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IoT Based Real-Time Measuring and Monitoring System for Irrigation Canals

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***Abstract*—Efficient water resource management is vital for sustainable agriculture, particularly in the operation of irrigation canals. This project introduces an Internet of Things (IoT)-based system designed to provide real-time data on water discharge within these canals, aiming to enhance distribution efficiency and minimize wastage. The system features a user-friendly mobile application, Flow Tracker, which offers real-time visualization of water levels and discharge rates, empowering users to make informed decisions promptly. To accommodate diverse operational environments, the system supports multiple power input options, including DC power input, rechargeable lithium batteries, and ESP module charging. Field tests have demonstrated the system's accuracy and reliability across various environmental conditions. By integrating IoT technology with real-time data analytics and intuitive interfaces, this system represents a significant advancement over traditional discharge measurement methods, addressing common challenges in irrigation management and promoting the sustainable use of water resources.**

Keywords: IoT, Discharge, Irrigation Canal, ESP32, Flow Tracker

I. INTRODUCTION

Water is vital for agriculture, particularly in areas dependent on surface irrigation. Traditional methods for measuring canal discharge—such as staff gauges and weirs—are manual, labor-intensive, and often lack real-time capabilities. To address these limitations, an IoT-based Real-Time Discharge Monitoring System has been developed.

This system employs an ESP32 microcontroller paired with an ultrasonic sensor to measure water depth. Using Manning's equation and fixed channel parameters, it calculates discharge rates. Data is transmitted to a Firebase cloud platform and visualized through the Flow Tracker mobile app, enabling stakeholders to monitor canal discharge remotely and in real time.

Field deployment in Kerala, India, demonstrated the system's accuracy, aligning well with official discharge data. Designed for scalability, the system supports potential enhancements like solar power integration, GPS mapping, and LoRaWAN connectivity, paving the way for smarter irrigation and digital water management. [10]

II. METHODOLOGY

2.1 Study Area

This study was conducted at two strategic locations in Kerala, India: the drainage canal at the Federal Institute of Science and Technology (FISAT), Angamaly, and the Kalady Main Canal, a key component of the Angamaly irrigation system. The FISAT drainage canal served as a controlled environment for initial testing of the system, including sensor calibration, signal stability, and wireless data transmission. This setting provided stable flow conditions and accessibility, allowing early-stage validation of system functionality. Following prototype validation, the system was deployed in the Kalady Main Canal, which supplies irrigation to surrounding agricultural lands and experiences seasonal variability in flow. The canal's trapezoidal cross-section and open-channel characteristics made it suitable for discharge estimation using Manning's equation. Ultrasonic sensors and ESP32 microcontrollers were installed at representative sections of the canal, and each location was geotagged using Google Earth Pro for reference. These two test sites allowed comprehensive assessment of the system's accuracy,

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scalability, and operational reliability in both experimental and real-world conditions.[7]

2.2 *Hardware Design*

The hardware design of the system is a crucial aspect that ensures accurate data collection, efficient power consumption, and stable performance in diverse environmental conditions. The system integrates several core components, including sensors, a microcontroller, a power supply unit, and protective enclosures. Each component was chosen carefully to maximize durability, precision, and functionality.[1],[3],[6]

2.2.1 Ultrasonic Sensor – JSN-SR04

The JSN-SR04 ultrasonic sensor was selected for its accuracy, reliability, and suitability for non-contact water level measurement. This sensor is widely used in IoT applications due to its straightforward functionality and robust design. The JSN-SR04 operates by emitting ultrasonic sound waves from its trigger pin, which then reflect off the water surface and return to the sensor's echo pin. By calculating the time taken for the reflected wave to return, the system determines the water level with high precision.

