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Underwater Drone for Surveillance and Environmental Monitoring

Monika J[1], Sebastiya U[2], Sreenidhi M[3], Dr. J. Jebastine[4]
[1, 2, 3]Bachelor of Engineering in Electronics And Communication Engineering, Jeppiaar Engineering College, Chennai. Anna University, chennai
[4]Ph. D, Professor and Head Department of Electronics and Communication Engineering, Jeppiaar Engineering Chennai

Abstract: The Underwater Drone for Surveillance and Environmental Monitoring packs a lot of tech into a surprisingly affordable package. It's built to watch over ponds and lakes, letting users keep tabs on what's happening below the surface all in real time, and without anyone needing to wade in or get their feet wet. The core is an Arduino Mega 2560 microcontroller. That, along with propulsion units, a waterproof camera, and a handful of environmental sensors, powers solid underwater surveillance. While cruising under the water, this drone streams live video and checks on the environment things like temperature and pressure. Monitoring these details is key for measuring water quality and figuring out what's going on in the ecosystem. To connect everything, the design uses a wired communication system, so all the data and controls move smoothly between the drone and the people running it. The whole goal is to be tough, reliable, affordable, and simple to use. It's a strong fit for environmental monitoring, research, and keeping an eye on freshwater spots. Down the road, there's plenty of room to level up this project things like adding wireless communication or artificial intelligence for autopilot could really push it further.

I. INTRODUCTION

A. Background

Lakes and ponds are not merely visually appealing; they play a vital role in maintaining ecological balance and support a wide variety of plant and animal life. Monitoring these water bodies is essential for detecting pollution, studying underwater biodiversity, and ensuring long-term environmental sustainability. However, conventional methods used for underwater monitoring are expensive, labor-intensive, and often limited in effectiveness.

Recent advancements in robotics, sensors, and embedded systems have enabled the development of compact and cost-effective underwater drones capable of autonomous operation. These systems can monitor aquatic environments and collect real-time data without the need for direct human intervention. This project focuses on the design and development of an economical underwater drone suitable for freshwater applications, where relatively stable conditions allow efficient operation and reliable data acquisition.

B. Problem Statement

Traditional methods of monitoring water bodies, such as manual sampling or visual observation, are time-consuming and may involve potential risks. These approaches do not provide real-time data, resulting in a lack of continuous updates regarding environmental conditions.

Existing underwater robotic systems are generally expensive and primarily designed for deep-sea exploration, making them unsuitable for smaller-scale applications such as monitoring lakes and ponds. There is a need for a system that is compact, cost-effective, and efficient, capable of providing real-time data and visual feedback to support accurate environmental analysis.

C. Objectives

The main objectives of the project are:

- To design and develop an underwater drone capable of stable navigation in freshwater environment.
- To capture real-time underwater images and video using a waterproof camera.
- To measure environmental parameters such as temperature and pressure.
- To establish a reliable communication system for real-time monitoring and control.
- To develop a cost-effective and user-friendly system for environmental monitoring applications.

D. Scope of The Project

Monitoring ponds and lakes is not merely important; it is essential to protect water quality and maintain ecological balance. The traditional approach involves sending personnel to collect water samples manually and record observations. This process requires significant time and effort and may not always be safe. Even after such work, real-time updates are not available, and underwater conditions cannot be directly observed.

Most underwater monitoring systems are designed primarily for ocean environments. These systems are bulky, expensive, and overly complex for smaller water bodies such as lakes and ponds. As a result, such environments are left with limited means for effective monitoring.

Here’s the main trouble:

- No way to track water quality as it changes in real time, can’t watch what’s happening underwater continuously, most systems that exist cost too much and are hard to use and collecting samples by hand isn’t just tough it can be risky
- This project focuses on small and medium-sized freshwater bodies. Ponds and lakes are affected by significant challenges including pollution, temperature fluctuations, and ecological imbalance. The proposed system enables real-time monitoring, continuous data collection, and reduced human involvement in field operations. It is cost-effective, scalable, and provides accurate, real-time insights required for environmental assessment and management. This approach facili-tates effective monitoring of critical parameters and supports timely responses, thereby improving the management of these important freshwater resources.

