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Development of Autonomous Underwater Vehicle (AUV) for Crack Detection in Canals

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***Abstract*—The cracks in the canals or dams caused by waterborne particles or some external disturbances lead to canal deterioration and water wastage. For determining the repair of such cracks, periodic inspections of canals are required. For detection of these cracks imaging techniques are popularly used. In this technique there is a need for an Autonomous Underwater Vehicle (AUV). The AUV carries a camera for image capturing. This paper aims at developing a PVC material fabricated cost-effective underwater vehicle for reliable crack detection. The system would detect the cracks in the canal up to a depth of 3-5 meters. The integrated system will obtain the image of the concrete surface of canals in the desired position from the camera mounted on the vehicle. The proposed AUV is equipped with 2 thrusters in order to achieve easy maneuverability along with the modular electronics consisting of the controller and the battery module. AUV control is achieved through Radio control where throttle input is given to the receiver from the 6-channel radio transmitter. Neutral stability is achieved with the partial submerged AUV model. In a nutshell, the developed AUV is low weight and economical due to the materials used and radio control makes the model user friendly.**

***Index Terms*— Dams, Cracks, Seepage, Inspection, AUV, Image capturing.**

I. Introduction

Civil infrastructure systems represent a significant fraction of global assets, and due to many factors, cracks will appear on the surface of these structures. These cracks not only affect the visual appearance of the structures but also lead to steel corrosion, which accelerates concrete aging affecting the normal use of these structures and leading to underuse of the infrastructure and a shorter life span.

Canals are an integral part of the dam water distribution system. Canals are built for a variety of uses including irrigation, urban water supply, hydroelectric power generation etc. Waterproof linings keep a canal's water from seeping into the ground. The Canals are built using a mixture of sand, clay, and water that dried to a waterproof state and Modern materials and additives that are more durable include concrete, fly ash. Since the flow of water through this open channel is huge, the pressure of water on the walls is high. Also, the canal walls are subjected to erosion.

Due to these cracks are developed in canal walls. Due to these cracks, there is a water seepage, and thus the canal walls get deteriorated. Underwater environments are complex, cracks are quite random and diverse in nature. Marine life in the water bodies, atmospheric temperature, heavy rainfall, and local bodies can contribute

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to the canal strength deterioration. Over the period the developed cracks widened. Cracks are always used to indicate the degree of risk in the field of canal damage. These cracks if not monitored regularly can cause accidents. In the year 2018, Pune witnessed unexpected flooding when a wall of the Mula-Mutha canal saw a breach. Several vehicles were damaged in the sudden floods, causing panic in several areas.

An autonomous underwater vehicle (AUV) is a robot that travels underwater without requiring input from an operator. They are considered autonomous because they have no physical connection to their operator, who may be onshore or aboard a ship. They are self-guiding and self-powered vehicles. The oil and gas industry uses AUVs to make detailed maps of the seafloor before they start building subsea infrastructure; pipelines and subsea completions can be installed in the most cost-effective manner with minimum disruption to the environment. The AUV allows survey companies to conduct precise surveys of areas where traditional bathymetric surveys would be less effective or too costly. Also, post-lay pipe surveys are now possible, which include pipeline inspection. The use of AUVs for pipeline inspection and inspection of underwater man-made structures is becoming more common. The proposed system aims at early detection of such cracks in the canal walls to avoid such instances in future. The system aims at developing a crack detection system which is cost effective using the latest technology for reliable crack detection.

II. Literature Review

This paper [1] discusses the operating scope for the Autonomous Vehicle Research Platform (AVRP). It mainly focuses on types of sensors for understanding the surrounding environment, and their optimal mounting locations, and hardware for positioning and navigating within that environment. It also covers the power estimation for the hardware and systems, computing benchmarks from other autonomous research platforms, and a communication structure for the AVRP. The author of the [2] has employed a prototype of the Autonomous vehicle system (car) using the Internet of Things. They have used a Raspberry Pi, a Picamera, a Web interface and Internet modem. It is based on Computer vision algorithm. Using this module we can transfer the digital parameters to cloud storage through the internet. The saved data so obtain find a use for monitoring purpose and analysing the information. This paper [3] aims to design and develop an AUV as a test bed platform for a variety of research in underwater technologies especially involving small-scale and low-cost underwater robots. It also can be used for testing and learning conventional and advanced control algorithms and techniques to other underwater systems. With a limited budget a small autonomous underwater vehicle has been developed.

