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Design and Development of an Early Warning System for Monitoring Rising Water Levels

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Abstract

Floods rank among the most catastrophic natural disasters, inflicting considerable damage to ecosystems, human lives, and infrastructure. This study centres on the design and implementation of an Internet of Things (IoT)-based early warning system for real-time monitoring of rising water levels. The system incorporates an ESP32 microcontroller and an HC-SR04 ultrasonic sensor to quantify the rate of water level elevation, relaying data through the Blynk IoT platform to deliver real-time notifications. The design features durable hardware, effective programming, and an intuitive interface, guaranteeing dependable performance across diverse conditions, including gradual increases and sudden surges in water rise velocity. Thorough testing confirmed the system's capability to approximately detect and report substantial variations in water rise velocity. Integration with Google Sheets enables effective data recording for trend analysis and decision-making. This cost-effective and scalable system, designed for flood-prone regions, improves disaster preparedness by facilitating prompt responses to swiftly evolving conditions and provides a basis for extensive flood management applications.

1. Introduction

Floods are among the most devastating natural disasters, causing substantial damage to ecosystems, livelihoods, and infrastructure worldwide. In Malaysia, flood-prone regions such as Hulu Langat have experienced significant consequences, with events like the 2021 floods underscoring the need for advanced monitoring systems to rectify deficiencies. The floods inflicted significant damage and exposed the inadequacies of existing early warning systems, especially their failure to react swiftly to abrupt alterations in water conditions [1, 2, 3]. The design and development of early warning systems have markedly progressed owing to technological innovations. Conventional methods, dependent on manual measurements, frequently led to postponed identification of significant alterations in water dynamics. Contemporary systems utilise Internet of Things (IoT) technology to address these challenges. This study centres on the development of an IoT-based system utilising the ESP32 microcontroller and the HC-SR04 ultrasonic sensor, intended for the precise and efficient real-time monitoring of water level rise.

The system utilises IoT technologies, including the Blynk platform, to facilitate real-time notifications and remote monitoring. These features enable authorities and communities to promptly respond to swift fluctuations in water levels, thereby enhancing disaster preparedness [6]. Essential design components encompass the incorporation of ultrasonic sensors, selected for their non-contact operation, resilience, and economic efficiency. The sensors determine the rate of water level ascent by emitting ultrasonic waves and measuring the duration of their reflection, yielding actionable data [7, 8]. The design incorporates cloud-based applications like Google Sheets to improve system functionality, facilitating long-term data logging, trend analysis, and informed decision-making. These features enhance system reliability while facilitating scalability and future enhancements [9, 10].

This research seeks to rectify the shortcomings of current flood monitoring systems by creating a cost-efficient IoT-based system that tracks the velocity of rising water levels and delivers real-time notifications through mobile applications. The study emphasises the significance of system design in leveraging IoT technologies to mitigate flood risks, bolster community resilience, and enhance disaster management in susceptible areas such as Hulu Langat [3, 7, 10].

2. Research Methodology

The establishment of the water-rise velocity monitoring system adhered to a systematic methodology to guarantee dependability and efficacy. The process commenced with the circuit design, choosing essential components like the ESP32 microcontroller and HC-SR04 ultrasonic sensor for their compatibility and efficacy in detecting and measuring the velocity of ascending water levels [11]. The circuit schematic was developed and utilised as a reference for assembling the hardware components, including the ESP32, ultrasonic sensor, breadboard, and wiring, as illustrated in Fig. 1. Meticulous attention was devoted to guaranteeing appropriate connections and a reliable power supply for uninterrupted system functionality [12]. The next phase entailed programming and integration. Custom code was created and uploaded to the ESP32 microcontroller, allowing the system to interpret ultrasonic sensor data, compute the rate of water rise, compare outcomes to established thresholds, and trigger real-time alerts [13].