Fig.1: JSN-SR04 Ultrasonic Sensor

With a measurement range of 2 cm to 400 cm and an accuracy of ±3 mm, the JSN-SR04 sensor proved ideal for monitoring water levels in irrigation canals. Its non-contact operation eliminates the risk of damage caused by debris or contamination, ensuring longevity in outdoor environments. To enhance its performance, the sensor was mounted at an optimal height above the canal surface to maintain a clear path for sound waves. Calibration adjustments were made to improve accuracy under varying flow conditions, accounting for temperature-induced changes in the speed of sound. Since the sensor was deployed in outdoor conditions, protective measures were implemented to ensure durability. A transparent acrylic cover was installed to shield the sensor from rainfall, splashing water, and debris without interfering with ultrasonic wave transmission. Additionally, a protective mesh filter was added to prevent insects, leaves, or dirt from accumulating around the sensor, which could otherwise distort readings. These protective enhancements significantly improved the sensor's reliability in real-world conditions. The Fig.1 shows ultrasonic sensor JSN-SR04.[5],[7],[10]

2.2.2 Microcontroller

The ESP32 microcontroller was chosen as the core processing unit due to its powerful dual core processor, integrated Wi-Fi connectivity, and low power consumption. The ESP32 efficiently handles data acquisition, signal processing, and wireless transmission, making it ideal for real-time monitoring applications. The ESP32 was programmed using the Arduino IDE, incorporating specialized libraries for sensor data management, cloud integration, and power optimization. Custom code was developed to read data from the JSN-SR04 sensor, process the values, and calculate discharge rates based on the measured water levels. The ESP32's integrated Wi-Fi module ensured seamless data transmission to the Firebase cloud platform, enabling remote monitoring via the mobile application. To improve system efficiency, the ESP32 was configured with power-saving features such as deep sleep mode. During periods of stable water flow, the microcontroller automatically enters a low-power state to conserve battery life. The system was also equipped with interrupt-based triggers that instantly wake the ESP32 whenever significant changes in water levels are detected. This dynamic approach balances energy efficiency with responsive data reporting. The Fig. 2 shows microcontroller ESP-32.[1],[4],[8],[9]

Fig. 2: ESP-32

The ESP32 was securely housed in a protective enclosure to safeguard it from dust, moisture, and environmental wear. The enclosure was fitted with ventilation slots to prevent overheating and ensure stable performance during extended operation. With its powerful features and efficient programming, the ESP32 played a pivotal role in achieving real-time data collection and enhancing system reliability. The ESP32 serves as the central processing unit, handling sensor data acquisition, processing, and wireless transmission to the cloud. It features built-in Wi-Fi connectivity, enabling real-time data transmission to Firebase. The JSN-SR04 ultrasonic sensor is connected to the ESP32's GPIO pins, allowing direct communication between the microcontroller and the sensor. The trigger and echo pins of the JSN-SR04 are assigned to dedicated ESP32 GPIO pins optimized for timing-sensitive signals. This configuration ensures precise water level measurements by accurately computing the time delay between transmitted and received ultrasonic waves. .[1],[4],[8],[9] 2.2.3 Capacitors(63V)

A capacitor is an electronic component that temporarily stores and releases electrical energy. It consists of two conductive plates separated by an insulating material (dielectric). When a voltage is applied, it accumulates charge on its plates, which can later be discharged when needed. Capacitors are widely used in electronic circuits for various purposes, such as filtering noise, stabilizing voltage, smoothing power supply fluctuations, and enabling signal.

Fig. 3: Capacitor

coupling and decoupling. In the IoT-based irrigation monitoring system, capacitors play a crucial role in maintaining stable operation. One of their primary functions is voltage stabilization. The 5V regulator in the circuit converts the 7.4V battery output to a steady 5V supply required for the ESP32 microcontroller and ultrasonic sensor. However, voltage fluctuations can occur due to sudden load changes or power spikes. Capacitors connected to the regulator help smooth these fluctuations, ensuring a consistent voltage supply and preventing potential malfunctions. Additionally, in the level shifter module, capacitors help maintain signal integrity during voltage conversion. The ESP32 operates at 3.3V logic, while the ultrasonic sensor and other components may require 5V logic. The level shifter ensures proper communication by adjusting voltage levels between components. Capacitors assist in stabilizing these transitions and filtering out high-frequency noise, preventing erratic behavior in sensor readings. Furthermore, capacitors improve the reliability of the system by reducing electrical noise that could interfere with sensor accuracy and microcontroller performance. This ensures that real-time discharge measurements remain accurate and consistent, supporting effective irrigation management. The Fig. 3 shows the capacitor. [1],[3],[8]

