IoT-enabled Real-Time Water Level Monitoring System for Early Flash Flood Detection

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Abstract

Flash flood is a significant natural hazard in Cambodia, causing severe damage to infrastructure and posing a substantial risk to human life. Its sudden and unpredictable occurrence, intensified by climate change, underscores the need for reliable real-time monitoring and early warning systems. This paper presents an Internet of Things (IoT)-based solution that employs multiple sensors to capture critical environmental data, including water level, rainfall, and water flow. The system is designed with an emphasis on accuracy, durability for outdoor conditions, and cost-effectiveness, making it suitable for deployment in vulnerable communities. Sensor data are transmitted to a cloud platform for storage and analysis, while a real-time notification mechanism delivers early alerts to users, enabling them to respond promptly to potential flood events. The proposed prototype provides a practical and affordable approach to enhancing community preparedness, awareness, and disaster risk reduction in flood-prone regions.
Keywords: *Flash flood, IoT, early warning*

1 Introduction

Flooding remains one of Cambodia's most destructive natural hazards, affecting urban and rural populations during the rainy season. The 2022 floods affected 14 provinces, demonstrating the country's vulnerability to sudden flood events [1]. Urban areas are particularly prone to street-level flooding when intense rainfall overwhelms drainage systems, while rural and riverine regions can experience rapid river surges that threaten communities near tributaries such as the Stoeng Prek Thnaot Basin [2], [3]. In Phnom Penh city, intense rainfall, specifically flash flood, often overwhelms drainage infrastructure and causes street-level inundation, disrupting transportation and damaging property [1]. Figure 1 shows urban flash flooding in Phnom Penh that illustrates the rapid onset and local impacts of such events.

Figure 1: Street-level flash flooding in Phnom Penh, Cambodia [4].

Additionally, riverine and basin-scale flooding are also recurrent problems, especially in tributaries such as the Stoeng Prek Thnaot Basin. Hydrological studies of the Prek Thnaot basin highlight changing water-balance regimes and increased extremes under climate-change scenarios, underscoring the need for localized monitoring and early warning [3], [7]. Existing flood monitoring solutions in Cambodia and neighbouring countries rely primarily on manual water-level measurements or basic sensor networks [2], [5]. Although these approaches provide some awareness, they often lack real-time monitoring, predictive capabilities, and cost-effectiveness, which limits their usefulness for widespread deployment. To address these gaps, this paper proposes an integrated, real-time flash flood monitoring system based on Internet of Things (IoT) technology. The system collects key environmental data such as water level, rainfall, and water flow and delivers real-time alerts through a cloud-based notification mechanism.

The objective of this study is to develop a practical, durable, and cost-effective IoT system suitable for communities in flood-prone areas, with a pilot implementation focused on the Stoeng Prek Thnaot Basin. The development prototypes compose of Node MCUs and various sensors to keep track on the current water level. The system will provide alert notifications via mobile app when serious flooding is happening from the real-time IoT system.

2 Methodology

Prototype systems utilize ESP32 Node MCU, sensors, and cloud platforms to enable near-real-time data acquisition and notification [2], [8], [9]. Reviews of digital innovations for flash-flood early warning observe two clear trends including, increased adoption of cloud-backed IoT sensor networks for situational awareness, and expanding use of AI/ML for prediction [6], [10]. These studies suggest that a pragmatic approach is to pair robust, low-cost sensing with cloud messaging and simple local alerts, reserving predictive analytics for later enhancement. Despite progress, important gaps remain for practical deployment in Cambodia, specifically many prototypes are validated only under controlled conditions rather than diverse field settings and the assumption of good internet connectivity. This consideration reduces reliability in areas with intermittent service, and the issues of cost and long-term durability are not always fully addressed [2], [5].

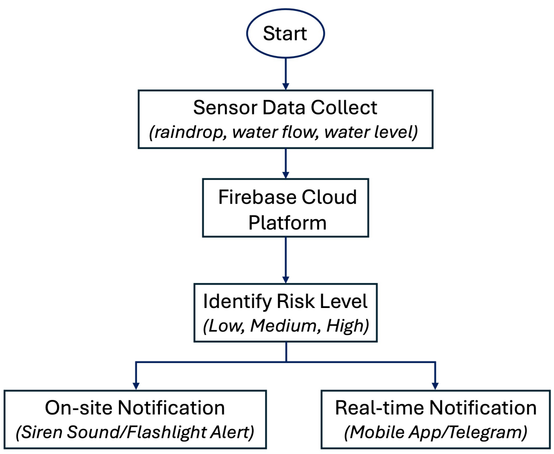

Figure 2: A flow diagram of the system operational process.