The stated paper [4] introduces Maribot LoLo and presents the underlying design philosophy which focuses on versatility and endurance. The vehicle is designed to be operated at moderate water depths and on long-range missions. This leads to challenges in the design of the variable buoyancy system (VBS) which also is presented. The achievable range of the AUV is evaluated with a simple hydrodynamics model based on frictional drag. The concerned research [5] describes the electromechanical design of a compact, light-weight Autonomous Underwater Vehicle (AUV) for archaeological applications; the vehicle is named Zeno (Zeno Environment Nautical Operator), protector of freshwater and flood victims, and was developed in the framework of the European project ARCHEOSUb; the AUV specifications, its navigation devices and payload are given. The main characteristics of the vehicle are described with particular attention to its system architecture, propulsion system and structural design.

Author of [6] had introduced a model-driven control realization, which was based on the systems engineering concepts of the model-driven architecture (MDA) or model-based systems engineering (MBSE) approach combined with the real-time UML or SysML, extended/ unscented Kalman filter algorithms, and hybrid automata, in order to conveniently deploy controllers of autonomous underwater vehicles. The model also created a real-time communication pattern, which could permit the designed components to be customizable and reusable in new application developments of different AUV types. It had stepwise adapted the AUV dynamics for the control that are then combined with the specialization of MDA or MBSE features. Mentioned research in [7] had a new, low cost and modular AUV design and was built to replace Odyssey IV, the primary research vehicle. The new AUV was a shallow cruising vehicle with a depth rating of 100 meters. With a weight of less than 50 kg, the AUV could easily be launched and recovered by hand from Sea Grant's 25 ft vessel. Although specifically designed to support Didemnum research, the AUV incorporated a flexible and modular design that allowed the vehicle to be reconfigured for existing Didemnum missions or upgraded with additional sensors and payload. Incorporating a separate, interchangeable Li-Polymer Battery pack allowed the vehicle to achieve both a high mission duty cycle and extended bottom time.

III. System Overview

Our AUV system is combination of the Electronics and the Mechanical assembly and it is discussed below.

A. Electronics System

For powering up the AUV, we had designed the electronics module which consists of BLDC Motors, propellers, ESC, ESC Calibration throttle hub, radio transmitter, receiver, battery, power distribution module as shown in the Figure 1. Further, image processing will be done by either a transmitter and receiver pair as shown in the Figure 1 or it will be carried out via WiFi

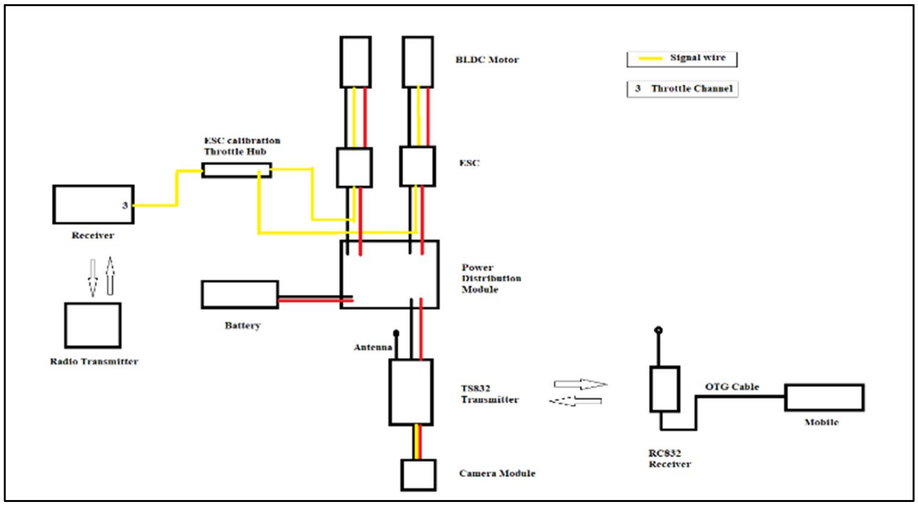

Figure 1. Block diagram of AUV

The complete electronics architecture overview has described below:

<u>BLDC Motor</u>:

As the BLDC motor has high power density, high efficiency, and lower rotor inertia, it could give better torque characteristics than other motor types. We compared BLDC motors of different makes. Considering our thrust requirements, we decided to go with the BLDC motor of 935 kV which provides us with the required thrust and weight constraints. In our AUV design, we have used 2 BLDC motors for the forward and backward motion.

<u>ESC</u>:

Ampere rating of ESC should be 20-30 % more than the maximum current requirement of the motor. This will allow the motor to work at a lower temperature. The 935kV BLDC motor draws a current of 18 Amp. So, for safety purposes, we are using ESC of 40 Amp, which is also recommended by the manufacturer.