2.2.4 Level Shifters

Since the ESP32 operates at a 3.3V logic level, and the JSN-SR04 sensors require a 5V logic signal for optimal performance, bidirectional level shifters are incorporated into the circuit. These level shifters ensure proper voltage conversion between the ESP32 and the sensors, preventing damage and ensuring stable communication. The Fig. 4 shows level shifters. [4],[8]

Fig.4: Level Shifter

2.2.5 Power Supply System

To ensure continuous and reliable operation in remote locations, the system was designed with an efficient power management system. A 3.3V lithium-ion battery was selected as the primary power source due to its compact size, stable voltage output, and long operational lifespan. Lithium-ion batteries are well-suited for outdoor monitoring systems as they provide consistent energy delivery with minimal maintenance. Since the ESP32 microcontroller and JSN-SR04 sensor require a stable 5V power supply, a step-up voltage regulator was integrated into the system. This regulator efficiently boosts the 3.3V battery output to a steady 5V, ensuring that all components receive the required voltage for smooth operation. The regulator also includes overcurrent protection, preventing sudden power surges from damaging the system.

Fig.5: Lithium Battery

A charging module (B-type) is incorporated to allow convenient battery recharging. This module facilitates charging through a USB Type-B cable, ensuring safe and controlled power input. To enhance flexibility, the system includes a DC cable attachment, allowing an external DC adapter to be connected for power supply. Additionally, the USB Type-B input enables power delivery through standard USB connections, making the system adaptable for various power sources based on availability. The Fig. 5 shows lithium battery. [1],[3],[4],[8],[9]

2.2.6 Charging Module

The J5019 charging module is an essential component in the power management system, ensuring safe and efficient charging of the 3.3V lithium-ion battery used in the system. It is designed to regulate the charging process, preventing overcharging and ensuring battery longevity. This module is particularly useful in IoT-based applications where continuous power supply is crucial for reliable operation. The J5019 module is compatible with USB Type-B connections, allowing easy recharging via a standard USB cable or an external DC adapter. It features built-in overcharge, overcurrent, and short-circuit protection, ensuring safe and stable power input. The module efficiently manages the conversion of incoming power to match the charging requirements of the lithium-ion battery, ensuring optimal charging performance.

Fig. 6: Charging Module

When integrated into the system, the J5019 module works alongside the step-up voltage regulator, which boosts the battery's 3.3V output to a stable 5V required by the ESP32 microcontroller and other circuit components. This allows the system to function seamlessly while the battery is charging or running on stored power. The DC cable attachment provides an additional option for powering the system directly from an external power source, making it versatile and suitable for deployment in remote monitoring applications. The figure 6 shows charging module.[3],[8]

2.2.7 Circuit Design and Integration

The system's circuit was carefully designed to ensure seamless communication between hardware components, minimize power loss, and improve data accuracy. The circuit consists of an ESP32 microcontroller, JSN-SR04 ultrasonic sensors, bidirectional level shifters, a rechargeable battery, and a 5V voltage regulator. Integration of Hardware Components The integration of the ESP32 microcontroller, ultrasonic sensors, level shifters, power supply, and cloud connectivity ensures seamless operation of the IoT-based real-time discharge monitoring system. The ESP32 serves as the central hub, collecting water level data from multiple JSN-SR04 ultrasonic sensors. Since the ESP32 operates at 3.3V logic while the ultrasonic sensors require 5V signals, bidirectional level shifters are employed to facilitate accurate communication between the components.

A rechargeable battery supplies power to the system, with a 5V voltage regulator ensuring stable voltage levels for both the microcontroller and sensors. The ESP32 processes real-time water depth measurements and calculates discharge values before wirelessly transmitting the data to Firebase cloud storage. This enables remote access via mobile or web applications, allowing irrigation authorities and farmers to monitor water levels efficiently. The entire circuit is enclosed in a durable, waterproof casing to protect against dust, moisture, and environmental fluctuations.

