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Design of AI based Robotic Life Safety System

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ABSTRACT: The offshore industry poses significant challenges to human safety due to harsh environments, remote locations, and complex operations. This project presents the design of an AI-based, IoT-enabled robotic rescue boat system to enhance emergency response and life-saving efforts in offshore settings. The system utilizes components such as Arduino, ESP32, speed controllers, ultrasonic sensors, and Wi-Fi modules to autonomously navigate, detect, and retrieve individuals in distress. Leveraging sensor fusion and autonomous control, the boat locates a person, secures them, and returns to shore. Simulation and prototype testing show the system's potential to improve rescue efficiency and safety in offshore environments.

KEYWORDS: Rescue Boat, IOT based rescue system, sensor Fusion, Arduino, Emergency response Automation.

I. INTRODUCTION

Where search and rescue robots have produced a clear advantage in the air and water environments where humans aren't naturally designed to go. Robots don't need to breathe underwater, they don't need food (or restrooms) at sea, and they aren't bothered by motion sickness [1, 2]. On the rescue side, the RESCUE BOAT is being used to save people who are drowning or stuck in rough waves.[2] The highly durable, remote controlled vehicle can easily propel and be easily deployed in places that might be too dangerous for a human lifeguard. Individuals in the water can grab onto the vehicle to use a flotation device[2]. The rescue boat can tow people back to shore or to a nearby boat. It is also capable of bringing rescue ropes into the surf so that once an individual has grabbed by the robotic boat they can be pulled back in more easily[2]. The RESCUE BOAT was meant to work very close to shore under human control, but the boat since added AI & IOT capacity to other versions of their robots meant to travel farther out. RESCUE BOAT is capable of traveling via autonomous autopilot control and can travel to scanning an area via radar, sonar, wifi module, speed controller and also with remote control[3].

The scope of AI-based rescue boats in offshore applications is significant and growing rapidly due to advances in artificial intelligence, robotics, and marine technology[3]. These vessels are designed to operate autonomously or semi-autonomously in challenging marine environments, enhancing the safety and efficiency of rescue operations. The applications of the proposed model are

Search and Rescue (SAR):[3]

- Locating and assisting people overboard, stranded vessels, or oil rig workers.
- AI systems use thermal imaging, radar, sonar, and computer vision to detect humans and debris.

Emergency Evacuation Support:

- Autonomous boats can transport injured or stranded personnel to safety when helicopters or manned boats are unavailable or unsafe[4,5]

Monitoring and Patrolling:[5]

- Regular patrolling around offshore installations (oil rigs, wind farms, etc.) to detect threats or unusual activity.

Disaster Response:[5]

- In case of offshore explosions, oil spills, or natural disasters, AI boats can quickly respond without risking human rescuers.

II. DESIGN CALCULATIONS OF RESCUE BOAT

2.1 BUOYANCY FORCE CALCULATIONS:[5]

The **buoyant force (F_b)** acting on the rescue boat determine whether it will float or otherwise. Buoyancy is governed by **Archimedes' Principle**,

Weight of the Rescue boat = 7.51kg

Volume of the Boat = 0.01m³

Where F_m represents Force due to mass (M)

$$F_m = m * g$$

$$F_m = 7.51 * 9.81$$

$$F_m = 73.67 \text{ N}$$

Where F_b represents buoyancy force (B)

$$F_b = \delta_g * g * v$$

$$F_b = 1000 * 9.81 * 0.01$$

$$F_b = 90.1 \text{ N}$$

Data:

Center of mass: (mm)

$$X = 40.61$$

$$Y = 212.51$$

$$Z = 140.93$$

Therefore

$$F_b > F_m$$

2.2 METACENTRIC HEIGHT CALCULATIONS:[5,6]

The **Metacentric Height (GM)** is a measure of a floating body's **initial static stability**—its ability to return to an upright position after being tilted.

$$GM = KB + BM - KG$$

Where,

GM =Metacentric Height

KB =Distance from the keel [Bottom of the floating surface]

BM =Metacentric Radius

$$BM = I / V$$

Where,

I = Second moment of Area [Approx as 1/12 B³ for a rectangular surface]

V =Volume of Displacement [same as volume].

KG = Distance from kell to center of gravity.

Density of water (δ) = 1000 kg/m³.

Mass (**m**) = 2.8409 kg.

Volume (**V**) = 0.002202 m³.

Surface Area (**A**) = 115778.651 mm².