<u>Propeller</u>:

We had selected three bladed propellers of 6x4.2, where 6 signifies six inches of diameter and 4.2 signifies 4.2 inches. of propeller pitch. Both the propellers are of clockwise rotation.

<u>Battery:</u>

LiPo battery was chosen because of its convenience, reliability, affordability, and its renewability. The maximum draw from the 935kV BLDC motor is 18A. The battery should be able to deliver more current than this. We had chosen a 2200 mAh 30 C 3S LiPo battery for our mission.

The effective battery capacity = Battery Capacity x Battery Efficiency = 2.2Ah x 80% = 1.76Ah

Maximum Current delivered by battery = Effective Battery Capacity x C Rating = 1.76Ah x 30C = 52.8A

<u>Radio:</u>

The AUV control was done by a transmitter and receiver pair with 2.4GHz of range.

<u>Underwater Camera</u>:

We are using a waterproof action camera with 4k resolution for best capture of the underwater environment. It comes with Wi-Fi connectivity which is capable up to 50-60 meters range. This camera is perfect for our application.

<u>Underwater Flashlight:</u>

To explore the underwater scenario in the dark, underwater flashlight was chosen with the specification of 12V and 12 W power.

Power Distribution Board:

As we were using two BLDC motors with two ESCs, there was a requirement of handling two motors with the single throttle of the radio transmitter. Power distribution board of 6 ESC tabs was selected for this purpose with regulated 5V and 12V outputs.

ESC Calibration Throttle Hub:

8 in 1 throttle calibration hub distributes throttle signal up to 8 ESCs where we used only 2 hubs out of 8.

B. MECHANICAL SYSTEM:

The primary goal of ours was to design our AUV in 2D model before directly hopping onto the manufacturing. We modelled it in *AutoCAD* as shown in the Figure 2.

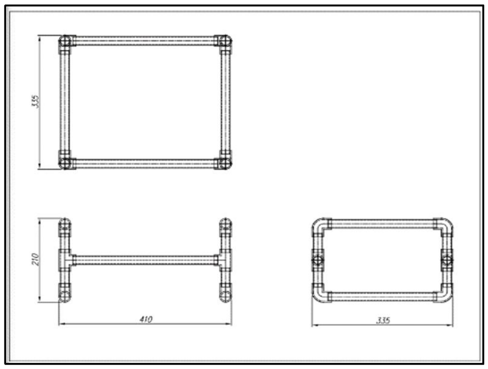

Figure 2. 2D CAD design

Later, we proceeded with the 3D model of the vehicle according to our specifications in the *TinkerCAD* as shown in the Figure 3 and 4. 3D modelling made us go with further fabrication of the vehicle.

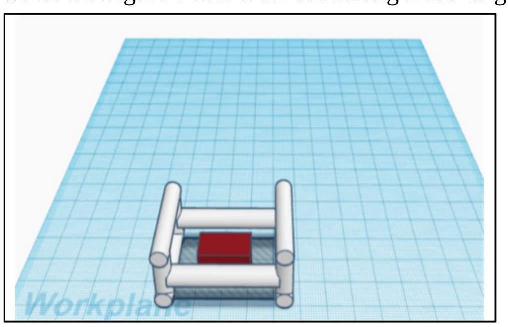

Figure 4. Side view of 3D CAD model

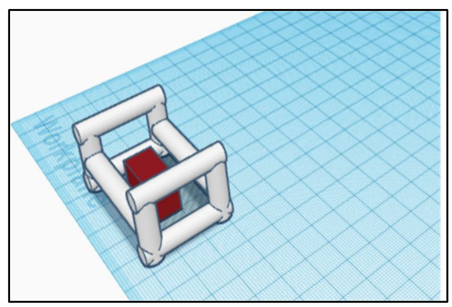

Figure 3. Front view of 3D CAD model

AUV was manufactured with the PVC pipes for cost effective solution and weight reduction. The detailed specifications are listed below:

Materials Required:

- PVC pipe
- 2 Pool Noodles
- Tie Wraps - Motor Mount
- 2 Film Canister
- 2 Propellers
- Electronics (refer to section III.A.)
- Underwater Camera
- Underwater Flashlight

PVC Pipes:

- Two Pipes - 16.5” long
- Four Pipes - 13.5” long
- Four T Connectors
- Eight Round Connectors

Figure 5. Vehicle Architecture

Before locking this configuration of vehicle structure, we had tested various PVC frames but the CG was not balancing and we were not getting desired results so we decided to go for a symmetrical structure. The results were desirable for the above vehicle frame. This Vehicle consists of PVC structure as shown in the Figure 5. We are using pool noodles for the ease of floating. This vehicle assembly has been tested and found stable in the water. Its CG is balanced along with the BLDC motors, propellers, underwater camera, and underwater flashlights onboard.