The modular circuit design allows for easy scalability, making it adaptable for future enhancements, such as additional sensors or alternative power sources. This integration of hardware and software components ensures a highly reliable, automated, and scalable solution for real-time irrigation canal monitoring. [1],[3],[4],[5],[8]

2.2.8 Enclosure and Environmental Protection

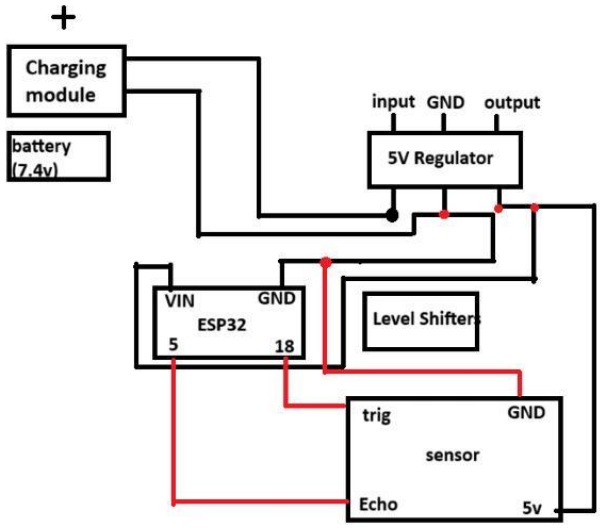


Fig. 7: Circuit Diagram

Since the system was designed for outdoor use, protecting the hardware from environmental elements was crucial. The ESP32 microcontroller, battery, and voltage regulator were housed in a durable, weather-resistant enclosure. This enclosure was made from high-impact plastic, designed to withstand rain, dust, and extreme temperatures. To prevent overheating, the enclosure was equipped with ventilation slots that allowed sufficient airflow while maintaining a protective barrier against moisture. The JSN-SR04 ultrasonic sensor was installed in a separate protective casing fitted with a transparent acrylic shield. This shield enabled uninterrupted ultrasonic wave transmission while providing physical protection from debris and splashing water. During installation, the enclosure was mounted on a raised platform to minimize the risk of water exposure during flooding or heavy rainfall. The protective measures taken ensured that the system maintained stable performance even in challenging environmental conditions. The Fig. 7 shows the whole circuit diagram.[5],[6],[7]

2.3 *Software Design*

The software architecture of the system is responsible for sensor data acquisition, data processing, cloud storage, and mobile-based visualization. It ensures seamless integration between the hardware components, cloud-based platforms, and user interface, allowing for real-time monitoring and efficient data management. The system is developed using embedded programming, cloud database integration, and mobile application development to ensure that water depth and discharge data are collected, processed, stored, and visualized effectively. The ESP32 microcontroller serves as the core processing unit, running a custom program developed in the Arduino IDE.[1],[3],[4],[8]

2.3.1 Sensor Data Acquisition and Processing

The ESP32 microcontroller is programmed to acquire water level readings from the JSN-SR04 ultrasonic sensor, filter out noise, compute discharge values, and transmit data to Firebase cloud storage.
The data acquisition process follows these steps:

1. The ESP32 triggers the JSN-SR04 ultrasonic sensor to emit an ultrasonic pulse toward the water surface.
2. The pulse reflects off the water surface and returns to the sensor.
3. The time delay between emission and reception is recorded.

The ESP32 calculates the water depth using:

d = H – Measured distance

where:
d = Water depth (m)
H = Fixed sensor mounting height above the canal bed (m)
Measured Distance = Distance recorded by the ultrasonic sensor (m)

A moving average filter is applied to smooth out variations caused by ripples, floating debris, and wind disturbances. Once the water depth is determined, the ESP32 processes this data and prepares it for further calculations, cloud transmission, and mobile application visualization. [5],[7],[10]

2.3.2 Discharge Calculation Using Manning's Equation

The ESP32 microcontroller is key to real-time discharge computation by continuously analyzing water depth data from IoT sensors. Using Manning's equation, it calculates flow rate based on channel shape, slope, roughness, and water depth without manual input. The ESP32 dynamically updates discharge values as water levels change, providing accurate data for efficient water management. It also wirelessly transmits this information to cloud storage, enabling remote monitoring and informed decision-making.