Center of mass (**CG**)

$$X_G = -0.00039968 \text{ m}$$

$$Y_G = -0.004955684 \text{ m}$$

$$Z_G = -0.064089224 \text{ m}$$

$$KG = Z_G = 0.064089224 \text{ m (From Analysis).}$$

2.3 METACENTRIC RADIUS CALCULATIONS [BM][5]

$$BM = I / V$$

$$I = 1/12 [B^3 * L]$$

Overall,

Length = 200mm,

Width = 100mm,

Height = 190 mm.

$$I = (0.100^3 * 0.200) / 12$$

$$I = 0.00000001667 \text{ m}^4.$$

$$BM = 0.000000016 / 0.002202$$

$$BM = 0.00757 \text{ m}$$

2.4 CENTER OF BUOYANCY CALCULATIONS:

$$KB = H/2 = 0.190 / 2 = 0.095 \text{ m}$$

2.5 METACENTRIC HEIGHT:[5]

$$GM = KB + BM - KG$$

$$GM = 0.095 + 0.00757 - 0.064089224$$

$$GM = 0.03848 \text{ m} = 38.48 \text{ mm.}$$

GM is Positive Therefore, The boat is **stable**.

2.6 RIGHTING MOMENT CALCULATIONS:[6]

Measures how effectively a boat resists capsizing when tilted by an external force [Waves, Wind, etc.,]

$$\begin{aligned} \text{RM} &= W * GZ \\ W &= 7.51 \text{ N} \end{aligned}$$

GZ = Righting Arm [Distance between center of gravity (g) & center of buoyancy (b) when tilted].

$$W = 7.51 * .81$$

$$W = 73.67 \text{ N.}$$

I. Determining Righting arm (GZ):

G_z Depends on the boat's tilt angle [θ]

$$G_z = GM * \sin \theta$$

Assume small hull angle (θ) = 10.

$$GZ = 0.03848 * \sin [10]$$

$$GZ = 0.006681 \text{ m}$$

Therefore, RM = 73.67 * 0.006681

$$\text{RM} = 0.492 \text{ Nm}$$

At 10 degree Tilt:

Safe RM range = **0.3 – 0.5 Nm** [for small boat].

RM stays above 0.3 Nm at different tilt angle [10, 20, 30], the boat is considered to be **stable**

When
θ = 10 degree RM = 0.4921 Nm.

θ = 20 degree RM = 0.9695 Nm.

θ = 30 degree RM = 1.4174 Nm.

2.7 ASSESSMENT: CAPSIZE RISK [6]

Provides an estimate of sailboat's stability & likelihood of capsizing in rough seas.

Capsize screening formula [CSF]:

$$\text{CSF} = \text{Beam [feet]} / [\text{Displacement (Pounds)} / 64.2]^{1/3}$$

$$\text{CSF} = 0.77601706 / [16.55672 / 64.2]^{1/3}$$

$$\text{CSF} = 1.2186$$

CSF for rescue boat range [Between 1 - 2]

- ✓ CSF is **1.2186** It falls well below 2 therefore, the boat is **stable & suitable for open water condition**.
- ✓ It is resistant to **capsizing in normal & moderate rough water**.
- ✓ Safer for rescue operation compared to boats with $CSF > 2$.

III. MASS PROPERTIES:[7]

The mass properties of the PLA material rescue board is shown in Fig.1

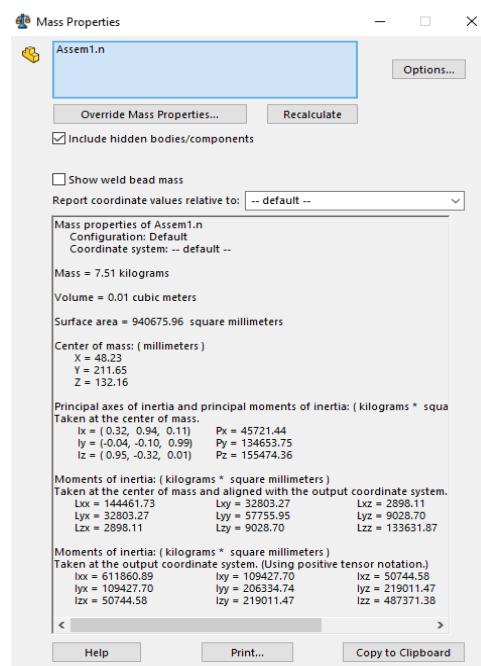


Fig 1Mass Properties

IV. MATERIALS AND ELECTRICAL COMPONENTS: [7]

4.1 GENERAL

The characteristics of the rescue boat (BODY AND HULL) is prepared by the 3D printing using the **PLA** (POLYLACTIC ACID OR POLYLACTIDE) filament material and further IOT components are also used to control and propel the rescue boat which are easy to function. Such IOT components are used in this work are Arduino UNO R3, Ultrasonic Sensor (water proof), Bi directional 30A 2-4S UBEC2A, Power distribution board (PDB-XT 60), ESP-32 wireless module were assembled and programmed in this project & experimental work and covered in this chapter.