II. LITERATURE REVIEW

A. Research Studies on Underwater Drone For Surveillance And Environmental Monitoring

Researchers have spent a lot of time digging into how underwater drones, IoT tech, and sensor systems can make monitoring lakes, rivers, and oceans easier. Instead of sending people into the water, these tools deliver real-time data and sharper measurements. Cameras, sensors, and microcontrollers now work together, making water quality checks and underwater inspections much more efficient.

Here’s how they're being used:

- IoT systems collect real-time data right from the water.
- Cameras peek underwater to help with surveillance and inspection.
- Sensors track temperature, pressure, and quality to keep us informed.
- Remotely Operated Vehicles (ROVs) let people explore underwater safely, without getting wet.
- Automation ensures stable operation and controlled navigation of the system.

The integration of sensing, imaging, and communication technologies enhances aquatic monitoring by reducing cost and improving safety, while increasing the ac-curacy of environmental analysis.

Recent studies in this domain are reviewed as follows:

1) Title: Design and Development of Low-Cost Underwater ROV for Monitoring

Authors: Kumar, S., Reddy, P., and Nair, V. Year: 2018

A low-cost remotely operated vehicle (ROV) for underwater monitoring was developed. The system utilizes a microcontroller, thrusters for propulsion, a camera, and basic sensors. It is controlled through a wired interface, enabling real-time video transmission and navigation. The affordability and simplicity of the system make it suitable for applications in smaller water bodies such as ponds and lakes..

2) Title: IoT-Based Water Quality Monitoring System

Authors: Sharma, K., Gupta, R., and Verma, A. Year: 2020

An IoT-based system for monitoring water quality was proposed. Sensors are deployed in water to measure parameters such as temperature, pH, and turbidity. The collected data is processed by a microcontroller and transmitted to the cloud for real-time analysis. This approach reduces the need for manual sampling and improves scalability and accessibility in environmental monitoring.

3) Title: Underwater Surveillance Using Camera-Enabled Robotic System

Authors: Singh, D., Mehta, S., and Joshi, R. Year: 2019

A robotic system equipped with a high-resolution camera is utilized for underwater surveillance and inspection. The system provides real-time video transmission through a wired communication link. It is applied in pipeline inspection, aquatic life observation, and security monitoring. This approach enhances visibility and significantly reduces risks associated with human involvement in underwater operations

4) Title: Sensor-Based Aquatic Environment Monitoring Using Embedded Systems

Authors: Patel, H., Shah, M., and Trivedi, J. Year: 2021

An embedded system for continuous monitoring of aquatic environments was developed. The system employs temperature and pressure sensors to collect data in real time. The collected data can be analyzed to better understand underwater conditions, thereby supporting the maintenance of ecological balance.

So, the takeaway is clear: smart tech and automation let us watch aquatic environments more easily, cheaply, and safely than ever.

III. EXISTING SYSTEM

A. Traditional Underwater Monitoring Techniques

Traditional underwater monitoring techniques rely heavily on manual observation and basic equipment such as divers and stationary sensors. These methods are often time-consuming, risky, and limited in data collection capabilities. In many cases, divers are deployed to inspect underwater conditions, which poses safety risks and restricts the depth and duration of monitoring. Additionally, stationary monitoring systems lack mobility and cannot provide comprehensive coverage of the water body.

- Manual inspection using human divers
- Use of stationary sensors with limited coverage
- Lack of real-time visual monitoring
- Time-consuming and labor-intensive processes

Despite being widely used, these methods are inefficient for continuous monitoring and fail to provide accurate and real-time environmental data.

B. Limitations & Challenges

Traditional underwater monitoring systems face several limitations, including high risk to human life, lack of real-time data, and limited operational efficiency.

- High risk involved in manual underwater inspection
- Lack of real-time data acquisition and monitoring
- Limited mobility and coverage of stationary systems
- Inability to capture continuous visual data
- High operational effort with low efficiency

These challenges highlight the need for a modern, automated solution that ensures safety, accuracy, and efficiency in underwater monitoring.

C. Proposed System

The proposed system is an Underwater Drone for Surveillance and Environmental Monitoring, designed to overcome the limitations of traditional methods. It integrates a microcontroller-based control unit, propulsion system, camera module, and environmental sensors to enable efficient underwater operation.