Manning's equation for trapezoidal canal discharge:

Where:

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \qquad \text{------------------------ (i)}$$

- Q = Discharge (m³/s)
- n = Manning's roughness coefficient
- A = Cross-sectional flow area (m²)
- R = Hydraulic radius (m) = A/P
- P = Wetted perimeter (m)
- S = Channel slope (m/m)

Area (A) = Flow depth × (Bottom width + Side slope × Flow depth)

Wetted perimeter (P) = Bottom width + 2 × Flow depth × Square root of (1 + Side slope squared).[2],[7],[10]

2.3.3 Data Transmission to Firebase Cloud

Once the water depth and discharge calculations are completed, the ESP32 transmits the processed data wirelessly to Firebase, a real-time cloud database. Firebase was chosen for its:
Scalability – Supports large-scale data storage, ensuring future expand-ability.
Real-time updates – Provides instant access to the latest discharge readings.
Low latency – Ensures fast and efficient data retrieval for real-time monitoring.
The water depth, discharge values, and timestamps are structured into JSON format and stored in Firebase, allowing remote access via the FlowTracker mobile application. [1],[3],[8]

2.4 *Integration of GPS Mapping in Irrigation Monitoring*

The integration of GPS mapping into the irrigation monitoring system provides a spatially referenced approach to tracking water distribution and analyzing water flow variations across different sections of the canal network. By utilizing Google Earth Pro, the system enables precise geo tagging of sensor locations, allowing users to visualize discharge variations and structural changes in irrigation canals. GPS mapping plays a critical role in water resource management, aiding in decision-making, infrastructure planning, and efficient water allocation. The system incorporates GPS data into the Flow Tracker monitoring framework, where each sensor location is assigned latitude and longitude coordinates. These coordinates are used to create an interactive digital map of the irrigation network, improving visualization and accessibility of discharge data. Implementation of GPS Mapping. The GPS mapping process begins with recording latitude and longitude coordinates at each major in the irrigation canal network. These data are then imported into Google Earth Pro, where the irrigation network is digitally represented. The system employs color-coded line styles to differentiate between the main canal and its branches, ensuring clear and structured visualization.[1],[2],[6]

III. RESULT AND DISCUSSION

3.1 *System Implementation and Functional Overview*

The IoT-based real-time discharge monitoring system was successfully designed and implemented for the Chalakudy River Canal to overcome the limitations of manual methods like float gauges and staff readings. The system includes a JSN-SR04 ultrasonic sensor for measuring water surface distance, an ESP32 microcontroller for processing and discharge calculation using Manning's equation, Firebase for cloud data storage, and a custom Android app, FlowTracker, for real-time visualization.

Powered by a rechargeable lithium-ion battery, the system operates off-grid and is housed in a 3D-printed protective casing. It was mounted on a concrete slab to ensure a clear sensor view. Canal cross-sectional geometry and slope were measured during setup and programmed into the microcontroller for accurate discharge computation.

3.2 *Calibration and Depth Measurement Accuracy*

Calibration is essential to ensure accurate water level measurements, which directly influence the reliability of discharge calculations. The process included measuring the vertical distance from the sensor to the canal bed and programming it into the microcontroller, validating sensor readings with manual staff gauge measurements at various depths, and ensuring the sensor was mounted perpendicular to the water surface to avoid angular errors. To reduce fluctuations from ripples or debris, averaging algorithms were applied in the microcontroller. This procedure was carried out during installation and repeated in testing, achieving a depth measurement accuracy of ±3 mm—suitable for precise open channel flow monitoring.

3.3 *Channel Slope Data*

The slope of the canal (S) directly affects flow velocity, making it a crucial parameter for discharge calculation. A steep slope increases water velocity, while a flatter slope slows down the flow. The slope of the canal is determined using elevation measurements taken at different s along the canal path.
The slope is calculated using the equation:

$S = \Delta hL$
where:
S = Channel slope (m/m)
Δh = Elevation difference between two s along the canal (m)
L = Horizontal distance between the two s (m)

To ensure accuracy, multiple elevation readings were taken at different locations along the canal. The average slope value was used in Manning's equation to ensure consistent and precise discharge calculations.