4.2 PLA FILAMENT:

PLA Filament (Polylactic acid), also known as PLA, is a thermoplastic monomer derived from renewable, organic sources such as corn starch or sugarcane[7]. Using biomass resources makes PLA production different from most plastics, which are produced using fossil fuels through the distillation and polymerization of petroleum. Despite the raw material differences, PLA can be produced using the same equipment as petrochemical plastics, making PLA manufacturing processes relatively cost efficient[7]. PLA is the second most produced bioplastic (after thermoplastic starch) and has similar characteristics to polypropylene (PP), polyethylene (PE), or polystyrene (PS), as well as being biodegradable.

4.3 PROS AND CONS OF USING PLA FILAMENT:[8]

The major advantages and disadvantages of using PLA filament are presented in Table 1.

Table 1 Advantages and disadvantages

PROS	CONS
Economically friendly	Low heat resistance
Easy to print	Comparatively low strength
Safe for use in food containers&medical devices	Machine processing should be difficult

4.4 APPLICATIONS OF PLA

PLA Filament has a number of common uses, including for medical and food purposes. It is also widely used as a 3D printing feedstock for desktop fused filament fabrication 3D printers[8]. PLA Filament is popular for 3D printing as it can easily be sanded, painted or post processed. A user friendly material, this plastic works with low extrusion temperatures and there is no need for a heated bed, printer chamber or reinforced nozzle[8].

PLA Filament can degrade into lactic acid, it can be used for medical implants such as anchors, screws, plates, pins, rods or as a mesh. It breaks down in between 6 months and 2 years, depending on the exact type of material used. This means that these products can gradually transfer a load from a PLA support structure to the body as it heals.

4.5 UNDERWATER BLDC PROPELLER MOTOR [9]

The UJEAVETTE Boat Underwater Propeller Motor Engine Thruster Ship Boat Model Durable Set is a versatile and durable underwater thruster designed for various remote-controlled aquatic applications. It's suitable for refitting remote control ships, nest boats, net boats, remote control submarines, and micro underwater robots[9]. The motor used in the study is shown in Fig.2.



Fig 2 Underwater motor

4.6 KEY FEATURES OF UNDER WATER MOTOR:[9]

- **Resistance:** Built with materials that resist corrosion, ensuring longevity in various water conditions.
- **High Efficiency:** Designed for excellent performance with high thrust output and energy efficiency.
- **Corrosion Versatile Applications:** Suitable for refitting remote control ships, nest boats, net boats, remote control submarines, and micro underwater robots.
- **Durable Construction:** Made from aluminum alloy and other robust materials for enhanced durability.
- **Compact Design:** Its compact size allows for easy integration into various aquatic models.

- **Bi-Directional Rotation:** Available in both clockwise and counterclockwise versions for flexible configuration in dual-motor setups
- **Long Cable Length (~250mm):** Provides installation flexibility for connecting to ESCs and powersources[9].

4.7 PARAMETERS OF UNDERWATER MOTOR[9]:

Product Name: Brushless underwater propeller

Weight : 162g

Power : 30-200W

Voltage : 12-24V

Current : 13A

Motor (kV) : 480kV

Dimension : line length 250mm diameter 74mm total length 75mm propeller diameter 60mm

Material : Motor 304 stainless steel bearing + aluminum alloy steel PLA PC propeller

4.8 BATTERY (LITHIUM POLYMER 8000 mah) :[10,11]

Pro-Range batteries are known for performance, reliability and price. Pro-Range (LITHIUM POLYMER) batteries that deliver the full rated capacity[10,11]. Pro-Range batteries are equipped with heavy duty discharge leads to minimize resistance and sustain high current loads. Pro-Range batteries stand up to the punishing extremes of aerobatic flight and RC vehicles. Each pack is equipped with gold plated connectors and JST-XH style balance connectors. All Pro-Range Lithium Polymer batteries packs are assembled using IR matched cells.