The system uses an Arduino Mega 2560 for control, along with thrusters for movement, and a waterproof camera for live video streaming. Sensors such as temperature and pressure sensors are used to collect environmental data in real time. The drone is connected to a monitoring system through a wired communication link for stable control and data transmission.

- Real-time underwater surveillance using a camera module
- Temperature and pressure monitoring using sensors
- Stable navigation using thrusters and propellers
- Wired communication for continuous data transmission
- Microcontroller-based control system for efficient operation

This system provides a cost-effective and practical solution for monitoring freshwater environments such as ponds and lakes.

D. Features, Innovation & Advantages

The proposed underwater drone stands out by combining surveillance and environmental monitoring into a single integrated system. It introduces an efficient and affordable approach to underwater exploration using simple yet powerful components.

The system enables real-time video monitoring along with environmental data collection, reducing the need for manual intervention. Its compact design and ease of operation make it suitable for small-scale applications and research purposes.

Key Features and Benefits:

- Real-time underwater video surveillance
- Continuous monitoring of temperature and pressure
- Safe operation without human intervention
- Cost-effective and easy to deploy
- Stable and controlled navigation system
- Reduced risk compared to manual inspection
- Improved accuracy in environmental data collection

IV. BLOCK DIAGRAM & WORKFLOW

A. Block Diagram

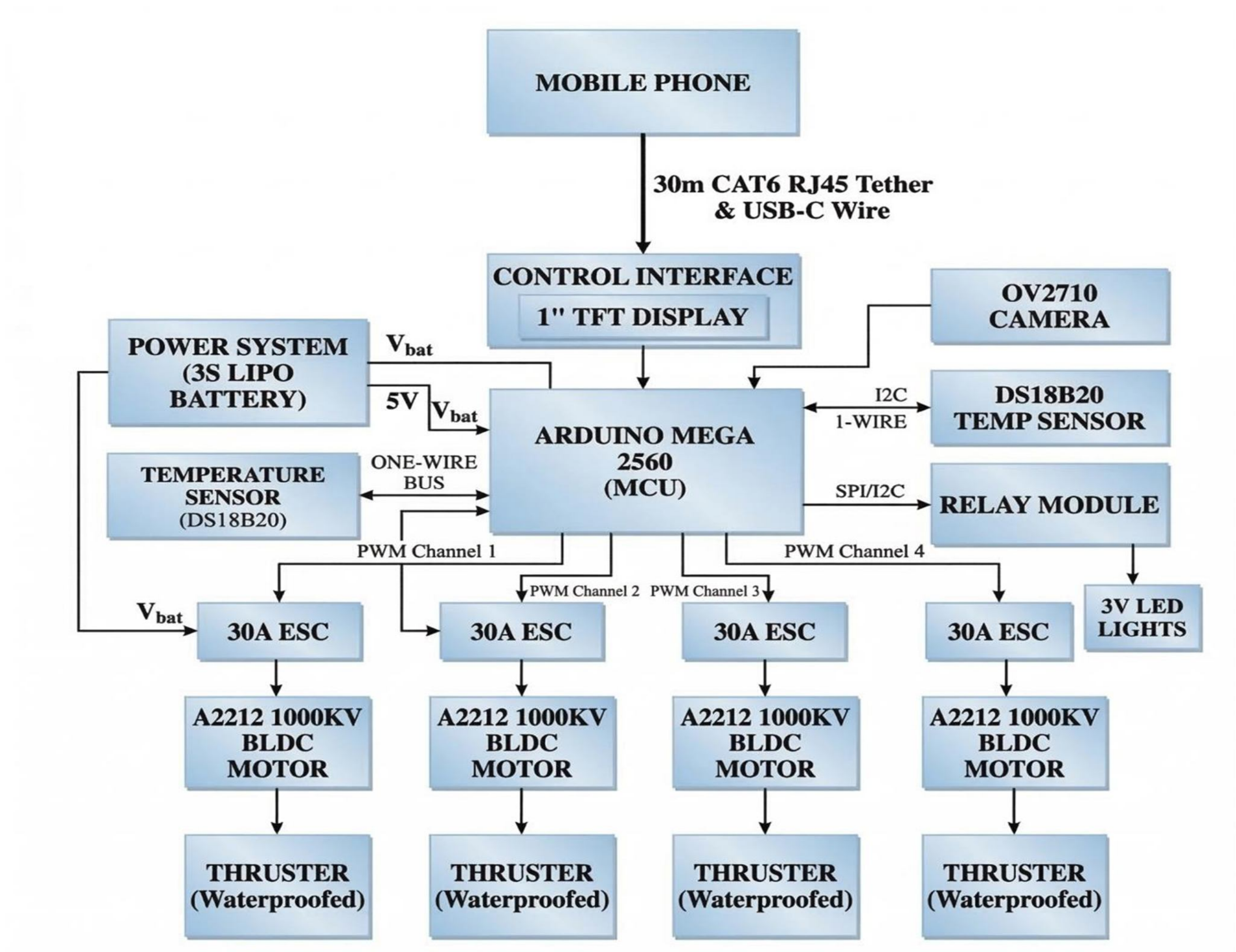

Fig 4.1 Block diagram

B. Workflow

The workflow of the underwater drone system consists of a sequence of coordinated operations that enable real-time surveillance and environmental monitoring. Each stage plays a vital role in ensuring efficient underwater navigation, data acquisition, and transmission with minimal human intervention.

1) System Initialization: The system begins with power supply activation, where the battery energizes all onboard components through a voltage regulator. The microcontroller initializes connected modules and prepares the system for operation.
2) Signal Transmission (Tether Communication): A tether cable (CAT6 RJ45) establishes communication between the underwater drone and the surface control unit. It enables real-time transmission of control signals and data between the operator and the drone.
3) Navigation and Movement: The Arduino Mega controls the BLDC motors through Electronic Speed Controllers (ESCs). These motors drive the thrusters, allowing the drone to move in multiple directions (forward, backward, vertical, and rotational movement) underwater.
4) Data Acquisition: Sensors such as the DS18B20 temperature sensor continuously monitor environmental parameters like water temperature. This data is essential for environmental analysis and research purposes.