3.5 *Manning's Roughness Coefficient (n)*

The Manning's roughness coefficient (n) accounts for flow resistance caused by the canal's surface material. Different canal types—lined, unlined, or vegetated—have varying frictional effects on water flow, influencing discharge rates. During field inspections, the canal conditions were analyzed, and the appropriate n-value was assigned based on standard hydraulic reference values:

Concrete-lined canals: $n = 0.012 - 0.018$
Gravel or rocky bed canals: $n = 0.025 - 0.035$
Vegetated or earthen canals: $n = 0.030 - 0.045$

Since canal conditions may change over time due to sediment deposition, erosion, or vegetation growth, the system allows for manual adjustments to enduring calibration to improve accuracy in discharge estimations.

The water level d is only found using the device the all other data is given from theb irrigation department all the data are fixed which is calculated during the construction period.[1],[2],[7],[10]

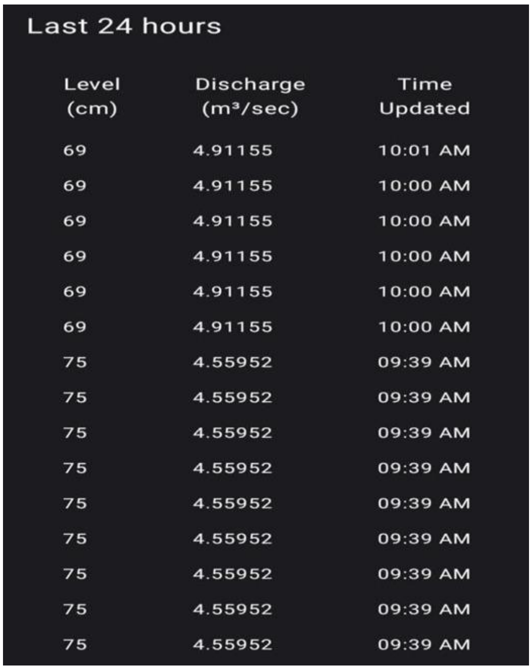
Table 1: the comparison discharge data given by irrigation department and discharge data found by the system.

SI. No	Location	Avg Discharge [App]	Avg Discharge [Given]
1	Kalady Main Canal	2.52	5.33
2	South Bhootamkutty	0.35	0.35
3	Manjapra Branch	3.73	3.6
	i)Annapara Branch	0.155	0.182
	ii)Manjapra Distributary	0.188	0.182
	iii) Naduvattom	0.27	0.3
4	Komarappadam Branch	0.43	0.5
5	Mundopilly Branch	discontinued	Discontinued
6	Vengoor Branch	0.594	0.68
7	Thottakam Branch	0.192	0.215
8	Axhakam Branch	0.195	0.198
9	Kalady Branch	0.281	0.297
10	Karukuttikara Branch	0.375	0.405

3.6 FlowTracker Mobile Application Performance

The FlowTracker Android application, developed using Andriod studio it is the official integrated development environment (IDE) for Android app development, offering tools for coding, debugging, and testing applications. It provides features like a flexible Gradle-based build system, a rich layout editor, and an emulator for app testing., allowed users to access real-time and historical data seamlessly.
The app's features included:
1.Real-time display of discharge and water depth values pulled from Firebase.
2. Time stamped records for each reading, aiding in water usage analysis.
3. Simple and lightweight UI, allowing even non-technical users to navigate it easily.
4. A history button to view past flow values and time stamps in tabular format.

While it did not feature automated alerts or control capabilities, it served effectively as a visual and decisionsupport tool for farmers, canal authorities, and researchers alike. The FlowTracker app greatly enhanced the practical usability of the system by reducing the dependency on laptops or field personnel for data logging and enabled off-site access to canal conditions in real-time. The figure 8 shows the history of 24 hrs water level, time and discharge data and figure 9 shows the Interface of the application showing discharge, time and water level.[4],[8]



Last 24 hours

Level (cm)	Discharge (m^3/sec)	Time Updated
69	4.91155	10:01 AM
69	4.91155	10:00 AM
69	4.91155	10:00 AM
69	4.91155	10:00 AM
69	4.91155	10:00 AM
69	4.91155	10:00 AM
75	4.55952	09:39 AM
75	4.55952	09:39 AM
75	4.55952	09:39 AM
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Fig. 8: History of 24 hrs Discharge data