The proposed flood monitoring system is designed to provide real-time and reliable alerts for flood-prone areas by combining on-site data collection, wireless transmission, cloud integration, and two-way notification methods. Figure 2 shows the operational design of our system to handle detection and notification tasks. The transmitter node integrates three main sensors including raindrop sensor, water flow sensor, and an ESP32-CAM for capturing water level images. The receiver node serves as a gateway to relay the sensing data to be stored and processed with Firebase Cloud Messaging to enable near real-time notification via mobile or web applications. Simultaneously, the receiver triggers offline alerts, such as buzzers or flashing lights, to ensure immediate warnings even without internet access. This dual-alert mechanism guarantees timely and reliable flood notifications to users under all conditions.

3 Design and Implementation

The system is designed to provide real-time monitoring of flood-prone areas and deliver early alerts to users. It consists of two main units a transmitter and a receiver shown in Figure 3. The transmitter collects environmental data using sensors, while the receiver processes the data, stores it in the cloud, and triggers alerts. Wireless communication between the units is handled via the ESP-NOW protocol, and Firebase is used for cloud-based monitoring and online notifications. The core components of the proposed system include the ESP32 microcontroller, which serves as the central controller for data acquisition and wireless communication, and an ESP32-CAM module for capturing water-level images. Environmental sensing is carried out using a raindrop sensor to detect rainfall and a water flow sensor to measure stream or drainage velocity. The receiver unit integrates with Firebase for cloud storage and notification services, while local alert devices such as buzzers or flashing lights ensure immediate offline warnings. A rechargeable battery or solar power source sustains continuous outdoor operation, making the system suitable for deployment in remote or flood-prone areas.

To demonstrate the cost-effectiveness of the proposed prototype, Table 1 summarizes the component-level cost breakdown in USD. The total cost of the system is approximately \$33, which is significantly lower than previously reported IoT-based flood monitoring systems costing \$100–\$150 per unit [2; 8]. This cost-efficient design supports the claim that the proposed system is low-cost and practical for community-

Table 1: Cost breakdown of the proposed IoT flood monitoring prototype (USD).

Component	Quantity	Unit Cost (USD)	Total Cost (USD)
ESP32 NodeMCU	1	5	5
ESP32-CAM	1	10	10
Raindrop Sensor	1	2	2
Water Flow Sensor	1	5	5
Battery / Power	1	8	8
Enclosure / Box	1	3	3
Total			**33**

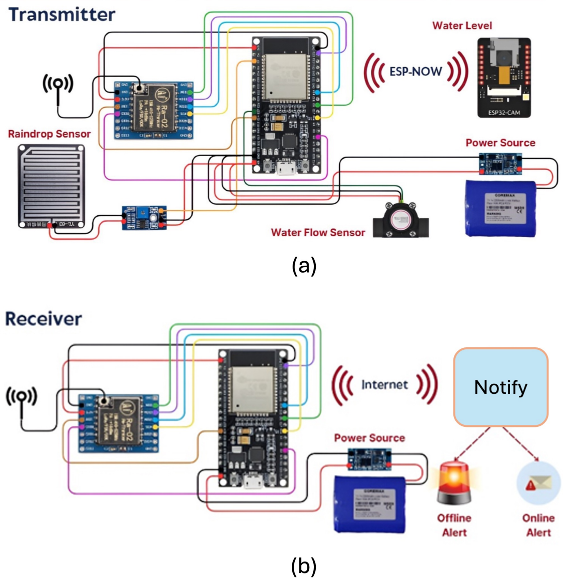

Figure 3: Design schematic: (a) Transmitter node, (b) Receiver node.