5) Visual Monitoring: The onboard camera module captures real-time underwater video footage. This visual data is transmitted to the surface control unit for surveillance, inspection, and monitoring applications.
6) Data Display and Monitoring: The collected sensor data is displayed on the TFT display module, allowing real-time monitoring of parameters such as temperature directly from the system
7) Control Mechanism: Relay modules are used to control auxiliary components such as lights and additional devices. The microcontroller manages these components based on input signals from the operator.
8) Buoyancy and Stability Control: The drone maintains stability and balance underwater using its structural design and buoyancy control mechanism. Proper buoyancy ensures smooth operation and prevents sinking or floating excessively.
9) Data Transmission to Surface: All collected data, including video and sensor readings, are transmitted to the surface control unit through the tether cable, enabling real-time monitoring and decision-making.

V. MODULES

A. Modules & Their Description

The underwater drone system consists of multiple functional modules, each responsible for a specific operation such as navigation, sensing, communication, and monitoring. These modules work together to ensure efficient underwater surveillance and environmental data collection.

B. Control Module (ARDUINO MEGA)

This module acts as the central processing unit of the underwater drone, controlling all operations and coordinating different components.

- Controls motors, sensors, and communication system
- Processes input signals and executes control logic
- Ensures synchronized operation of all modules
- Provides real-time response to operator commands

C. Thruster Module (Waterproofed System)

The thruster system converts motor rotation into thrust for underwater movement.

- DIY thrusters waterproofed using mineral oil
- Ensures safe operation of motors underwater
- Generates thrust for navigation and control
- Improves maneuverability of the drone

D. Surveillance Module (Camera System)

This module enables real-time underwater monitoring and inspection.

- Uses CMOS OV2710 camera module
- Captures real-time video footage

- Transmits visual data to surface system
- Useful for surveillance and environmental observation

E. Sensor Module (Temperature Sensor – DS18B20)
This module collects environmental data from underwater surroundings.
- Measures water temperature accurately
- Provides real-time data to control unit
- Supports environmental monitoring applications
- Waterproof design suitable for underwater usage

F. Communication Module (Tether System)
This module ensures data and signal transmission between the drone and the surface.
- Uses CAT6 RJ45 cable (30 meters)
- Enables real-time communication
- Transfers control signals and sensor data
- Provides stable and reliable connection

G. Display Module (TFT Display)
This module displays system parameters for monitoring purposes.
- 1-inch TFT display used
- Shows temperature and system status
- Provides real-time feedback
- Enhances user interaction

