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IOT Enabled Smart Pond Monitoring System with Real-Time Tracking and Offline Database

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Abstract: ***Water bodies such as ponds play a crucial role in agriculture, aquaculture, and environmental sustainability. However, maintaining optimal water quality is challenging due to fluctuations in parameters like temperature, pH, turbidity, and dissolved oxygen. This paper presents an IoT-enabled Smart Pond Monitoring System that provides real-time monitoring along with an offline database capability to ensure data reliability even in low or no internet conditions.***

The proposed system uses multiple sensors integrated with a microcontroller to continuously collect water quality parameters. These data are transmitted to a cloud platform when connectivity is available, while simultaneously being stored locally in an offline database (e.g., SD card or local server). A user-friendly dashboard enables real-time visualization, historical data analysis, and alert generation for abnormal conditions.

This hybrid architecture improves system reliability, supports rural deployment, and ensures uninterrupted monitoring. The system is cost-effective, scalable, and suitable for applications such as aquaculture management, irrigation planning, and environmental monitoring.

I. INTRODUCTION

Water bodies such as ponds play a vital role in agriculture, aquaculture, and environmental sustainability by supporting irrigation, fish farming, and ecological balance. Maintaining optimal water quality is essential for ensuring productivity and preventing environmental degradation. Key parameters such as pH, temperature, turbidity, and dissolved oxygen directly influence aquatic life and water usability. Traditionally, monitoring these parameters has been carried out through manual sampling and laboratory analysis, which are not only time-consuming and labor-intensive but also fail to provide continuous or real-time insights. With the advancement of the Internet of Things (IoT), smart monitoring systems have emerged that enable real-time data acquisition, remote access, and improved decision-making. However, many existing IoT-based systems rely heavily on continuous internet connectivity, which limits their effectiveness in rural and remote areas where network availability is inconsistent. To address these challenges, there is a growing need for a reliable and intelligent monitoring system that combines real-time tracking with offline data storage, ensuring uninterrupted operation and data availability. This paper proposes an IoT-enabled Smart Pond Monitoring System that integrates sensor-based data collection, cloud connectivity, and an offline database mechanism to provide a robust, scalable, and efficient solution for water quality monitoring.This system ensures continuous operation even during network failures, making it highly practical for real-world deployment.

II. EXISTING METHOD

Existing pond monitoring methods can be broadly categorized into manual, electronic, and IoT-based systems, each with its own advantages and limitations. Traditional manual monitoring involves periodic collection of water samples followed by laboratory testing, which is accurate but lacks real-time capability and requires significant human effort. Basic electronic monitoring systems use sensors connected to local display units to measure parameters such as temperature and pH; however, these systems do not support remote access, data storage, or historical analysis. With the development of IoT technologies, modern monitoring systems have been designed using microcontrollers like Arduino or ESP8266/ESP32, where sensor data is transmitted to cloud platforms such as ThingSpeak or Blynk for real-time visualization and remote monitoring. While these systems offer improved accessibility and continuous tracking, they are highly dependent on stable internet connectivity and often fail to function effectively during network disruptions, leading to data loss and reduced reliability. Additionally, most existing systems lack offline storage capabilities and efficient synchronization mechanisms, making them unsuitable for deployment in areas with poor network infrastructure.

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These limitations highlight the need for a hybrid monitoring system that ensures both real-time data access and reliable offline operation.

III. PROPOSED SYSTEM

The proposed IoT-enabled smart pond monitoring system is designed to continuously measure and track critical water quality parameters using a sensor–microcontroller–communication architecture powered by renewable energy. The central processing unit of the system is an STM32 ARM Cortex-M3 microcontroller, which interfaces with multiple sensors and modules to ensure reliable data acquisition, storage, and transmission.

Sensor Integration:

- DHT11 sensor measures ambient temperature and humidity.
- pH sensor monitors the acidity/alkalinity of pond water.
- TDS sensor evaluates total dissolved solids, indicating water purity.
- Turbidity sensor measures water clarity.

These sensors are directly connected to the STM32 microcontroller through GPIO and analog input pins, enabling real-time data collection.

