

A Comprehensive Review of IoT-Based Flood Monitoring and Early Warning Systems

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Abstract - Flooding is one of the most devastating natural calamities in the world. It causes huge loss to infrastructure, agriculture, and lives. With the advent of Internet of Things (IoT) technology, many flood monitoring systems have been proposed to minimize the loss due to flood. This review paper discusses the recent research articles on flood monitoring systems based on IoT technology. The review of the articles will include the various techniques used in the flood monitoring system. These technologies enhance real-time monitoring accuracy and system responsiveness. However challenges remain in system integration, power-reliability and real-world deployment.

Index Terms - Flood monitoring, Internet of Things (IoT), early warning systems, ESP32, LoRaWAN, predictive analytics

I. INTRODUCTION

Flooding is one of the most frequent and destructive natural disasters, particularly in developing countries such as the Philippines, where heavy rainfall, typhoons, and inadequate drainage systems contribute to recurring flood events. These disasters result in significant damage to infrastructure, agriculture, and human life. Despite the presence of conventional flood monitoring methods such as manual observation and delayed warning systems, these approaches are largely reactive and provide limited support for early disaster preparedness.

The development of IoT technology has resulted in an increased level of automation and real-time data acquisition using sensors, microcontrollers, and wireless communication systems. Most of the existing systems use ESP devices, ultrasonic sensors, and cloud computing technologies to detect the levels of water and raise alerts. Nevertheless, the major drawback of most of the systems is their limited ability to predict changes based on past records.

There is also an apparent lack in the field of research on IoT flood monitoring systems. This is seen through the absence of proper incorporation between real-time monitoring and prediction techniques, difficulties in ensuring reliable

communication in extreme weather conditions, inadequate energy sustainability of the technology in emergencies, and overall system evaluation in actual situations. There is a need to address the whole process as opposed to only particular parts of it.

To address these issues, the current study intends to design an Intelligent IoT-Based Flood Monitoring and Early Warning System which includes aspects such as real-time sensing, visualization, and predictive analysis of water levels in the environment. Specifically, the study is intended to:

1. Detect real-time water level using IoT and microcontrollers
2. Visualize the real-time data using cloud technology
3. Predict flooding events using predictive analytics for short term forecasts
4. Develop an automated alarm system for issuing alerts

The scope of this research study will encompass the designing and testing of an intelligent system utilizing ESP32 hardware, ultrasonic sensor technology, and cloud technology in order to detect and predict flooding.

II. REVIEW OF RELATED STUDIES

2.1 Real-Time IoT Flood Monitoring Systems

The current research work on IoT-based flood monitoring systems mainly centers around real-time data collection techniques through the use of ESP-based microcontrollers and ultrasonic sensors. For example, systems using ESP32 and NodeMCU have shown significant potential in offering affordable and easily deployable flood monitoring solutions within communities. The systems prove to be highly responsive and easily implementable owing to their Wi-Fi network connectivity capabilities.

But, although efficient, these technologies rely mainly on threshold detection that makes them responsive instead of

predictive. Also, because they depend on the use of Wi-Fi networks, they are less reliable when dealing with extreme weather conditions. As compared to more sophisticated technologies, these have fewer chances of success when used at large areas.

2.2 Long-Range Communication Systems

In order to solve some of the problems related to communication, researches have been conducted on utilizing LoRaWAN to monitor floods. LoRaWAN communication systems offer features such as long range and low energy consumption, making them appropriate for large scale deployment.

When comparing LoRaWAN and Wi-Fi based systems, the former is proven to be more reliable and capable of wider coverage; however, they also tend to be more complicated and expensive because of the gateways that need to be installed. Also, while improving communication, most of the research involving LoRaWAN does not include predictive analysis.

2.3 Predictive Flood Monitoring Systems

Predictive analytics involving the use of time series forecasting, neuro-fuzzy techniques, and genetic algorithms have been suggested in recent research to enhance the capability for early warnings. Predictions can be made regarding floods, and thus effective action can be taken against disasters.