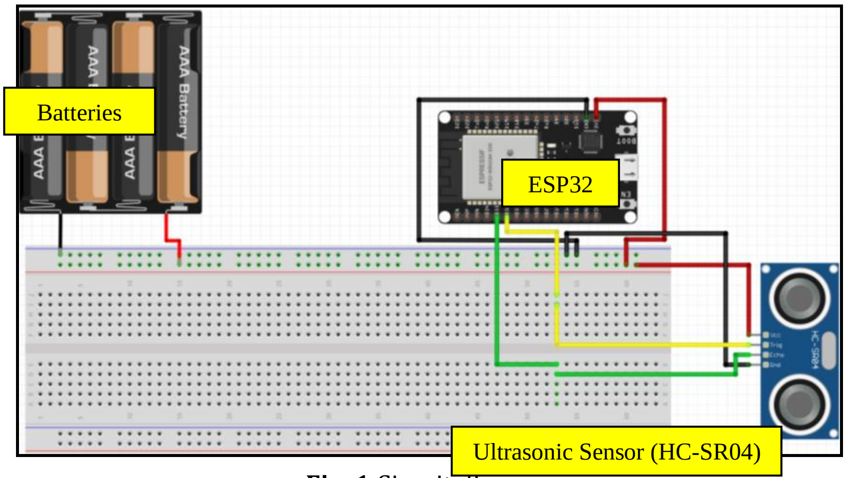


Fig. 1 Circuit diagram

Integration with the Blynk IoT platform allowed users to remotely monitor the water rise speed via an intuitive user interface. The Blynk dashboard allowed users to receive notifications and access data trends efficiently [14]. To validate the system, testing was performed in controlled environments that simulated diverse water rise scenarios, as illustrated in Fig. 2. The system's capacity to identify both gradual and rapid increases in water levels was assessed to guarantee approximate and prompt notifications. Testing encompassed scenarios involving gradual elevations in water levels and abrupt surges to replicate flood conditions. Real-time data was recorded in Google Sheets for subsequent analysis, facilitating the detection of trends and potential system enhancements [15].

Fig. 2 Testing Situations (a) Enclosed environment prototype testing; (b) Real-world prototype deployment

The methodology highlights the practical application of the system, concentrating on the interplay among the ultrasonic sensor, ESP32 microcontroller, and Blynk IoT platform. The system exhibited its practicality and reliability in improving disaster preparedness by providing real-time data and activating alerts during swift water rise incidents [17, 18]. Although simulations were not conducted, the resilient hardware implementation and comprehensive testing confirm the system's efficacy in tackling the issue of flood risk mitigation [16, 20].

The water-level rise monitoring system functions through a series of interrelated processes, as depicted in Fig. 3. The process commences with Water Rise Detection; wherein ultrasonic sensors quantify variations in water levels over time to ascertain the rate of ascent. The Data Processing module subsequently receives this data, analysing it to ascertain if predefined thresholds have been surpassed. The outcomes are recorded in the Data Logging module, facilitating historical analysis and performance monitoring. The system utilises IoT connectivity to integrate with the Blynk IoT platform, facilitating real-time monitoring and remote access. The Alerts and Notifications module guarantees that users obtain timely updates regarding potential risks, thereby enabling swift responses and enhancing disaster preparedness.

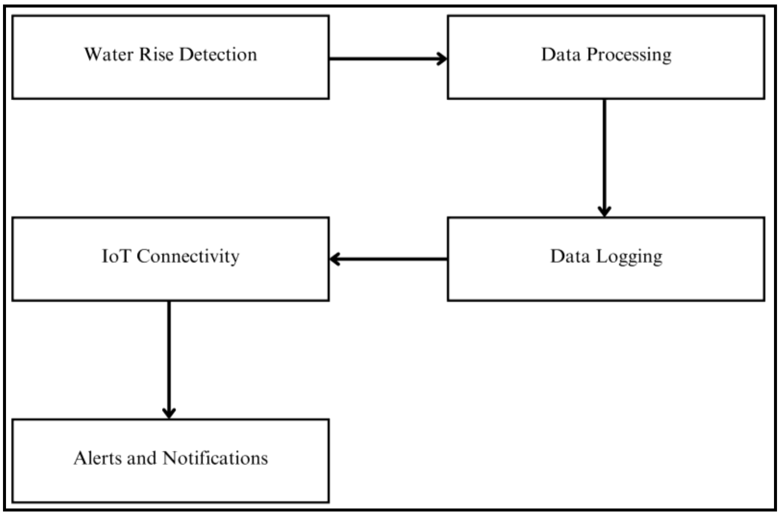
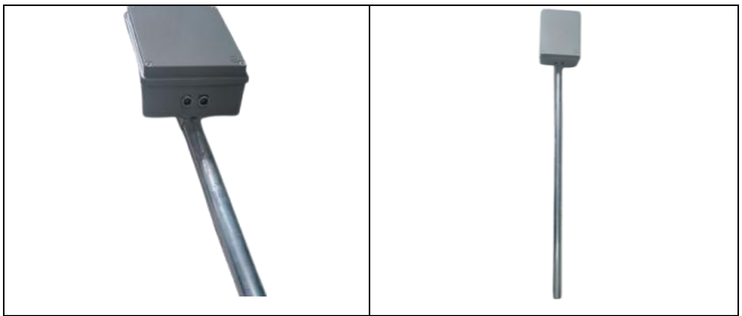