H. Lighting Module (LED System)
This module provides illumination in underwater environments.
- Uses 3V LED lights
- Improves visibility in dark conditions
- Enhances camera performance
- Low power consumption

I. Control Switching Module (Relay Module)
This module controls switching of electrical components.
- Uses 5-pin sugar cube relays
- Controls lights and other devices
- Provides isolation and safety
- Enables automated control

J. Structural Module (Hull & Frame)
This module forms the physical body of the underwater drone.
- 3D printed using PETG filament
- Coated with epoxy resin for waterproofing
- Protects internal components
- Provides mechanical strength and durability

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VI. HARDWARE COMPONENTS

A. Arduino Mega (ATMEGA 2560)

Fig 6.1 Arduino Mega

- Arduino Mega serves as the central control unit for the underwater drone system. It is responsible for coordinating and managing all the hardware components integrated into the system.
- The microcontroller continuously receives input data from sensors such as the DS18B20 temperature sensor and processes this data to make real-time decisions.
- It generates Pulse Width Modulation (PWM) signals to control the speed and direction of BLDC motors through Electronic Speed Controllers (ESCs), enabling smooth and precise underwater movement.
- The Arduino Mega is capable of handling multiple tasks simultaneously due to its large number of input/output pins and memory capacity, making it suitable for complex embedded applications like underwater robotics.
- The microcontroller operates with high reliability and stability, even under continuous operation in challenging environments.

Key Specifications

1) Microcontroller:
ATmega2560 microcontroller based on AVR architecture Designed for high-performance embedded applications

2) Operating Voltage:
5V regulated operating voltage
Ensures stable functioning of connected components

3) Input Voltage (Recommended): 7–12V external supply
Can tolerate input voltage from 6V to 20V

4) Digital Input/Output Pins: 54 digital I/O pins
15 pins support PWM output

5) Analog Input Pins:
16 analog input channels
Used for reading sensor data with high accuracy

6) Clock Speed:
16 MHz crystal oscillator

7) Memory:

Flash Memory: 256 KB (for storing program code)
SRAM: 8 KB (for runtime data processing) EEPROM: 4 KB (for permanent data storage)

8) Communication Interfaces:
UART: 4 hardware serial ports for communication SPI: High-speed communication for peripherals I2C: Interfacing with sensors and modules

9) Power Supply Options:
Can be powered using USB cable External DC adapter or battery supply

10) GPIO (General Purpose Input/Output):
Allows flexible interfacing with external hardware Supports both digital and analog signal processing

11) Form Factor and Design: Dimensions: 101.5 mm × 53.3 mm Lightweight and compact design
Easy integration into embedded systems

B. BLDC Motor (A2212 1000KV)

Fig 6.2 BLDC Motor

The A2212 1000KV Brushless DC motor converts electrical energy into rotational motion for propulsion. It uses electronic commutation for high efficiency and low heat. Paired with an ESC, it enables precise speed control. Its lightweight design suits drone and underwater applications.

C. Electronic Speed Controller (30A ESC)

Fig 6.3 ESC

An ESC controls the speed and direction of a BLDC motor by converting PWM signals into three-phase outputs.
A 30A ESC ensures smooth operation with protection features, enabling stable and controlled underwater movement.

D. Thruster

Fig 6.4 Thrusters

A thruster is a propulsion unit with a motor-driven propeller in a waterproof housing. It generates thrust by pushing water backward, enabling precise underwater movement in multiple directions.

E. Hull Structure

Fig 6.5 Hull structure

The hull is the protective outer body of the underwater drone that houses all components. It is made from water-resistant materials like PETG with epoxy coating for waterproofing, ensuring protection, stability, and reduced drag.

F. Waterproofing System

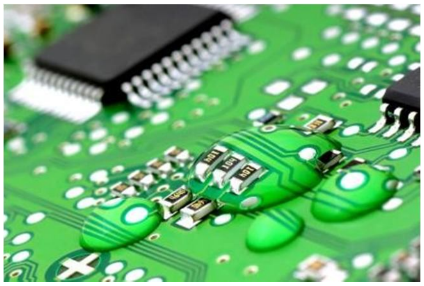

Fig 6.6 Waterproofing system

The waterproofing system protects electronics from water exposure using epoxy sealing. It prevents leakage, ensures durability, and enables reliable underwater operation.