Predictive analysis enhances the capability for early warnings to a great extent when compared to real-time systems. Nevertheless, the use of artificial intelligence involves extensive computation and large amounts of data, which cannot be afforded by low-cost IoT solutions. Time series prediction models, although accurate and efficient in their performance, are relatively simpler than other models.

2.4 Integrated and Decision Support Systems

There have been attempts made to integrate the IoT systems with decision-support systems and multivariate monitoring systems, including temperature and humidity monitors. These would give a better picture of the environmental status and facilitate decision making for disaster mitigation.

Although integrated systems improve situational awareness, the current implementation is limited and only includes individual aspects and does not integrate the entire system together. The alerting systems like telegram alerts make it easier to communicate but do not help resolve any underlying issues, including predicting accuracy and system dependability.

2.5 Comparative Analysis of Existing Systems

IoT-based flood monitoring systems may be classified under four main categories as per the literature

discussed above: real-time monitoring systems, long-range communication systems, predictive systems, and integrated decision support systems.

Real-time monitoring systems with ESP microcontroller-based devices and ultrasonic sensors are efficient, cheap, and quick flood detectors which can be used in communities. These flood detectors however do not have advanced capability for prediction since they operate on an alarm mechanism [1][2].

Long-range communication systems with LoRaWAN provide more communication capacity and are energy-efficient compared to other types. This allows such systems to be used widely despite the complexities they may bring about. They are also used for monitoring purposes only and lack analytical capabilities [3].

Flood monitoring prediction systems improve predictive warning through the use of time series prediction analysis and AI methods. Predictive flood monitoring systems allow one to respond proactively by predicting future flood trends. However, they have high computational demands and the need for large data sets, which is a drawback for IoT implementations with limited computing resources [4][5].

Intelligent systems, which involve sensing, communication, and decision-making components, facilitate more accurate response. But many of these solutions only concentrate on limited integration, with limited verification in actual situations [6][7].

Overall, despite having unique advantages, there is still no complete solution among the presented categories of systems that could fulfill all of the requirements stated above.

III. METHODOLOGY

3.1 Research Design

This paper uses systematic and analytical review as the main research method to investigate the state of art in the field of flood monitoring and forecasting based on the Internet of Things. It concentrates on gathering, analyzing, and comparing articles dedicated to system architecture, sensor technology, communication, prediction, and warning. The review aims to identify strengths, limitations, and research gaps in current systems to support the development of improved and integrated solutions.

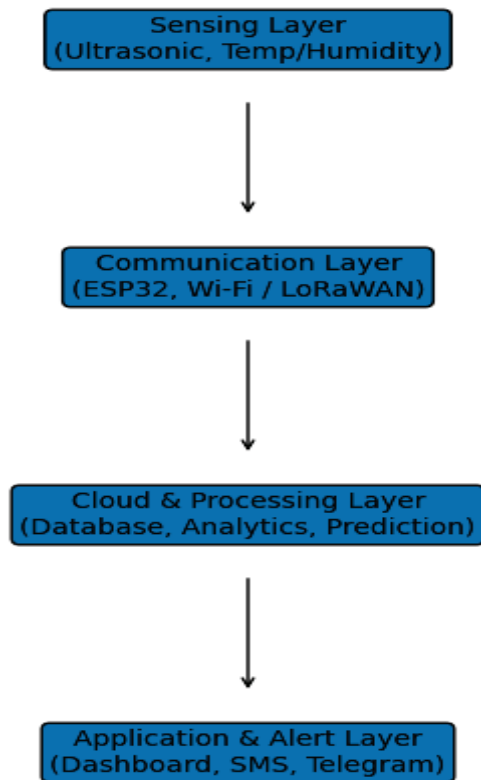
The design approach of the study is based on the systems reviewed in Chapter II of the thesis, which emphasized the ESP-based real-time monitoring systems [1][2], LoRaWAN communication approach [3], predictive forecasting models [4][5], and decision support systems [6]. However, the systems reviewed were implemented separately from each other, which led to the identification of the gaps to be filled by the proposed study.

3.2 System Architecture Overview

The proposed system architecture follows the four-layer IoT architecture model given below:

1. Sensing Layer
2. Communication Layer
3. Cloud and Processing Layer
4. Application and Alert Layer

This architecture matches the IoT-based environmental monitoring system architecture presented by various authors in the literature [1][6].



