ROV For Submersible Rig Platform Inspection

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***Abstract*—This study presents the design of a cost-effective Remotely Operated Vehicle (ROV) for underwater rig inspection. The ROV ensures water resistance through advanced sealing mechanisms and features an optimized propulsion system for precise maneuverability. It is equipped with systems for real-time navigation, depth estimation, and environmental monitoring, enhancing inspection accuracy. The design prioritizes durability, efficiency, and ease of deployment, making it a practical solution for underwater infrastructure assessment.**

The offshore industry relies on submersible rigs for various operations, including exploration, maintenance, and resource extraction. However, inspecting these rigs poses significant challenges due to the extreme underwater conditions, such as high pressure, low visibility, and strong currents. Traditional inspection methods often require human divers, exposing them to hazardous environments and increasing operational risks. To mitigate these challenges, this research aims to develop a Remotely Operated Vehicle (ROV) capable of performing efficient and reliable inspections of submersible rigs.This research will focus on developing a robust and intuitive control interface, allowing users to operate the ROV with ease while maintaining precise maneuverability in underwater environments. The system will incorporate advanced imaging and sensor technologies to detect structural anomalies, corrosion, and other critical factors affecting submersible rigs. By integrating cutting-edge engineering principles, this project aims to provide a sustainable and effective solution for underwater inspections, reducing operational costs and improving safety standards in offshore industries.

I. DESIGN AND CONSTRUCTION

A. Environment

The operational environment for the Remotely Operated Vehicle (ROV) presents a variety of challenges that influence its design, functionality, and performance. The underwater conditions in which the ROV will be deployed range from shallow coastal waters to deep-sea environments, requiring specialized adaptations for efficient and reliable operation. The ROV must be capable of withstanding extreme hydrostatic pressure, especially in deep-sea applications where depths can reach several thousand meters. Structural integrity is essential to prevent water ingress and ensure the longevity of the vehicle. Additionally, the underwater environment often presents low visibility due to suspended sediments, biological activity, and variations in light penetration. To address this, the ROV will be equipped with high-resolution cameras, sonar systems, and advanced imaging technologies such as LiDAR to enhance visibility and data acquisition.

Another critical aspect of the deployment environment is the dynamic nature of underwater currents, which can affect the stability and maneuverability of the vehicle. The ROV will require an efficient propulsion and stabilization system to counteract these forces while maintaining precise control during inspections. Furthermore, variations in temperature and salinity levels can impact the performance of electronic and mechanical components, necessitating the use of corrosion-resistant materials and adaptive control systems. By incorporating these design considerations, the ROV will be well-suited for reliable and efficient operations in diverse underwater environments, ensuring effective monitoring and inspection of submersible rigs.

B. Material Selection and Assembly

The choice of materials for the Remotely Operated Vehicle (ROV) plays a crucial role in ensuring durability, structural integrity, and overall performance in underwater environments. Acrylic offers excellent impact resistance, making it an ideal material for housing sensitive electronics and sensors while allowing clear visibility for onboard cameras. To enhance the mechanical strength of the acrylic pipe and improve its resistance to underwater pressure, the structure will be reinforced with epoxy resin, which provides additional rigidity and a protective waterproof layer.

Fig 1. Acrylic Pipe

For external components such as thruster mounts, sensor brackets, and frame structures, corrosion-resistant materials like marine-grade aluminum or stainless steel will be used. Marine-grade aluminum is preferred due to its high strength- to-weight ratio and resistance to seawater corrosion, while stainless steel components will be used in critical areas requiring additional mechanical strength. High-density polyethylene (HDPE) or polycarbonate may also be incorporated for non-load-bearing parts due to their flexibility and impact resistance.The choice of fasteners and sealing materials is equally critical to ensure structural integrity. All bolts and screws will be made of stainless steel with anti- corrosion coatings to prevent rusting. Waterproof gaskets and O-rings made from nitrile rubber or silicone will be applied at all sealing points to prevent water ingress. Additionally, waterproof connectors will be used for all external wiring to maintain a sealed environment while allowing necessary electrical connections. These material choices will collectively enhance the longevity and operational efficiency of the ROV in challenging underwater conditions.

Fig 2. Underwater Connectors

II. ARCHITECTURE

A. Water Sealing System

The water sealing system of the ROV is designed to ensure tight protection against water ingress, utilizing both static and dynamic sealing mechanisms. Static sealing is achieved using flat gaskets and standard O-rings, which are carefully selected based on the dimensions of the PVC tube forming the main structural component of the ROV. These seals are crucial in maintaining a watertight enclosure, preventing water from penetrating critical electronic and mechanical components housed within the ROV.