G. Temperature Sensor (DS18B20)

Fig 6.7 Temperature sensor

The DS18B20 is a digital sensor used to measure water temperature accurately. It uses a one-wire protocol for easy microcontroller interfacing. The waterproof design makes it suitable for underwater use. It provides real-time temperature data for monitoring.

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H. Camera Module (OV2710)

Fig 6.8 Camera module

The camera module captures real-time underwater images and video for surveillance. The OV2710 sensor provides good image quality in low light, aiding inspection and exploration.

I. TFT Display

Fig 6.9 TFT display

A TFT display is used to show real-time data such as temperature and system status. It provides a graphical interface for monitoring system performance. The display communicates with the microcontroller using SPI or serial communication.

J. CAT6 RJ45 TETHER CABLE

Fig 6.10 CAT RJ45 cable

A CAT6 RJ45 cable is used for communication between the underwater drone and the surface system. It supports high-speed data transmission and ensures reliable signal transfer over long distances , minimizes data loss and interference for stable communication and enables efficient real-time monitoring and precise control of the system.

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K. Power Supply System

Fig 6.11 Power supply system

The power supply system provides electrical energy to all components of the drone. It includes batteries and voltage regulation circuits to ensure stable and continuous operation. Proper power management is essential for system reliability.

L. Buoyancy System

Fig 6.12 Buoyancy system

The buoyancy system ensures that the underwater drone maintains stability and balance in water. It uses materials like foam or air-filled chambers to achieve neutral buoyancy, allowing the drone to remain suspended at a desired depth.

M. Frame Structure

Fig 6.13 Frame structure

The frame structure provides mechanical support and holds all components in place. It ensures proper alignment of motors, sensors, and electronics while maintaining overall stability. A strong and lightweight frame improves performance and durability.

VII. SOFTWARE

A. Software Configuration & Description

The underwater drone system is powered by an embedded software architecture designed for real-time control, monitoring, and data acquisition. The system operates using an Arduino Mega microcontroller, which acts as the central processing unit. The software is developed and uploaded from a computer system running on Windows OS.

The control logic is implemented using Embedded C/C++ programming through the Arduino IDE. The software manages various functionalities such as motor control, sensor data acquisition, communication, and display output. The system ensures smooth coordination between hardware components, enabling efficient underwater navigation and environmental monitoring.

Software Stack:

- Operating System: Windows 7/10
- Programming Language: Embedded C/C++
- Microcontroller Platform: Arduino Mega
- Development Tool: Arduino IDE
- Communication Protocol: Serial Communication (UART)
- Control Signals: PWM (Pulse Width Modulation)

B. Key tools & utilities:

- Arduino IDE (Development Environment): The Arduino IDE is used to write, compile, and upload code to the Arduino Mega, offering a user-friendly interface and extensive library support for interfacing sensors and actuators
- Embedded C/C++ Programming: Embedded C/C++ is used to develop efficient and real-time control programs for the underwater drone system. The code defines the behavior of motors, sensors, and communication modules.
- PWM Control Mechanism: Pulse Width Modulation (PWM) is used to control the speed of the BLDC motors and thrusters. By varying the duty cycle of the PWM signal, precise speed control is achieved.
- Serial Communication (UART): Serial communication is used for data exchange between the Arduino Mega and the computer system. It allows monitoring and debugging of the system in real time.
- Sensor Integration: Sensor integration enables real-time temperature monitoring using the DS18B20, supporting underwater condition analysis and ensuring accurate data acquisition.
- Display Interface (TFT Display): The TFT display interfaces with the microcontroller to show real-time system parameters, displaying temperature and system status, providing visual feedback, and enhancing monitoring capability
- System Control Logic: The software continuously loops to read sensor inputs, process data using programmed logic, and control outputs like motors, relays, and LEDs while maintaining system stability.

VIII. RESULT & DISCUSSION

The underwater drone system was tested under both controlled laboratory conditions and real-time aquatic environments to evaluate its performance, stability, reliability, and monitoring capabilities. The system integrates propulsion units, control mechanisms, sensors, camera module, and communication interface to achieve efficient underwater navigation and environmental data acquisition. The experimental results indicate that the system performs effectively for applications such as underwater surveillance, inspection, and environmental monitoring.