3.2.1 Sensing Layer

The sensing layer is responsible for acquiring real-time environmental data, particularly water level measurements. This study emphasizes the use of ultrasonic sensors due to their non-contact measurement capability, cost-effectiveness, and widespread use in IoT-based flood monitoring systems.

Ultrasonic sensors are preferred over contact-based sensors because they reduce the risk of corrosion and damage during prolonged exposure to water. Previous studies have demonstrated that ultrasonic sensors integrated with ESP-based microcontrollers provide reliable and accurate water level measurements for flood detection applications [1][2].

Additionally, some studies incorporate pressure sensors to improve measurement accuracy by cross-validating water depth readings, particularly in dynamic flow conditions [3]. The inclusion of temperature and humidity sensors is also supported by multi-parameter monitoring approaches, which enhance situational awareness during flood events [7].

3.2.2 Communication Layer

The communication layer facilitates the transmission of sensor data to cloud-based systems. Wi-Fi communication is commonly used in ESP32-based flood monitoring systems due to its accessibility and ease of implementation [1][2]. However, its reliability is limited during extreme weather conditions when network infrastructure may be compromised.

This limitation can be overcome by adopting LoRaWAN technology as an alternative method of communication because of its ability to transmit signals over long distances and low energy consumption [3]. LoRaWAN technology is more appropriate than Wi-Fi for widespread implementation owing to its larger coverage area but requires more complex system design.

During the process of transmitting data, a light-weighted protocol such as MQTT is more favorable compared to HTTP because it consumes less bandwidth. This is in agreement with previous studies on low latency communications necessary for a real-time flood warning system.

3.2.3 Cloud and Processing Layer

Layer 3 consists of data storage, analysis, and visualization. The cloud and processing platform is employed extensively in IoT because of scalability and availability as well as its capacity to archive historical data for analysis [6].

This layer facilitates the real-time observation of data using dashboards as well as threshold-based detection. The threshold-based detection mechanism classifies water level into various ranges like normal, warning, and critical, depending on which automatic alert notifications are triggered. The threshold-based mechanism is very popular due to its efficiency and ease of application [1].

3.2.4 Predictive Analytics Module

However, predictive analytics is included as one of the components to mitigate the disadvantages of solely relying on the reactivity of the system. Time series analysis is typically adopted by IoT-based flood monitoring systems because it involves the prediction of future conditions based on the historical data [4].

Unlike the use of complex artificial intelligence such as neural networks and genetic algorithms in making predictions, time series analysis offers an optimal combination of both accuracy and computation speed [5]. Thus, it is applicable for the implementation of low-cost IoT flood monitors.

Through predictive analytics, the system is elevated from a reactive approach to being proactive about flood prevention and disaster mitigation measures.

3.3 Alert and Notification Mechanism

Flood warning alerts are generated to keep users aware about any possible flooding hazards. To make sure that all alerts

reach users without interruption, different modes of communication like SMS and Telegram are being used.

As proved by researches conducted on the issue, using multi-channel alerts makes flood warnings more effective in case of emergency [7]. Adding real-time dashboards to the alert system will make the situation clearer for users.

3.4 Power Management Design

Reliability of power is an important aspect for flood monitoring systems, as there is a tendency for blackouts to occur in bad weather conditions. To overcome this problem, solar power systems have gained prominence in IoT-based flood monitoring systems [9].

Solar power systems are more sustainable and reliable compared to conventional power systems. In addition, low power wireless communication systems can be incorporated to improve energy efficiency.

3.5 System Development Procedure

The process of development proposed in this work is inspired by popular approaches applied in currently available flood monitoring systems employing IoT solutions. The procedure itself is constructed based on several scientific works to give an example of a general procedure of system development.

The main stages of the procedure are as follows:

- Hardware Integration – hardware integration process, which involves sensors and microcontrollers, such as is often applied in ESP-based systems [1][2]
- Firmware Configuration – firmware programming related to collecting sensor data and communication protocols
- Cloud Integration – data storage and visualization platforms implementation [6]
- Trend Analysis Approach – time series forecasting models application [4]
- System Evaluation – latency and other performance measures verification [8]

3.6 Performance Evaluation Metrics

The measurement criteria that will be analyzed in this paper are based on the criteria used in flood monitoring systems based on the Internet of Things. As opposed to practical application and testing, this paper will analyze how previous studies evaluate the performance of their systems.