Fig 3. O Ring

For cable management, sealed cable glands with integrated seals are employed to secure the incoming and outgoing cables, including the communication cable. These glands provide an effective barrier against water intrusion while allowing necessary wiring connections to remain intact. To enhance the reliability of the sealing system, two pressure-resistant NBR (Nitrile Butadiene Rubber) gaskets, specifically sized at 107.3 mm x 5.33 mm, are used. This redundancy ensures a robust seal that withstands external pressure variations encountered during underwater operations.

Additionally, careful consideration is given to the placement and installation of these sealing components to minimize the risk of leaks. The design integrates precision-fit gaskets and O-rings at junction points where structural elements meet, ensuring a continuous waterproof barrier. By implementing these sealing techniques, the ROV achieves a high level of resistance to water penetration, allowing it to operate effectively in submerged conditions without compromising internal components.

B. Sensors

The ROV's sensor system is designed to accurately measure orientation, depth, and environmental conditions using a combination of gyroscope, accelerometer, and pressure sensors. The MPU6050, which integrates both a gyrometer and accelerometer, along with the LSM303DLHC add-on, provides critical motion and orientation data. These sensors support both I2C (Inter-Integrated Circuit) and SPI (Serial Peripheral Interface) communication protocols. However, due to conflicts between SPI libraries and those used for command execution, the I2C protocol has been chosen for seamless communication with the Arduino boards. This ensures efficient data transmission while avoiding compatibility issues.

C. Equations

The 6-DOF dynamic equations of motion for an underwater vehicle are given by:

$$M\dot{\nu} + C(\nu)\nu + D(\nu)\nu + g(\eta) = \tau \quad (1)$$

$$\dot{\eta} = J(\eta)\nu \quad (2)$$

Here, η represents position and orientation in the inertial frame, while ν denotes linear and angular velocities in the body-fixed frame. The term τ represents forces and moments acting on the vehicle.

The mass-inertia matrix M consists of rigid body and added mass components, while the Coriolis and centripetal matrix $C(\nu)$ accounts for rigid body and added mass effects. The drag matrix $D(\nu)$ includes both quadratic and linear damping terms, and $g(\eta)$ represents hydrostatic restoring forces. The transformation matrix $J(\eta)$ aligns the inertial and body-fixed frames.

For an ROV with a dry mass of 5.7 kg, the simplified rigid body inertia matrix is:

$M_{RB} = diag[m, m, m, I_{xx}, I_{yy}, I_{zz}]$

The hydrodynamic drag matrices, determined using CFD analysis, are:

$D_{quad} = diag[9.6, 40, 23, 0.01, 0.14, 0.04]$ .... (3)

$D_{lin} = diag[0.95, 5.3, 2.1, 0.07, 0.15, 0.2]$ .... (4)

Restoring forces and moments are defined by weight ($W = mg$) and buoyancy ($B = \rho gV$), assuming the center of buoyancy aligns with the body frame center.

D. Energy Management

The power supply of an underwater vehicle is a critical design consideration, primarily influenced by its distance from the ground station. There are two main power supply options: a Tethered Power System, which uses a high-voltage cable to minimize losses due to the Joule effect, and a Battery- Powered System, which provides onboard autonomy.

The tethered system requires a step-down transformer within the ROV, adding significant weight and volume, which could impact structural integrity. Additionally, the presence of a power cable increases drag, limiting the vehicle's mobility. Due to these constraints, this option was deemed impractical. A battery-powered system was selected as the optimal solution, though it presents its own challenges. The battery must be carefully chosen to meet the energy demands of the thrusters, the primary power-consuming components, as well as other onboard systems. To ensure efficient energy distribution, a comprehensive power balance analysis was conducted.

Fig 4. Lithium-Ion Battery Pack

E. Surface Control System

The surface control system serves as the primary interface for operating the ROV, enabling real-time monitoring and control during underwater inspections. It establishes a reliable communication link between the operator and the vehicle, transmitting commands and receiving sensor data for precise navigation and environmental assessment.

The control system consists of a user-friendly interface that displays depth, orientation, temperature, and other critical parameters. It allows the operator to adjust thruster speed, direction, and stability settings for smooth maneuverability. The communication between the ROV and the surface station is ensured through a tethered connection, minimizing signal loss and providing continuous data transmission.