4.9 LIPO BATTERY[11]

This battery is a rechargeable battery [11]. It is a lithium-ion technology using a polymer electrolyte instead of a liquid one. These batteries provide higher specific energy as compared to other lithium battery types. They are used in applications where weight is a critical feature, like mobile devices and radio-controlled drones and aircrafts.

4.10 CELL CONFIGURATION AND BATTERY VOLTAGE OF LIPOBATTERY

Lithium polymer battery (Fig.3) is constructed from the rectangular cells. We can increase the voltage of the battery using a series connection of the cells[11]. Also, by making the parallel connection of the cells, the battery current will be increased. The nominal voltage of a Lithium polymer cell is 3.7V. The three cell (3S) pack is 11.1 V, a four-cell (4S) pack is 14.8V. The safe operating voltage range of LIPO is, from 3V to 4.2V [11].



Fig 3 Battery

V. SIMULATIONS RESULTS: [12]

The stress strain, displacement and the solid work image are illustrated in Figs4-6

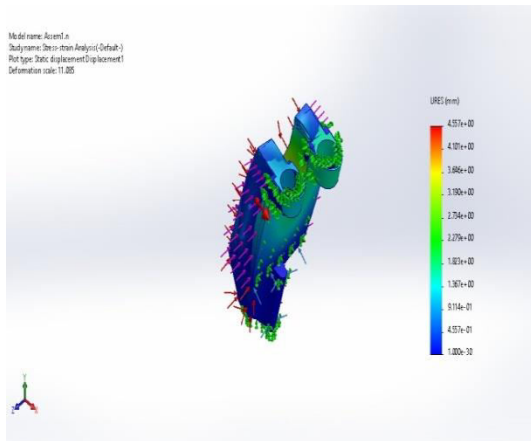


Fig 4 Stress-strain

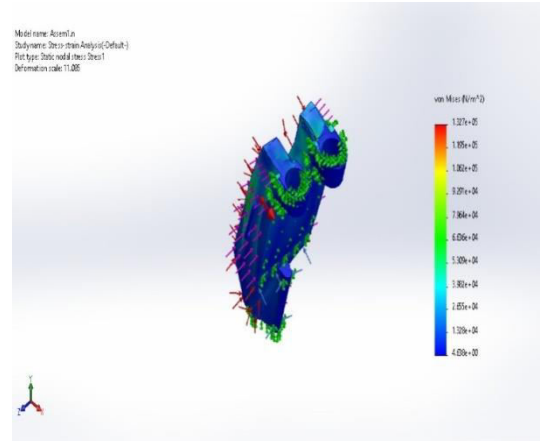


Fig 5 Displacement analysis

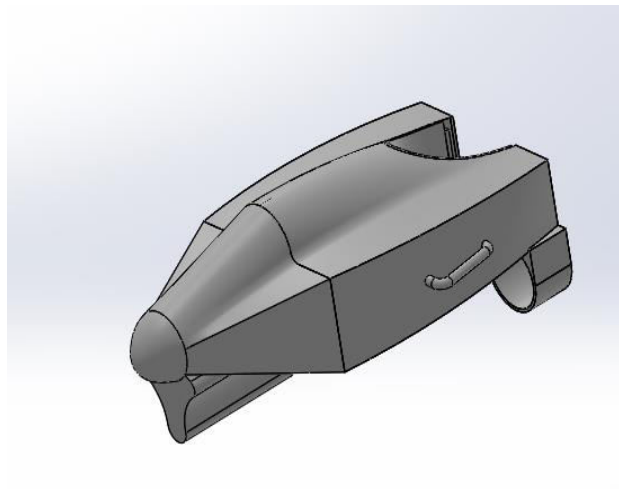


Fig 6 Solid work model

VI. RESULT AND CONCLUSIONS:

The Intelligent Emergency Remote Control Lifebuoy Water Rescue Robot project successfully achieved its objective of designing and developing a water-based robotic system capable of aiding in water rescue operations. The lifebuoy robot was engineered to be remotely operated, enabling rescuers to control its movement towards individuals in distress without entering dangerous waters themselves.

6.1 KEY RESULTS FROM THE DEVELOPMENT INCLUDE:

- Successful integration of wireless remote control for real-time maneuvering.
- Buoyant and waterproof construction suitable for aquatic environments.
- Effective propulsion and steering mechanisms tested in controlled environments.
- Enhanced safety and reduced response time in mock rescue scenarios.

In conclusion, the prototype demonstrated its potential to assist in water rescue missions by minimizing human risk and improving the efficiency of retrieval operations[12].

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