Fig. 3 Block function

3. Result and Discussion

3.1 Functionality

The system demonstrated competence in precisely replicating actual flood occurrences. The prototype illustrated in Fig. 4, comprising the ESP32, ultrasonic sensor (HC-SR04), and the Blynk IoT platform, operated consistently across diverse testing scenarios. It efficiently monitored water levels and provided immediate alerts upon detecting rapid increases. The ultrasonic sensor approximately measured water levels, relaying data to the Blynk IoT platform with minimal latency, thereby ensuring real-time updates.



(a) (b)

Fig. 4 Completed system (a) Close up view; (b) Overall view

The system was designed to detect rapid changes in water levels, which may indicate potential flooding events. Upon exceeding a specified threshold, the system-initiated notifications to the user via the Blynk application. This feature ensures that individuals in flood-prone areas receive prompt notifications, allowing them to take necessary actions to prevent or mitigate flood-related damage. The dataset acquired during testing confirmed the system's reliability under dynamic conditions, with notifications triggered in response to rapid water level fluctuations, demonstrating the system's ability to provide early warnings.

The prototype's performance demonstrated the design's feasibility, confirming its potential for practical application. Controlled testing scenarios evidenced the system's readiness for deployment in flood-prone regions, with prospects for future enhancements, including the incorporation of additional sensors or the advancement of scalability for broader applications.

4. Result

The water level monitoring system efficiently assessed and recorded water levels via the integration of the ESP32, ultrasonic sensor, and Blynk IoT platform. During the evaluations, the system demonstrated reliable performance in approximately measuring water levels and issuing alerts when critical thresholds of 6 cm/s were exceeded. The real-time data was displayed on the Blynk IoT dashboard, functioning as the graphical user interface (GUI) for monitoring and managing water levels, as illustrated in Fig. 5. This user-friendly graphical interface enabled users to monitor water level trends and receive prompt notifications for early flood alerts. The dashboard developed for this study operated effectively as the interface for real-time monitoring and analysis of water levels. The system provided critical metrics, including the current water level, historical data, and the rate of water rise (measured in cm/s).