By integrating efficient control mechanisms and responsive feedback, the surface control system enhances operational accuracy, ensuring safe and effective underwater exploration.

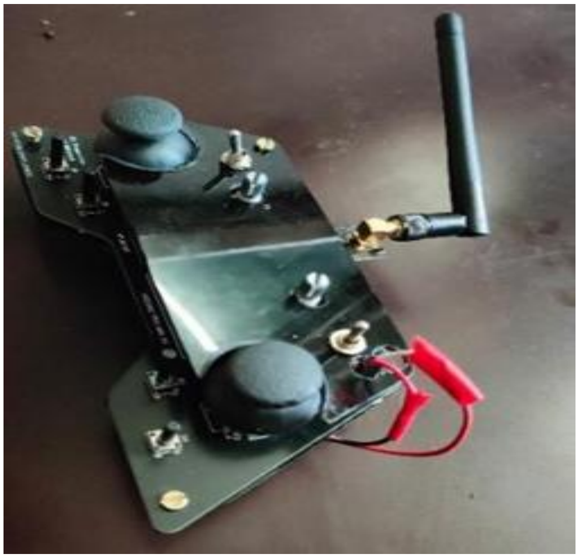

Fig 5. Joystick

F. Enclosure

The enclosure is designed to protect the internal electronics from water ingress and external pressure, ensuring reliable operation in underwater conditions. Constructed from a durable PVC tube, it provides a lightweight yet sturdy structure resistant to corrosion. A combination of Nitrile Butadiene Rubber (NBR) gaskets and O-rings ensures a secure seal, preventing leaks even under varying depths. Sealed cable glands are incorporated to maintain waterproofing while allowing necessary wiring connections. Inside the enclosure, sensitive electronic modules, including navigation and environmental sensors, are securely housed to prevent exposure to moisture and mechanical stress. The sealing system is carefully engineered to withstand underwater forces, with pressure-resistant gaskets positioned to maintain internal stability. Simulation tests and real-world validations confirm the effectiveness of the design, ensuring the enclosure can endure prolonged submersion without compromising performance.

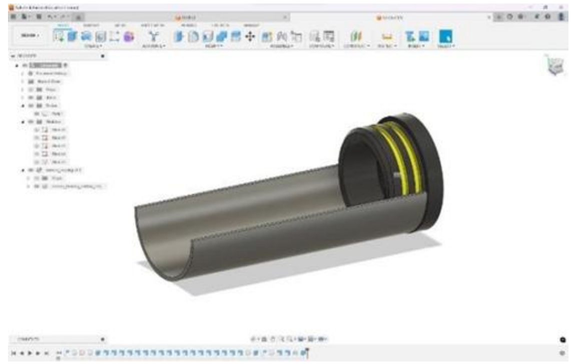

Fig 6. Water Tight Encloser

G. Thrusters

The thrusters are designed to provide efficient and precise propulsion for the ROV, enabling stable maneuverability during underwater inspections. Inspired by BlueRobotics models, they utilize three-blade propellers optimized for hydrodynamic efficiency. The propulsion system ensures smooth control and directional adjustments, allowing the ROV to navigate effectively in submerged environments.

To ensure durability in underwater conditions, the motor windings are coated with protective resin, eliminating the need for additional waterproofing. The thrusters are securely mounted on a support structure that is adjustable along threaded rods, allowing for optimal positioning based on operational requirements. The assembly of the motor, propeller, and fairing is done using fixing screws, ensuring a secure and vibration-resistant connection.

By integrating a reliable propulsion system, the ROV achieves precise depth control, stability, and efficient movement, making it well-suited for underwater exploration and dam inspection tasks.

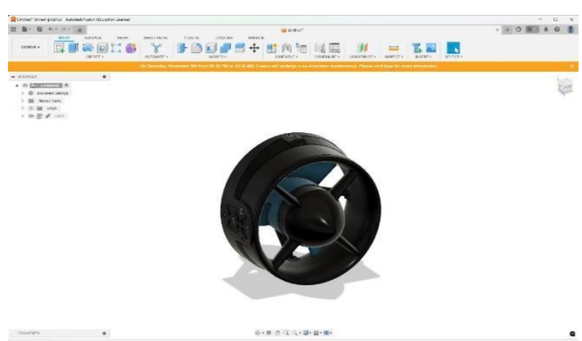

Fig 7. Thruster

H. ROV Integration With AI

Integrating AI into the ROV enhances its capability to perform autonomous underwater inspections, especially for object detection and environmental mapping. Using deep learning models, such as convolutional neural networks (CNNs), the ROV can identify objects, structural anomalies, and obstacles in real time, improving inspection accuracy and efficiency.