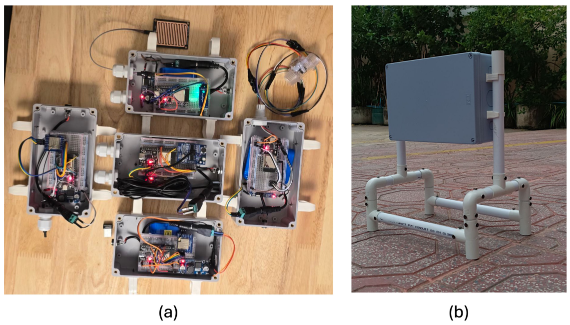

Figure 4: Prototype development: (a) sensor node boxes, (b) complete prototype.

level deployment.

The system continuously monitors environmental conditions at flood-prone locations. The receiving sensor data will be transferred to the Firebase cloud database through an internet connection, enabling real-time remote monitoring. From this data, we can analyze the risk levels and generate appropriate online notifications via Firebase Cloud Messaging on mobile or web applications. Simultaneously, the receiver triggers offline alerts, such as buzzers or flashing lights, to provide immediate warnings even without internet connectivity. This dual-alert mechanism ensures timely and reliable flood notifications under diverse operating conditions. Figure 4 shows the complete design of the prototype enclosed in a plastic box for outdoor deployment purposes.

4 Results and Discussion

The prototype was developed and tested to confirm that all core sensors were functioning correctly. Test scenarios simulated heavy rainfall, rising water levels, and varying flow rates in local drainage channels. In all cases, the system generated accurate and timely alerts, demonstrating its effectiveness for real-time monitoring and early warning in both urban and rural areas. The results confirm that the system provides real-time situation awareness and reliable early flood warnings.

Figure 5 presents the web-based dashboard interface designed for real-time monitoring of environmental data from the sensor nodes. The dashboard provides a centralized platform where water level, rainfall, and flow rate measurements are visualized through graphical charts and numerical indicators. This visualization facilitates user-friendly access to critical information, enabling stakeholders to track flood conditions remotely and respond effectively. Furthermore, the dashboard integrates alert notifications, thereby enhancing situational awareness and supporting timely decision-making in flood-prone areas.

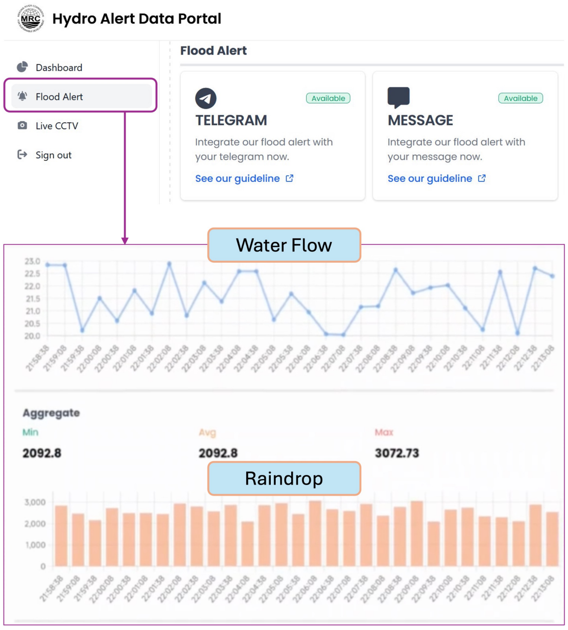

Figure 5: Web dashboard illustrating the feature and visualization of data monitoring for sensor node.

5 Conclusion

This study presented an IoT-based flash flood monitoring and early warning system that integrates an ESP32 microcontroller, ESP32-CAM, rainfall sensor, a water flow sensor, and cloud services through Firebase. The prototype demonstrated reliable data acquisition, real-time transmission, and a dual-alert mechanism that ensures both online and offline notifications, making it suitable for deployment in flood-prone areas. Its low cost, durability, and continuous operation capability highlight its potential as a practical solution for community-level disaster preparedness.

6 Future Works

Future improvements include integrating predictive algorithms for enhanced forecasting, and optimizing power consumption to extend deployment duration and improve sustainability for outdoor operation. The enhancement of the system through predictive analytics and broader system integration. Specifically, artificial intelligence (AI) and machine learning (ML) techniques will be incorporated to enable forecasting capabilities, moving beyond the current threshold-based detection approach. By leveraging historical hydrological records alongside real-time sensor inputs, the system can generate more accurate flood predictions and provide earlier warnings. These advancements will improve system resilience and strengthen its role as a comprehensive solution for flood risk reduction.

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