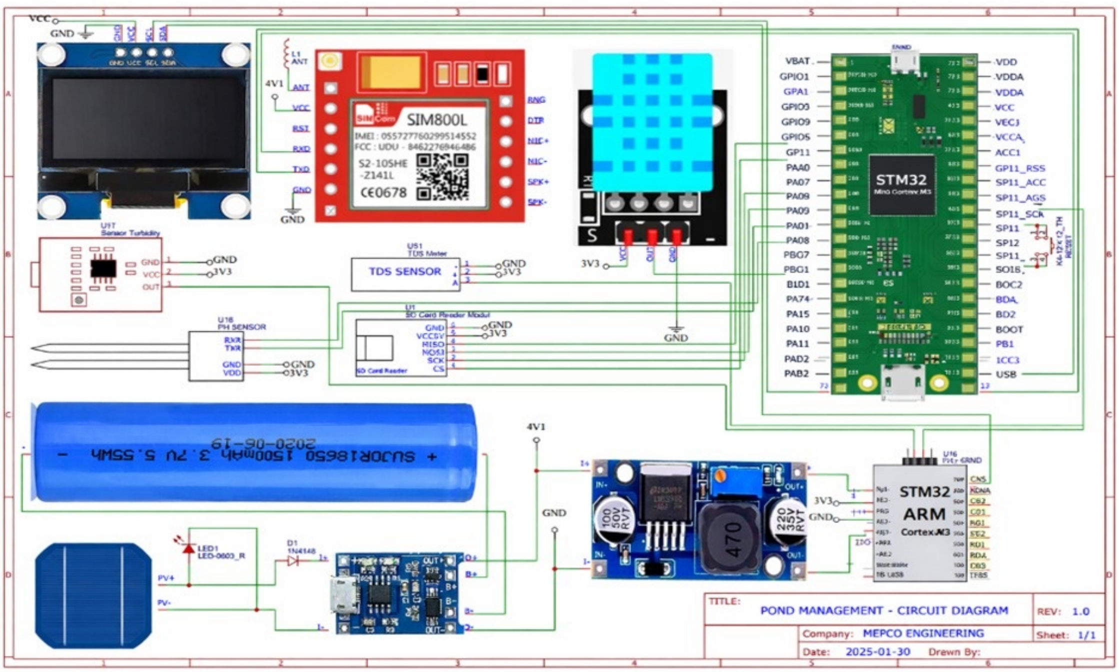

Fig 1 Circuit Diagram of Proposed Method

1) *Data Processing and Communication:*

The STM32 processes sensor signals and displays readings on an OLED module via I2C communication. For external communication, a SIM800L GSM module transmits data to remote users, enabling real-time tracking and alert notifications.

2) *Offline Database Support:*

A MicroSD card reader module is integrated with the STM32 controller to store sensor data locally. This ensures uninterrupted logging during network outages, with synchronization to the cloud once connectivity is restored.

3) *Power Management:*

The system is powered by a 3.7 V Li-ion battery (1500 mAh) supported by a solar panel and charging module. A voltage regulator ensures stable supply to the microcontroller and sensors. This renewable energy integration enhances sustainability and ensures continuous operation in rural aquaculture environments.

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4) Alert Mechanism:

Threshold values for each parameter are predefined in the microcontroller. When sensor readings exceed safe limits, the GSM module triggers SMS/email alerts to notify pond managers of abnormal conditions.

5) Advantages of the Proposed Method:

- Real-time monitoring of multiple water quality parameters.
- Offline database ensures resilience against connectivity interruptions.
- Renewable energy integration for sustainable operation.
- Compact and scalable design suitable for aquaculture applications.
- Early warning alerts for proactive pond management.

This proposed method ensures reliable, efficient, and sustainable pond monitoring, aligning with the goals of smart aquaculture and environmental sustainability.