Sensor Fusion for AI Processing**:** The ROV collects data from multiple onboard sensors, including the MPU6050 gyroscope, LSM303DLHC magnetometer, and MS5540C pressure sensor, ensuring stable positioning and depth estimation. A camera system captures underwater visuals, which are processed using AI algorithms to detect and classify objects of interest. The system can identify cracks in dam walls, detect foreign objects, or locate debris with high precision.

Edge Computing for Real-Time Processing**:** The AI model can be deployed on an onboard processing unit, reducing the need for continuous data transmission to the surface control system. This allows real-time object recognition and decision-making, optimizing thruster movements to adjust positioning automatically based on detected objects. The AI also refines navigation by integrating vision-based positioning with sensor data, ensuring smooth operation even in low-visibility conditions.

Adaptive Control and Autonomous Navigation**:** By integrating AI-driven object detection with the thruster system, the ROV can adapt its movements dynamically. If an obstacle is detected, AI algorithms adjust the propulsion system to avoid collisions. Additionally, pattern recognition techniques allow the ROV to follow predefined structures or pipelines, assisting in automated inspections. By incorporating AI for object detection, the ROV transitions from a manually controlled system to a more intelligent and autonomous platform, enhancing its effectiveness in underwater exploration and structural assessments.

For applications such as dam inspections, AI-powered object detection assists in identifying cracks, erosion, and structural weaknesses. By comparing real-time footage with previous inspection data, AI can detect changes over time and flag areas requiring maintenance. This predictive maintenance approach reduces inspection time and enhances safety by providing early warnings of potential failures.

With AI integration, the ROV becomes more than just a remote-controlled vehicle—it evolves into an intelligent underwater system capable of automated inspections, real- time hazard detection, and adaptive navigation, significantly improving its operational efficiency and effectiveness in underwater exploration.

III. CONCLUSION

The ROV was developed with the primary objective of performing dam inspections at minimal cost while maintaining functional efficiency. The design incorporates four degrees of freedom, achieved through the integration of four thrusters. The initial phase of development involved defining the ROV's specifications, which was essential in outlining the vehicle's functions and evaluating the feasibility of various implementation methods. These specifications served as a guiding framework throughout the design process. Computer-aided tools played a crucial role in the conceptualization of the ROV, with multiple software programs utilized for design, simulation, and manufacturing. These tools facilitated optimization, allowing for improvements in structural integrity and overall performance. Simulation software also contributed to the validation process by enabling the identification of key physical, geometric, and mechanical parameters before physical realization.

The embedded electronics system was structured around four key aspects: acquiring and processing the underwater vehicle's positional data, establishing an internal communication network within the ROV, ensuring seamless connectivity with the ground station, and refining the architecture of the internal components. Special attention was given to the thruster system, including its design, integration, and performance testing on a dedicated bench. The mathematical modeling of the ROV was established using Newtonian mechanics and Euler transformations, providing a comprehensive understanding of its motion dynamics. Kinematic modeling addressed the geometric aspects of movement, while dynamic modeling incorporated both external forces and hydrodynamic effects. The thruster model, being a fundamental component of underwater propulsion, was carefully analyzed to enhance the vehicle's maneuverability and stability.

Through this structured approach, the ROV model was effectively developed and thoroughly analyzed, leading to a well-defined understanding of its behavior in a marine environment. The insights gained from this project provide a strong foundation for further advancements, where future work could focus on enhancing autonomy, improving sensor integration, and optimizing energy efficiency for prolonged underwater operations.

Fig 8. ROV With Floating Buoy

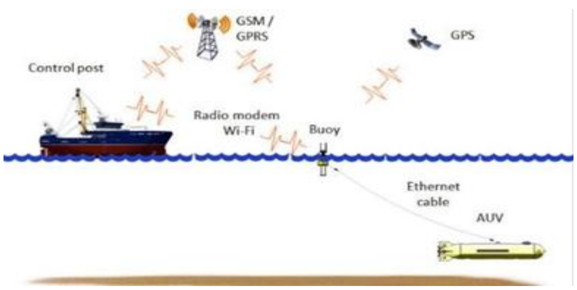

Fig 9. Schematic Diagram

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