluminium 6061-T6 alloy frame. This material is primarily chosen for its high yield strength and easy availability. The frame also helps in symmetrical placement of the thrusters for better control. It also provides flexibility in the placements of thrusters and other components. Moreover, it provides more options to attach various mechanisms required to be attached in the competition. The vehicle is easy to transport since each component can be detached from frame and separately carried [3].

Camera mounts

Two cameras are required for bottom and front view. But they are placed inside the main hull unlike Kraken 3 (two external pods). Two circular frames are created to hold them properly inside the cylindrical main hull. This relieves us from maintaining insulated external hulls which were tough in Kraken 3. Since the cameras are present in the main hull no external wires are required. Hence reduces the probability of failure and increases success rate (Figure 2).

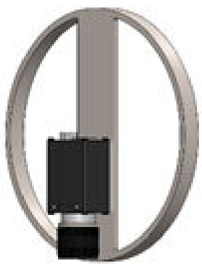

Figure 2. Camera mount.

Electronic stack

To accommodate all the electronic components inside the hull, a stack has been made from acrylic sheet. Various optimization techniques have been applied in the component placement so that the vehicle's CG is not affected (apart from vertical sink) by the placement of electronic components. Circular electrical boards have been set up to make connection management easier. This change in the setup of main hull (horizontal vertical boards in Kraken 3) resulted in a simple organized wiring. Four rods that runs along the main cylinder provides a path for wiring and also greatly help in stress management.

Sealing

We have used face O-ring for the purpose of sealing at every interface from where water can enter. Although we had used male type O-ring before but as it makes the manufacturing difficult in comparison to face type, we have changed it. On the either sides we have made caps to access the components inside main hull. The cap is made up of aluminium which also acts as heat sink, transferring the heat generated by laptop and batteries to the surrounding water. The cap consists of two parts. Both parts are connected with the help of flange. Between the touching surfaces of these parts we have employed face type O-rings for hydraulic sealing (Figure 3).

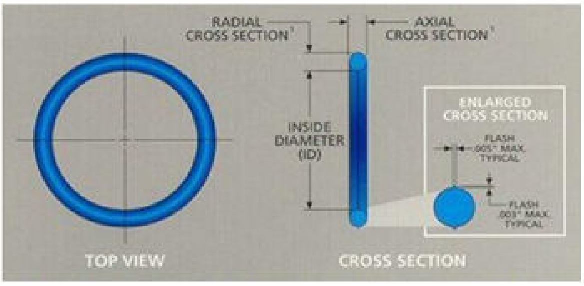

Figure 3. Detailed view of an O-ring.

For O-ring we have made glands on the end cap. This end cap can be opened to access the batteries and electronic circuits. For the glands dimensions, we mainly referred to parker's handbook for O-ring sealing. The O-ring is used at metal-metal interface namely at end caps of hulls. Medium size O-rings are used for sealing at connector-end cap interface of thrusters as well as camera pods. Smaller Size O-rings are used at joint where internal circuit wires are connected with thrusters [4]. The gland on the faces can be manufactured by CNC machine. The gland details and O-ring specifications which we used are as follows (Table 3).

Specifications	O-ring at hull faces (mm)
Internal diameter of O-ring	190
Cross-section	5
Gland depth	4
Gland width	7
Radius	0.1

Table 3. Gland details and O-ring specifications.

Actuators

In the NIOT SAVe competition our AUV have to complete various task like dropping a marker in the bin, firing torpedo through the heart cut out etc. We have different mechanisms for performing these tasks.

Dropper mechanism: In this task our AUV has to drop a marker in the bin. For this we have used a very simple and effective mechanism. We allow our marker to fall under gravity. So we put the marker in a cylindrical pipe which rests on an angular plate and is connected to a servo motor to rotate through accurate angle. The plate is such that we have to rotate very less to drop a marker. Servo motor is kept in cylindrical box which is sealed properly to prevent water from entering. The plate and the pipes are connected to a rectangular metal strip through C-clips. Hence when we have to drop the marker we will allow the plate to rotate and the marker will come out when the plate goes away from the base of the cylindrical pipe. By controlling the rotation of servo motor we can drop the markers at different bins.

Torpedo mechanism: In this we have to shoot a torpedo through an opening. Motor actuated and spring loaded torpedo has been design with keeping in mind the simplicity of design. In this mechanism we have two cylindrical pipes which contain compressed spring attached to a piston through S shaped gate and contain torpedo. The S- shaped gate is directly attached to the servo motor shaft and the motor is kept in a water sealed cylindrical box. As the motor rotates the spring gets relaxed and shoots the torpedo at the desired location. We can control the rotation of motor to shoot two torpedoes at different times.

Gripper: Gripper utilizes screw actuation mechanism to control the opening and closing of the three jaws. The reach of the gripper is controlled using a scissor mechanism which is actuated using a linear actuator. Screw actuator is controlled using a motor. The mounting and links are made from 6061-T6 and the gripper is 3D printed with ABS plastic [5].

