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# Design of Low-Cost Underwater Robotic Hull for Non-Marine Applications

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**Abstract—***Underwater robotics is being neglected by hobbyist and technologists with non-marine application area due to the unavailability of low-cost waterproof hull. This paper describes the design and manufacturing process of a low-cost hull for underwater rover. The main challenge of this design is to use low-cost material and get a sustainable waterproof hull with openable lids and transparent window for camera mount. The designed hull is found waterproof and usable for the application. Different design and manufacturing techniques and cost-time analysis for the hull is shown in this paper.*

## 1. INTRODUCTION

Hull is one most important mechanical part for underwater robots. It is useful for protecting the electronics components from water, pressure, temperature difference and other unwanted shocks [1,2]. The harsh environment exerts a huge amount of pressure with an increase of 14.5 psi at every 10.06 meter depth [5]. The salinity and other chemical properties of water corrode the hull very fast [6]. Along with pressure, the external collision can damage, rupture or may create a leak in the hull [2,6]. Composite structures of metallic alloys and plastics are used [2,3,6] to avoid such problems. But this makes the robots expensive. For military and other heavy-duty applications, such costly robots can be affordable. But for simple applications like underwater photography, sensor network, ecological survey rovers etc. there is a need for low cost, easy to fabricate and customizable hull with better efficiency [1,4]. In this paper, we propose an approach for the design of a low cost underwater hull. The highlights of this method are, the materials used are easily available and simple fabricate technology. This design is found to be more suitable for small-scale underwater robot.

## 2. PROBLEM FORMULATION

The objective of this paper is to design and fabricate a low-cost underwater robot hull. It is also required that the lids of the hull must be transparent for the camera mount and easily openable for inserting and removing components. The main vessel must be waterproof and should sustain up to high pressure. [5]

## 3. DESIGN OF THE HULL

### 3.1 Description of Materials

Our survey for materials used in underwater robotics and water related works reviled that PVC (Polyvinyl chloride) pipes (4-inch diameter), used for sanitary applications is a good option for our cylindrical hull [1,2,3,5]. For underwater application PVC is appropriate as it does not corrode, its density is low (1.4 g/cc) and it has a moderate tensile strength. The used material is shown in Fig. 1.

**Fig. 1: PVC pipe**

For the window lid of the cylindrical rover, transparent plastic fiberglass has been chosen. The supporting structure of the lid PVC socket (4 to 6 inch diameter) is used. Rubber (from vehicle tire tubes) gaskets are used for preventing leak between the lid and the body.

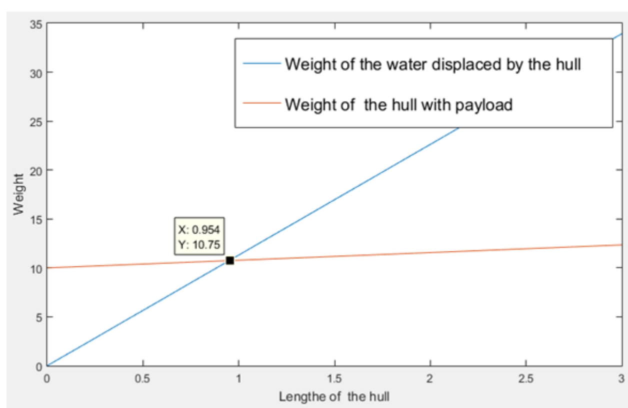

**Fig. 2: Simulation result**

**Fig. 2: Top view of modified Socket**

Hot plastic glue was used for sealing any unwanted holes and PVC adhesive solvent for joining the PVC parts.

Aluminum strips were used to design the propeller mount and extra mount for the robot. As aluminum is light in weight and does not corrode, it was a good option for our purpose.

Normal metallic nuts and bolts were used for attachment, which was painted with water resistant aluminum paint and supported with the rubber gasket.

Different physical property of the material is shown in Table 1.

### 3.2 Assumptions and Simulations

The hull design is targeted for the non-marine areas like rivers, lakes etc. so the pressure and the working depth is supposed to be less.

**Table 1: Physical properties of material used**

| Properties | PVC Pipe | Aluminum | Plastic Glass fiber |
|---|---|---|---|
| Tensile Strength | 541 MPa | 276 MPa | 76-160 MPa |
| Tensile Modulus of Elasticity | 2895.70 MPa | 68900 MPa | 5.6–12 MPa |
| Compression Strength | 66.19 MPa | 4000-12000 MPa | 120-180 MPa |
| Density | 1.4 g/cc | 2.70 g/cc | 2.076 g/cc |
| Melting Point | 320 F | 1079.6-1205 F | >320 F |

A MatLab simulation is programmed to get the minimum length of pipe required to make the hull neutrally buoyant with a payload of 10 kg. The simulation result is shown in Fig. 2.

The simulation shows 0.95-meter length is optimum for a payload of 10 kg with the inner volume of 0.0101 cubic meters.

**Fig. 4: Side view of modified Socket**

### 3.3 Design and Fabrication of Waterproof Openable Lids

For the lid, we have chosen gasket and nut bolt system which facilitates easy open and close operation without any twist. The 4-6-inch socket used for joining two pipes of different diameter (4 and 6 inches) is cut at the junction of 6 inch part to make the structure is shown in **Fig.** 3 and **Fig.** 4.