Among the most common performance criteria found in the reviewed literature are accuracy, alerting latency, accuracy of predictions, energy consumption, and system reliability. All these criteria are popular for measuring the effectiveness and operational efficiency of flood monitoring systems [8][9].

Accuracy, for example, is used for measuring the accuracy of water levels detected in relation to some standards, whereas alerting latency refers to the duration of time from the moment when the threshold is detected until the alert is generated. In the case of flood prediction, the

Mean Absolute Error (MAE) criterion can be applied to evaluate the results of predictions.

IV. RESEARCH GAPS

Although there have been great strides in IoT-based flood monitoring systems, there are still some challenges that can be observed from the previous literature review.

One is that most of the current IoT-based flood monitoring systems emphasize real-time monitoring via ESP-based microcontrollers and ultrasonic sensors. Even if they are capable of detecting any change in the water level, these systems are only reactive and cannot provide early flood warnings [1][2].

Second challenge is the problem with communication. Wi-Fi-based systems are popular due to the convenience they provide; however, they are vulnerable to harsh weather conditions. Meanwhile, although LoRaWAN-based systems provide efficient long-distance communication, they are often not equipped with data analytics tools [3].

Third, the use of prediction based on time-series forecasting and AI-based methods has been suggested. Yet, the aforementioned methods tend to be isolated and have not yet been incorporated into low-cost IoT-based platforms effectively [4][5].

Moreover, some systems fail to provide enough power sustainability. For example, they are often dependent on grid power or a simple battery system that can become unavailable in disasters. Some solutions incorporating solar energy have emerged but remain isolated from the current systems [9].

Lastly, most research fails to conduct any comprehensive evaluations or real-world testing. Instead, the majority of them are focused only on prototype testing and laboratory assessments and do not cover long-term aspects like reliability, latency, and precision [8].

This information implies the necessity for an IoT-based system that incorporates all these features.

V. DISCUSSION

The current state of the literature indicates an evolution in the use of Internet of Things (IoT)-based flood detection systems from basic real-time detection to data-driven methods. Initially, simple threshold-based monitoring using ESP-based microcontrollers and ultrasonic sensors was used, offering affordable and easy-to-implement flood detection tools. Yet, the systems are reactive and incapable of predicting impending situations.

In response to problems associated with connectivity, current flood monitoring systems have included LoRaWAN technology, allowing for long-range and power-efficient information transmission. Although it enhances the scalability of the process, it also adds complexity without improving predictive abilities.

Recently, research has emphasized the inclusion of predictive methods in IoT-based flood detection systems,

such as forecasting techniques and artificial intelligence (AI). As such, IoT-enabled flood monitoring systems can predict future scenarios regarding floods. Although the system is more efficient in providing early alerts, it is not always consistent with lower cost IoT applications.

In addition to the incorporation of multi-parameter sensing and decision support systems, this would improve situational awareness, which would lead to a better-informed reaction during the disaster. However, some of the systems that have already been put in place are disjointed, addressing each part of the system without addressing the whole.

From this analysis, there is an indication that while the progress being made is commendable, the systems being utilized currently lack an all-inclusive approach that considers real-time data acquisition, reliable communication, predictions, and sustainability within the system.

VI. CONCLUSION

These IoT flood monitoring systems were discussed, highlighting some of the major developments that have been achieved in areas like real-time data acquisition, communication networks, prediction algorithms, and cloud-based visualizations. These developments have shown promising results, but current solutions are still constrained by issues with implementation, prediction capabilities, communication, and energy management.

It was evident from the findings that a coherent and cohesive IoT flood monitoring solution is needed to improve flood management. Such a solution needs to incorporate real-time sensing, reliable communication networks, prediction capabilities, and sustainable energy consumption. Further studies could look at how these solutions can be validated, and other communication strategies can be introduced.

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