Working principle:

The proposed IoT-enabled smart pond monitoring system operates on the principle of **continuous sensing, local processing, resilient data storage, and remote communication**. The system is powered by a **solar panel–battery unit**, ensuring sustainable operation even in rural aquaculture environments.

a) Power Supply and Regulation

- A 6V/3W solar panel charges a 3.7V Li-ion battery through a TP4056 charging module.
- A voltage regulator ensures stable supply to the Raspberry Pi Pico RP2040 microcontroller and connected sensors.
- A toggle switch allows manual control of system power.

➢ **Data Acquisition**

➢ Multiple sensors continuously measure water quality parameters:

  - pH sensor (via interfacing circuit) for acidity/alkalinity.
  - TDS sensor (via amplifier) for dissolved solids.
  - Turbidity sensor (via amplifier) for water clarity.
  - DHT11 sensor (with pull-up resistor) for temperature and humidity.

b) Data Processing and Display

- The STM 32 Controller converts raw sensor signals into calibrated values.
- Processed readings are displayed locally on an **OLED module**, providing immediate feedback to users at the pond site.

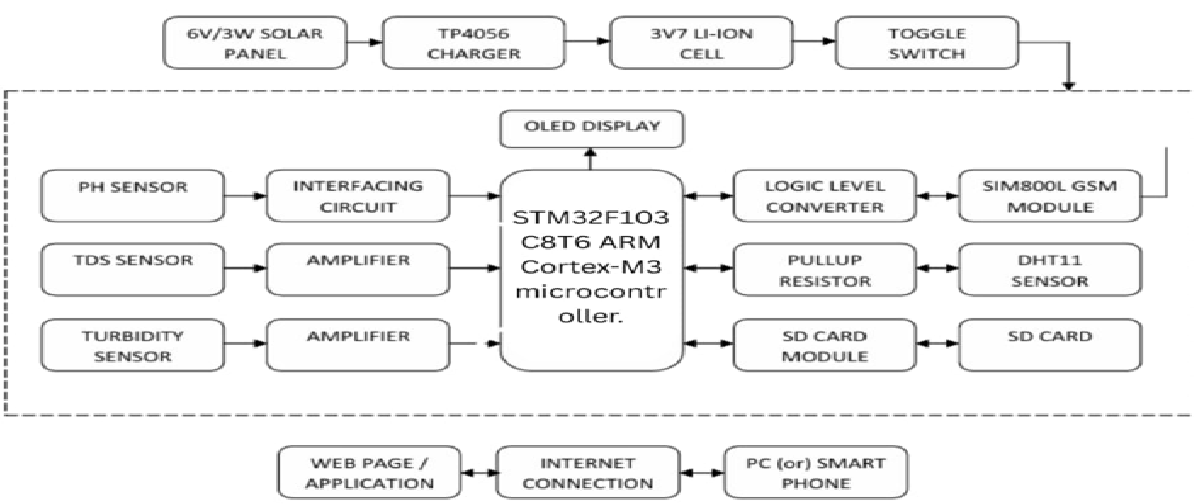

Fig 2 Block diagram

c) Data Storage (Offline Mode)

- A MicroSD card module stores sensor readings locally, ensuring uninterrupted logging during internet outages.
- This offline database can later synchronize with the cloud once connectivity is restored.

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d) Communication and Alerts

- A SIM800L GSM module, interfaced through a logic-level converter, transmits sensor data to a web server.
- The data is accessible via a web application or smartphone dashboard, enabling remote monitoring.
- Threshold-based alerts are triggered when sensor values exceed safe limits, notifying users via SMS or online dashboard.

e) Remote Monitoring

- The web application provides real-time visualization of pond conditions, historical trends from the offline database, and alert notifications.
- This enables proactive pond management and supports sustainable aquaculture practices.

IV. RESULT AND DISCUSSION

The IoT-enabled smart pond monitoring system was implemented and tested with sensors for pH, turbidity, TDS, temperature, and humidity. The Raspberry Pi Pico successfully acquired sensor data, processed it, and displayed readings on the OLED module. Data was stored reliably in the SD card during offline operation, and synchronized with the cloud once GSM connectivity was restored.
The system demonstrated:

1) Stable real-time tracking of water quality parameters with minimal delay.
2) Offline database resilience, ensuring no data loss during network interruptions.
3) Threshold-based alerts via GSM, which effectively notified users of abnormal conditions.
4) Solar-powered operation, confirming sustainability and continuous functionality.