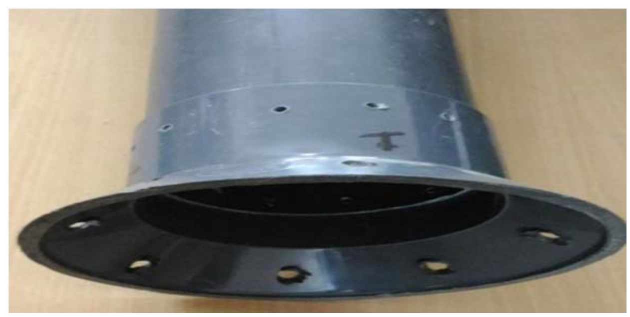

**Fig. 3: Joining of pipe and lid support**

This cap arrangement is done for providing mechanical support to bolts joining the transparent lid plate. The cap is then attached to the pipe leaving 1 cm (**Fig.** 5 and **Fig.** 6) to put pressure on the lid plate. The extra part of the pipe is ground and polished to get a smooth and even surface.

**Fig. 4: Extended part of the pipe**

A piece of tube is cut in a circular shape with diameter 10.5 cm, which is slightly larger than that of the pipe. A hole is made in the above circular shape with diameter of 9.5 cm. This gives a band of thickness of about 1 cm(shown in **Fig.** 7). The band is placed above the pipe and attached with waterproof glue as shown in **Fig.** 8.

**Fig. 5: Rubber gasket**

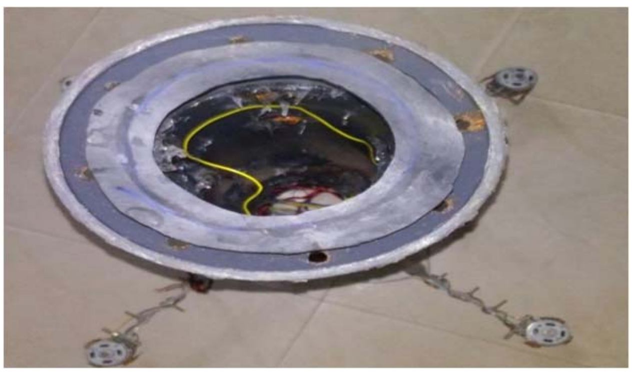

**Fig. 6: Lid in open condition**

The cap is drilled in 4 equal distant positions for the bolt. Similar drills are also made on the plastic fiberglass sheet. The lid plate is attached and bolted using metallic washers. A small ring of PVC pipe is used as pressure ring to exert equal pressure on the lid plate.

The Same process is repeated for both sides. The lid is now waterproof and easily openable by just opening four bolts.

### 3.4 Design of Propeller Mount

Propeller mount is designed using the aluminum strips. The pieces of aluminum are shown in Fig. 9. 16 pieces of aluminum is cut in 3 desired shape and structure and drilled for bolt holes. 8 strips connected circularly at the neck of the cylinder, where every 2 strips are joined together for one mount. Four diagonal linkages and four interconnected linkages are used for mechanical strength and stabilization. The aluminum pieces were attached with nut-bolts and extra rubber washer. Any extra leakage in the main pipe is sealed by applying the hot glue.

Propellers were prepared with high torque 12v DC motor and plastic blades (Fig. 10), mounted on the 4 propeller mounts. The Motors are made waterproof by applying machine grease on it and sealing the holes with silicon glue.

**Fig. 9: Different aluminum parts**

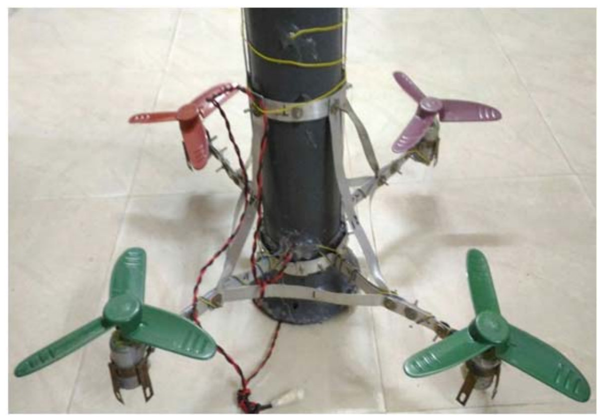

**Fig. 10: Complete motor mount.**

**Fig. 11: Complete Hull.**

### 3.5 Assembling the Hull

The length of the cylindrical hull is chosen 75 cm as the simulation shows 90 cm is sufficient for 10 kg payload. The lids were attached at the two end along with the motor mounts. Two 60 cm long aluminum strips were attached to two opposite sides of the pipe along with two aluminum ring for providing mechanical strength to lids and to provide mounting space for extra mounts for sensors, actuators, and extra buoyant. Any kind of leakage is avoided by sealing all the drill holes with hot glue.

## 4. TIME AND COST ANALYSIS

Table 2 shows the time and average cost required for the manufacturing of different parts of the robot with manual workshop tools.

**Table 2: Time and cost analysis**

| **Parts** | **Time (in hour)** | **Average cost (in INR)** |
|---|---|---|
| Cylindrical pipe | 1 | 150 |
| PVC Gasket preparation | 2 | 500 |
| Cutting and drilling of aluminum strips | 4 | 400 |
| Preparation of lid | 6 | 150 |
| Final assembly and testing | 5 | -- |
| Motor mounts and propellers | 2 | 1500 |
| Total | 20 | 2700 |

## 5. RESULTS AND ANALYSIS

Manufactured Hull (as in Fig. 11) was tested up to 2-meter depth. No leakage of water was found in the hull. Time required for the manufacturing of this structure was around 20 hours within a nominal cost 2700INR.

## 6. CONCLUSION AND FUTURE WORK

The key feature of this design is the use of easily available material and simple manufacturing process. Being a sustainable and economic hull, this design may be applicable for a wide range of low cost underwater robotic experiments.

## 7. ACKNOWLEDGEMENTS

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