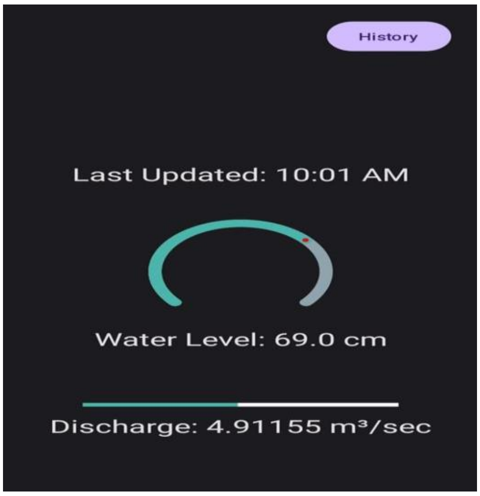

Fig. 9: Interface of the application showing discharge, time and water level

3.7 GPS Mapping Visualization

Fig. 10 illustrates the GPS mapping implementation of the irrigation canal network using Google Earth Pro. The GPS mapping conducted provides a representation of the water distribution system, covering key areas such as and their extended networks. This mapping effort ensures precise tracking of water movement and allows for a deeper understanding of connectivity between primary and secondary canal systems, aiding in efficient resource management. The integration of GPS technology allows for accurate geospatial referencing of key locations, ensuring systematic documentation of latitude and longitude coordinates. The map provides a visual representation of the water distribution system, with clearly marked main canal routes, sub-branches, and sensor locations. This visualization helps assess flow patterns, identify potential bottlenecks, and plan efficient water allocation strategies.[1],[6]

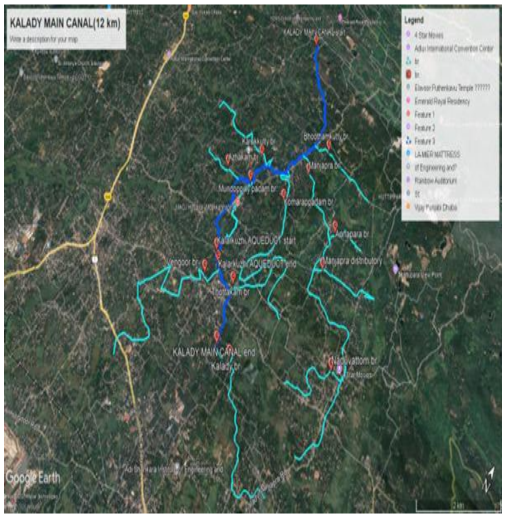

Fig. 10: Kalady Main Canal Mapping

IV. Conclusion

The development of an IoT-based real-time discharge measurement and monitoring system represents a significant advancement in irrigation water management. By integrating sensor technology, wireless communication, cloud storage, and GPS mapping, the system provides continuous, accurate, and remote monitoring of water levels and discharge. This approach eliminates the inefficiencies of traditional manual methods, enabling automated data collection, real-time analysis, and improved decision-making. The successful validation of the system in the FISAT drainage canal demonstrated its accuracy, reliability, and adaptability to real-world conditions. The use of Manning's equation for discharge computation, combined with sensor-based data acquisition, ensures precise flow measurement across varying canal conditions. Additionally, the FlowTracker mobile application enhances accessibility by offering a user-friendly interface for real-time visualization and historical data analysis. The incorporation of GPS mapping using Google Earth Pro adds spatial intelligence to the system, allowing for geotagging of monitoring points and improved water distribution planning. This capability supports proactive infrastructure maintenance and optimized irrigation scheduling, ensuring sustainable water resource utilization. Moving forward, the system can be further enhanced through AI-driven predictive analytics, expanded sensor deployment, and solar-powered operation. These advancements will improve scalability, efficiency, and sustainability, making the system a valuable tool for precision irrigation and climate-resilient agriculture. This project highlights the transformative potential of IoT in water management, providing a scalable and cost-effective solution to address challenges in irrigation efficiency, water conservation, and agricultural productivity. [1],[3],[5],[7],[8],[10]

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