IV. EXPERIMENTS

In this section, discussion is done on the various tests performed for the evaluation to meet the desired outcomes. Following tests were conducted-

A. Stability Test
B. Electronics Test
C. Vehicle Test

A. Stability Test

In this test, we checked the stability of our vehicle. At first it seemed that the PVC structure was tilting a little on one side. To see what was going wrong, we removed the 16.5” PVC pipe from the structure and it was still tilting on the same side. We figured out that it was because of the uncentered heave control motor mount PVC pipe. To make the structure more stable underwater, we decided to mount more structure on the opposite side edge of the 16.5” PVC pipe. Refer to Figure 6.

Figure 6. First Iteration

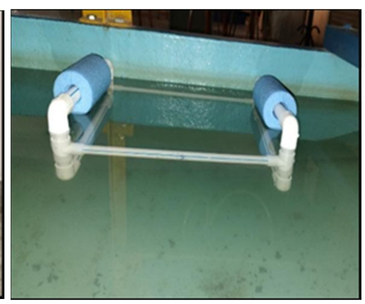

Figure 7. Second Iteration

After our third iteration we decided to go for a symmetric PVC structure for achieving the best stability. It was observed that the vehicle frame was stable. Refer to Figure 7.

B. Electronics Test

We tested our sealed electronics in a bucket full of water. In this test we sealed one BLDC motor with the silicon sealant and tested it in a bucket full of water to check whether the sealing was properly made or notc

C. Vehicle Test

After the conclusion of the above tests, we assembled the vehicle frame with the electronics shown in Figure 9. Then this assembled vehicle was tested in the tank with a depth of 5-6 feet.

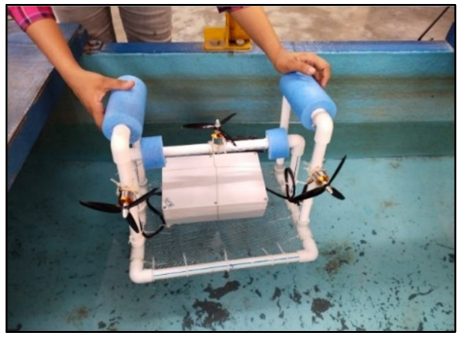

Figure 9. Vehicle Testing

V. RESULTS

Based on various experiments done, we have summed up the results as shown in the Table I and enhancement was carried out later.

After the proposed enhancement, amperage of ESC was increased to 40A, power distribution module was included and vehicle was furthe made stable.

VI. CONCLUSIONS

The AUV has an easy construction. The model constructed uses a transmitter - receiver pair which has reduced complexity caused due to the use of cables. It has wireless communication. In addition, it does not require a bulky and complex component for support. Using AUV to conduct Underwater Canal Inspection is far safer than using a human diver. Thus, the proposed system design will significantly contribute to efficient canal inspection and reduction in the water seepage through the cracks. This design is advantageous for cost effective solution and weight reduction of the vehicle. In addition to this, for future scope, we are aiming for image processing which will consists of a camera, a flashlight, WiFi Communication and image processing platform (MATLAB). This will enhance the crack detection system.

TABLE I. RESULTS OF VARIOUS TESTS CONDUCTED

	Execution	Results	Enhancement
Test 1. Stability Test	Vehicle Stability Check: First iteration included the unstable AUV structure Second iteration was concluded with the stable structure	Vehicle was unstable Structure was tilting at one side due to assymetry	Make the vehicle architecture more like a symmetrical to get the stable model
Test 2. Electronics Test	Electronics check : All the electronics were sealed inside the ABS container BLDC motors were sealed with the silicon Sealant	ESC had lesser amperage BLDC motors stopped working after a while due to sealant blocking	Increase the ESC amperage Remove the sealant in the BLDC motors and instead keep them inside the canister
Test 3. Vehicle Test	AUV maneuvering and communication check: AUV structure was asembled with the electronics It was then controlled by setting the communication by radio	Vehicle structure was floating on its own In the first iteration, due to absence of power distribution board and ESC calibration hub, only single thruster could run	Remove the pool noodle as we want our vehicle to partially submerge Connect 2 BLDC motors with ESCs and then futher with the power distribution board to which battery will be connected

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