The following observations were made during testing:

- System Performance: The BLDC motor coupled with thrusters provided smooth and stable propulsion, enabling efficient movement of the drone in forward, backward, and vertical directions. The Electronic Speed Controller (ESC) ensured accurate and responsive control of motor speed, which improved maneuverability and directional precision. The tether-based communication using a CAT6 RJ45 cable allowed continuous and reliable data transmission without significant delay or signal loss. Overall, the system demonstrated consistent performance during prolonged operation, indicating strong reliability of the hardware components
- Monitoring & Sensing Performance: The camera module successfully captured real-time underwater video, making it suitable for surveillance, inspection, and exploration applications. LED lights enhanced visibility in low-light and deep-water conditions, improving the clarity of captured images and videos. The DS18B20 temperature sensor provided accurate and stable readings, enabling effective monitoring of water temperature. The TFT display presented real-time system data, including sensor readings and operational status, thereby improving usability and interaction.
- Output Observations: Continuous live video streaming from the underwater environment was achieved, along with smooth and stable movement of the drone in multiple directions. Real-time temperature data was displayed accurately throughout the operation.

- Performance Analysis: The system exhibited high responsiveness to control inputs, allowing precise navi-gation and movement. The use of a tethered communication system enhanced reli-ability compared to wireless communication in underwater conditions. Stable per-formance was maintained even under varying water environments, demonstrating the robustness of the design.
- Comparative Analysis: Compared to manual underwater inspection methods, the system significantly re-duces human effort and eliminates risks associated with deep-water exploration. It also provides real-time monitoring capabilities, unlike traditional inspection ap-proaches that depend on delayed data analysis.
- Limitations: The operational depth is constrained by the length of the tether cable and the effec-tiveness of waterproofing. Visibility may be reduced in highly turbid or polluted water conditions. The system also requires careful handling to preserve waterproof integrity and prevent damage to components.
- Summary of Observations: The underwater drone achieved stable and controlled navigation while successfully implementing real-time monitoring and data acquisition. The system demonstrated reliable performance across different testing conditions, confirming its effective-ness for underwater applications.

IX. CHALLENGES

A. Challenges & Limitations

While the underwater drone system demonstrated reliable performance during test-ing, several challenges and limitations were identified throughout the design, devel-opment, and implementation stages due to the complex nature of underwater envi-ronments. Achieving precise navigation stability is difficult because unpredictable water currents, drag forces, and varying pressure conditions affect the drone's ori-entation and positioning, especially during long-duration operations. Communica-tion is another major constraint, as underwater environments do not support conven-tional wireless methods like Wi-Fi or Bluetooth, forcing reliance on tether-based systems that restrict mobility and operational range. Additionally, sensor accuracy and reliability are influenced by environmental factors such as temperature, pressure, and turbidity, while camera visibility and image quality are often degraded in low-light or murky conditions due to light absorption and suspended particles.

The system faces several technical and operational challenges. Coordinating motors, sensors, and communication modules in real time requires efficient control algo-rithms. Continuous use of BLDC motors and thrusters causes wear and reduces lifespan, while waterproofing is critical since small leaks can damage electronics. High-quality materials increase cost, and maintenance needs technical expertise. Performance also drops in muddy or polluted water, and careful handling is required to prevent damage. Despite its potential in underwater applications, challenges re-main in communication, environment, power management, and durability.

X. CONCLUSION

The underwater drone system presents an innovative and efficient solution for underwater surveillance and environmental monitoring by integrating embedded control systems, propulsion mechanisms, sensing technologies, and real-time monitoring modules, making it a reliable and cost-effective alternative to conventional underwater inspection methods. The project successfully demonstrates the combination of BLDC motors, thrusters, sensors, camera module, and communication interface ensures stable operation in aquatic environments while reducing human effort and minimizing risks through remote operation in hazardous and hard-to-access locations. The system enables smooth and controlled underwater movement, continuous live video streaming, and accurate environmental data collection using sensors such as the DS18B20 temperature sensor, while maintaining stable and uninterrupted communication through a tether-based CAT6 system. Its compact, lightweight, and modular design supports easy maintenance, repair, and future upgrades. The developed prototype shows strong potential for further enhancement with advanced technologies such as artificial intelligence, improved communication systems, and high-resolution imaging techniques, enabling its application in marine research, underwater inspection, disaster response, and environmental monitoring. Despite certain limitations related to communication range, power constraints, and environmental conditions, the system demonstrates significant potential for practical implementation with opportunities for future improvements in efficiency, durability, and overall performance.