- *Testing Process:*

Fig 3 testing process

- *Webpage Application:*

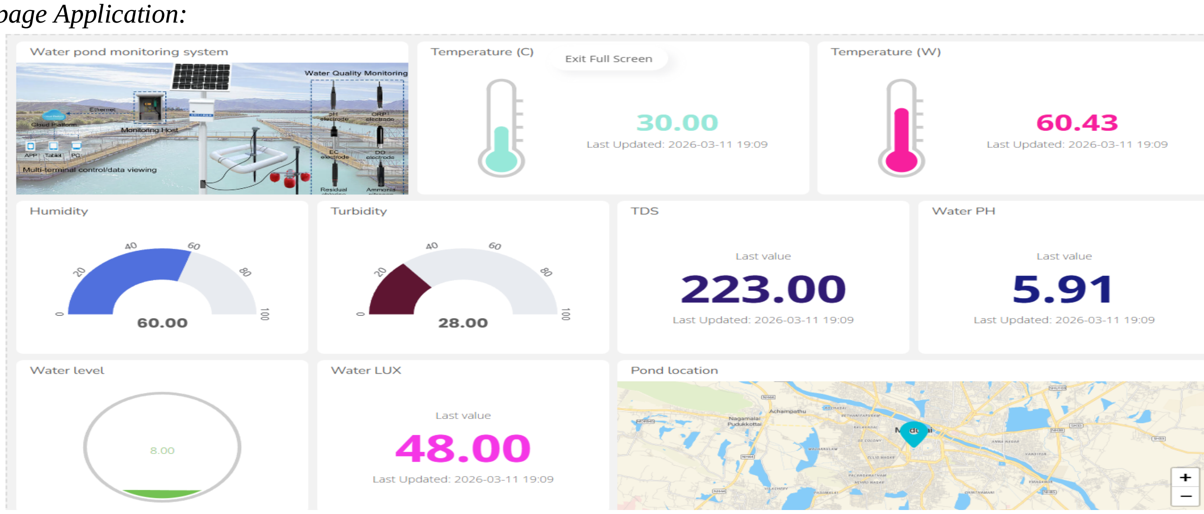

Fig 4 webpage application

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- *Readings Stored in Offline on SD Card:*

	A	B	C	D	E	F	G	H	I	J
1	TIME	LATTITUD	LONGITUI	TEMPERA	HUMIDITY	TURBIDIT	TDS	PH	LIGHT	LEVEL
2	19:20:28	0	0	31.00-63.9	55	29	74	9.12	0	14
3	19:20:43	0	0	31.00-63.9	55	29	74	10.67	0	12
4	19:20:56	0	0	31.00-63.9	55	29	75	10.85	0	12
5	19:21:09	0	0	31.00-63.9	55	28	75	10.89	0	12
6	19:21:23	0	0	31.00-63.9	55	28	75	10.89	0	12
7	19:21:40	0	0	31.00-63.7	55	28	75	11.52	0	11
8	19:22:03	0	0	31.00-63.6	55	28	80	11.07	6	0
9	19:22:25	0	0	31.00-63.6	55	28	81	11.04	6	2
10	19:22:42	0	0	31.00-63.6	55	28	81	11.07	8	2
11	19:23:05	0	0	31.00-63.6	55	28	79	11.52	2	2
12	19:23:23	0	0	31.00-63.5	55	28	80	10.78	7	2
13	19:23:37	0	0	31.00-63.5	55	28	79	10.96	10	2
14	19:23:51	0	0	32.00-63.5	55	28	78	10.89	19	2
15	19:24:07	0	0	32.00-63.5	55	28	78	10.89	9	2
16	19:24:21	0	0	32.00-63.5	55	28	78	10.93	9	2
17	19:24:38	0	0	32.00-63.4	55	28	79	11.07	9	2
18	19:25:00	0	0	32.00-63.4	55	28	78	10.89	9	2

Fig5offline data storage

Experimental results showed that sensor readings were consistent with reference values, and the communication module provided reliable data transmission to the web dashboard. The integration of renewable energy and offline storage enhanced system reliability. Overall, the proposed system improved monitoring efficiency, reduced manual intervention, and supported sustainable aquaculture practices.