Centre of gravity analysis

The centre of gravity is an important parameter where the kinetics of the AUV is concerned. The location of the CG determines the efficiency of the AUV in terms of energy consumed. The eight thrusters are the sites where most of the energy is consumed. So we put a lot of emphasis on the placement of the thrusters on the AUV. Through rigorous analysis we designed our AUV such that the thrusters are located on the plane of CG, while conserving the symmetry. The advantage is that if the thrusters are positioned on the plane of the centre of gravity, then we require very small torque to maintain the balance of the AUV underwater. Thus, less energy is needed. The following images show the location of the CG on our AUV.

Centre of buoyancy

Like the centre of gravity, the location of the centre of buoyancy is also a key parameter which controls the stability of the AUV underwater. The centre of buoyancy is the point where the buoyant force acts on the AUV. It is critical therefore, that the CB and the CG lie on the same vertical line. If this criterion is not met, the AUV is susceptible to toppling, and rolling underwater, leading to consumption of more energy to maintain the stability.

Electrical Components

Sensors

For navigation purpose: An IMU with 9 output data (3 axis Gyroscopic value +3 Axis Accelerometer +3 Axis magnetometer data) will be used to get feedback in the form of Heading, Acceleration and Euler angles. There are 2 such modules to allow a sensor fusion and reduce the magnetic error due to various currents flowing inside the hull. Component Model No: Spartan AHRS-8 (RS232 output) and TRAX AHRS.

Doppler velocity log: Our AUV will be using Link Quest 's MapQuest 600 Micro DVL (RS 232 output). DVL uses four Sonar s to measure the velocity of AUV in water. By integrating the velocity information, DVL will also give the XYZ co-ordinate information with respect to its initial Point.

Depth sensor: The pressure data is directly related with the underwater depth. Thus this sensor helps in depth monitoring. The pressure sensor that we use gives analogy data as output. The data is read by a microcontroller using ADC and then this data is relied to main processing board.

Leak sensor: High pressure inside water and inadequate sealing may lead to leakage of water inside the hull which may damage the electrical system. A leak sensor detects water inside the hull and immediately signal the kill switch to stop the vehicle.

Battery: AUV is equipped with two Lithium ion batteries with 6 cells in each with the rating of 11000mah each.

Microcontrollers: STM and Arduino are used for the sensor data acquisition.

On-board processor: Our AUV has a central On-Board Intel Core i5 8th gen processor. The whole software architecture is implemented on this processor.

Power Management System Board: This ensures that the power is supplied to each and every component through a controlled channel with an electrical kill switch mounted on it. As one battery discharges and difference between the two voltages of battery becomes a certain value the battery is switched to other. It receives signal from the on-board processor to cut the power in any fault. A mechanical switch is added to have the access to the power path manually so in case of need we can shut the power.

Battery management board: This ensures the efficient and balanced discharging and charging of cells of battery. The voltage difference in cells is balanced by charging and discharging of cells.

Fault detection and isolation system: This uses current and voltage sensors at different nodes of thrusters, other sensors and if any major change in the values of voltage and current would shut the power down and a microcontroller would store the data of the last stage.

Acoustic localization: This system is developed to locate the source by phase difference of signals received at different hydrophones. Two types of hydrophones are used, 3 one directional and 1 omnidirectional. And after the signal is processed in the IC to get the phase difference of the signals.

Controls System

Localization

Knowing the position of the bot with respect to its environment plays a vital role in the navigation process. To achieve this, AUV requires a more accurate navigation system, along with velocity, depth, altitude, and track-line control. Hence, State Estimation technique is used such that the resulting information is more reliable than what we get when these sources are used individually. In our AUV, Magnetometer, depth sensor, IMU and DVL data is fused using sensor fusion algorithms such as Extended Kalman Filter and Unscented Kalman Filter to get actual vehicle state. We have implemented robot localization which is a ROS package and implements a nonlinear state estimator in 3D space and estimates 15-dimensional sate of the vehicle. In marine vehicles, establishing an identified dynamics model of a vehicle is very important, since model can be applied in a variety of applications such as controls, navigation system and optimal design of a vehicle.

PID control

A PID control is implemented whose parameters are determined as mentioned above. The feedback for error calculation comes from data provided by state estimation which uses the sensor data, namely DVL, IMU, Pressure Sensor and Camera. Whenever the controller receives a goal which is either given by computer vision or mission planner, the state of the vehicle is continuously compared with the goal vector to find the error. This error is then used to find the actuation signal. The control system is capable of precise point-to-point movement and can switch between Position control and Velocity control. Set point is our goal vector and input is the current state of the vehicle. Output is the velocity (rpm) data provided to a thruster. For each thruster value of gain parameter values can be different based on its velocity *vs* Thrust characteristics. The PID controller is first tuned on simulator and then it is fine-tuned on the AUV.

Conclusion

Dynamic methods used to develop mathematical model for hydrodynamic coefficient estimation and system identification in AUV. The right hand side equations are external torques and forces. These forces and torques include hydrostatic force (buoyancy and weight), hydrodynamic force (drag and lift), added mass, control force (fin surface) and propeller thrust force. External forces should be taken into account to complete the right side. Outputs from all these trackers along with their confidence values are fused together using a Kalman Filter algorithm to generate high accuracy useful data.

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