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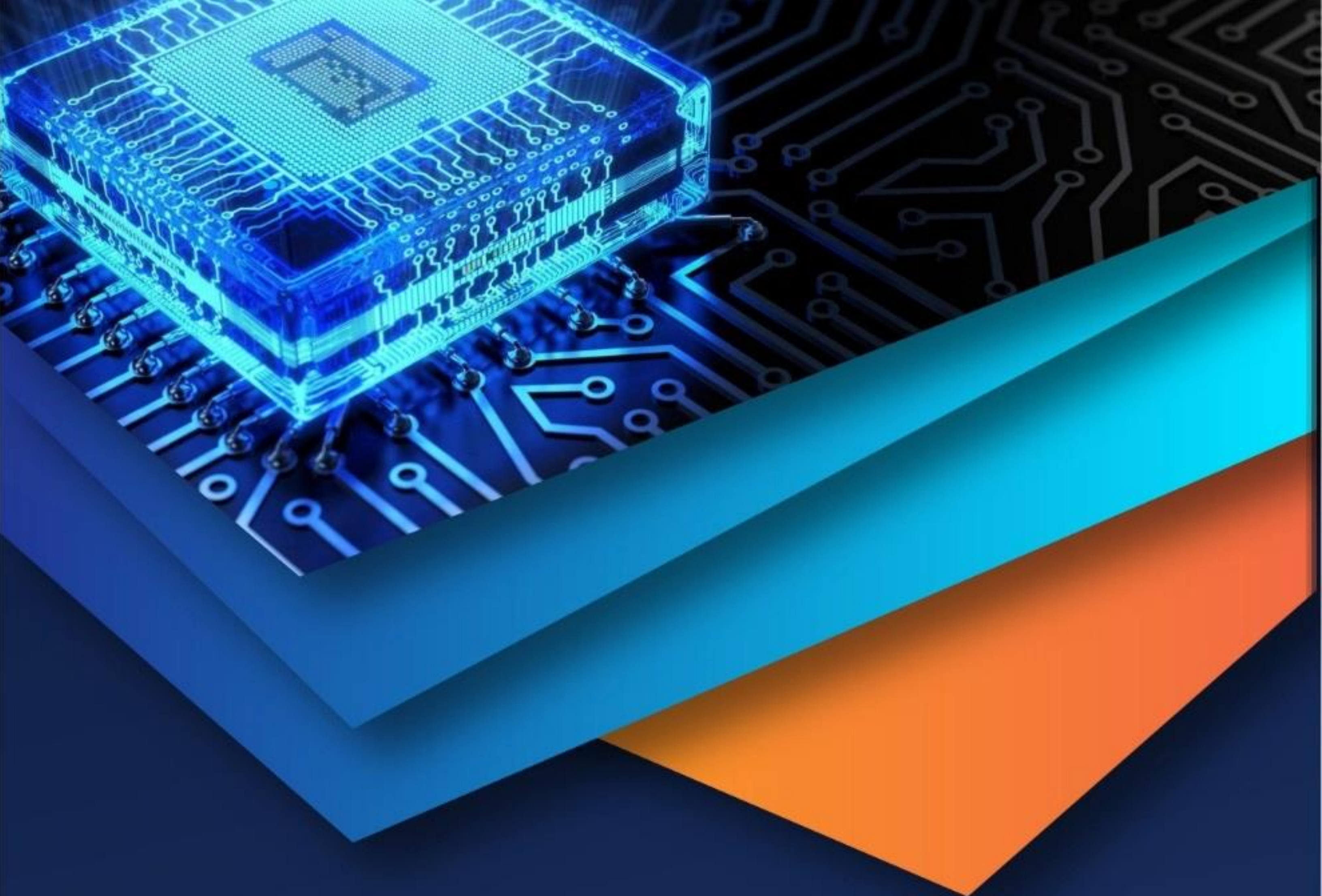

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