V. HARDWARE IMPLEMETATION

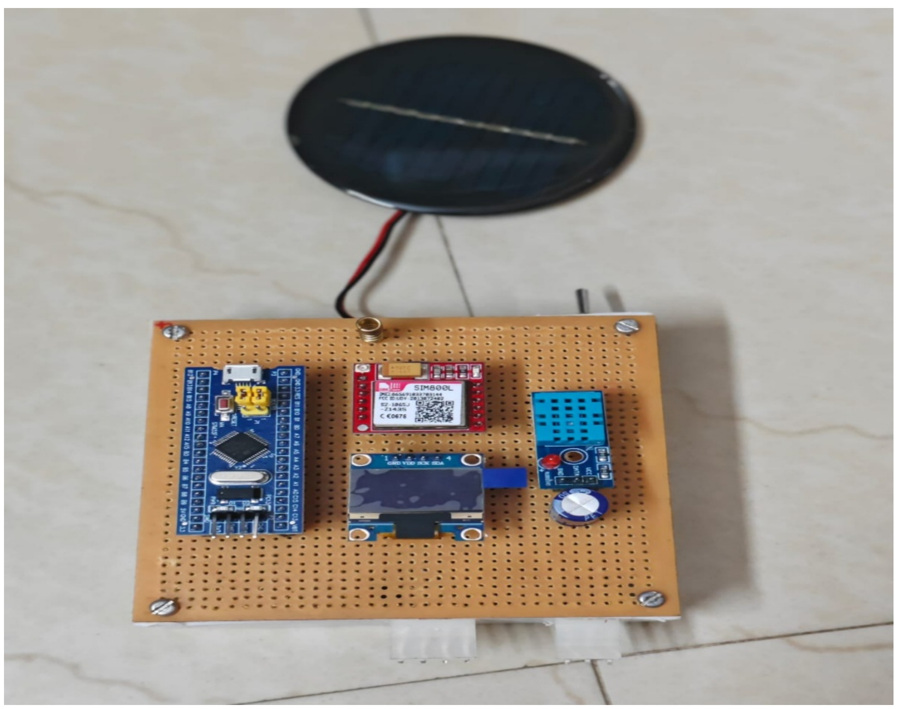

Fig 6 hardware kit

The hardware prototype of the IoT-enabled smart pond monitoring system was built using aSTM 32 microcontroller as the central unit, interfaced with sensors for pH, turbidity, TDS, temperature, and humidity. An OLED display provided local visualization of readings, while a SIM800L GSM module enabled remote communication and alerts. Sensor data was also logged into an SD card module to ensure offline database support. The system was powered by a solar panel–Li-ion battery unit with a TP4056 charging circuit and voltage regulator, ensuring sustainable and uninterrupted operation. Testing confirmed stable sensor acquisition, reliable GSM communication, and effective offline data storage, validating the system's suitability for real-time aquaculture monitoring.

VI. CONCLUSION

The proposed IoT Enabled Smart Pond Monitoring System with Real-Time Tracking and Offline Database effectively addresses the limitations of traditional and existing IoT-based water monitoring systems. By integrating multiple sensors with a microcontroller, the system continuously monitors critical water quality parameters and provides real-time insights through a cloud-based interface. The inclusion of an offline database ensures that data is securely stored during network failures, eliminating the risk of data loss and enabling uninterrupted monitoring. Additionally, the system incorporates automatic synchronization mechanisms to update the cloud database once connectivity is restored, along with real-time alert features to notify users of abnormal conditions. This hybrid architecture enhances reliability, scalability, and usability, making it highly suitable for rural and remote applications. The system is cost-effective and easy to implement, offering a practical solution for aquaculture management, irrigation planning, and environmental monitoring. Future improvements can include the integration of artificial intelligence for predictive analysis, automated control mechanisms, and renewable energy sources to further enhance system efficiency and sustainability.

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