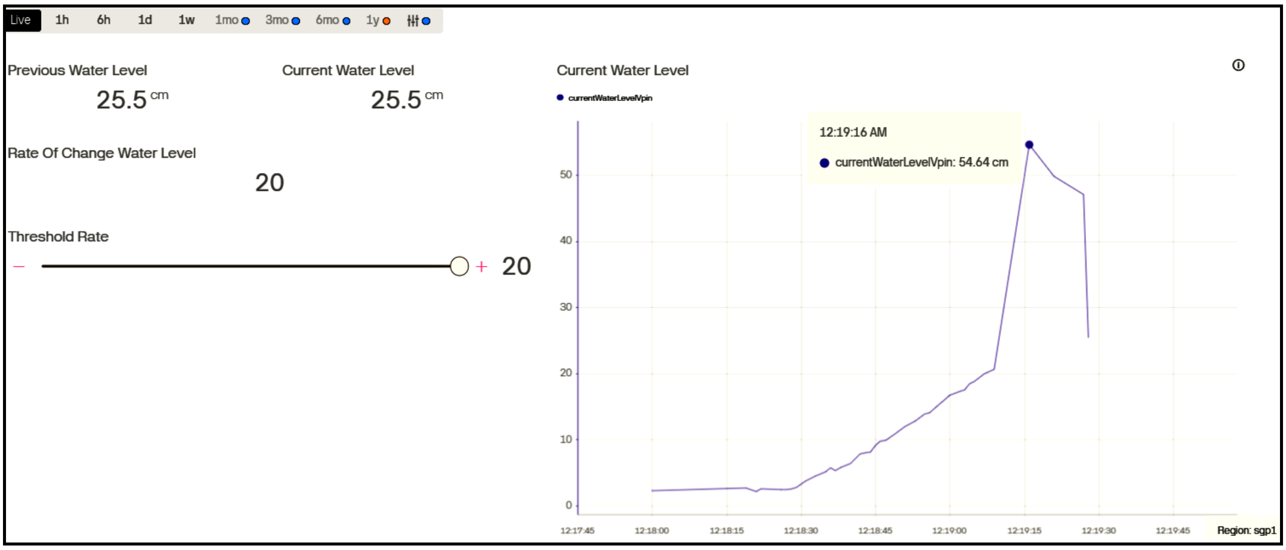


Fig. 5 Blynk IoT dashboard

The system's user-friendly graphical user interface offered an intuitive platform for real-time monitoring and analysis of water rise velocity. It presented water level trends via real-time graphs and numerical metrics, assisting users in recognising gradual increases or abrupt spikes. A rapid increase to 54.64 cm was promptly displayed on the dashboard and activated a notification. The Blynk IoT platform facilitated uninterrupted communication between the sensors and the mobile application, providing real-time updates. Users could modify the sensor's sensitivity directly through the GUI by adjusting the threshold settings. This feature enabled them to customise the system for conditions, reducing thresholds for minor alterations or increasing them to exclude inconsequential variations. The GUI indicated the water rising velocity in cm/s, issuing notifications when the speed surpassed a predetermined threshold, thereby alerting users to potential flooding hazards.

Notifications were intended to emphasise significant alterations without inundating users with erroneous alerts. The system's real-time notifications via the GUI and mobile application offered a concise and actionable summary, allowing users to respond promptly and mitigate potential flood damage.

4.1 Data

The system approximately recorded water level data over time, providing significant insights into the fluctuations of water levels during flood events. The data collected during the testing phase, as shown in Table 1, illustrates the variations in water levels over time, emphasising the rate of water rise. The data were gathered systematically, enabling a thorough analysis of the changes in water levels in relation to environmental variations. The system diligently tracked these fluctuations and generated notifications upon identifying significant changes, thus providing users with timely real-time alerts.

Table 1 Water level data and notifications triggered during testing

Date	Time (s)	Previous Water Level (cm)	Current Water Level (cm)	Water Rising Speed (cm/s)	Threshold Rate	Notification Triggered
18/12/2024	00:15:53	10.23	14.56	4.33	20	NO
18/12/2024	00:16:43	14.56	18.72	4.16	20	NO
18/12/2024	00:16:49	18.72	21.51	2.79	20	NO
18/12/2024	00:16:56	21.51	25.18	3.67	20	NO
18/12/2024	00:17:02	25.18	28.72	3.54	20	NO
18/12/2024	00:17:08	28.72	33.44	4.72	20	NO
18/12/2024	00:17:16	33.44	37.56	4.12	20	NO
18/12/2024	00:17:20	37.56	39.12	1.56	20	NO
18/12/2024	00:17:52	39.12	41.23	2.11	20	NO
18/12/2024	00:18:01	41.23	44.29	3.06	20	NO
18/12/2024	00:19:09	44.29	48.43	4.14	20	NO
18/12/2024	00:19:16	48.43	54.64	6.21	20	**YES**
18/12/2024	00:19:20	54.64	53.08	-1.56	20	NO
18/12/2024	00:19:28	53.08	51.38	-1.70	20	NO
18/12/2024	00:19:38	51.38	49.06	-2.32	20	NO

The data collected during testing highlighted the swift elevation in water levels, demonstrated by the increase from 48.43 cm to 54.64 cm at 00:19:16, which triggered a notification. The rapid increase was followed by a decrease in water level, demonstrating the system's ability to effectively monitor both ascending and descending water levels. The fluctuations in water levels and the ensuing alerts underscore the imperative for ongoing monitoring in areas prone to flooding. The system's capability to detect and alert users to gradual increases and abrupt surges in water levels underscores its potential for integration into early warning systems for flood prediction.

Moreover, the system disclosed patterns in water level variations, comprising a gradual rise followed by a rapid surge. From 00:15:53 to 00:16:56, the water level rose steadily from 14.56 cm to 25.18 cm, with rates of change consistently surpassing 3 cm/s. The system promptly responded to these escalations by issuing alerts when the rate of change exceeded the established threshold, thus informing the user of potential flooding events. The results illustrate the system's reliability and efficiency in detecting significant variations in water levels and promptly alerting users.

4.2 Performance Analysis

The assessment of the system's efficacy concentrated on the accuracy of the sensor data and the promptness of the alerts. The ultrasonic sensor displayed minimal variance, ensuring that the water levels were measured with remarkable accuracy. The interaction between the sensor and the Blynk IoT platform was efficient and reliable, demonstrating delays of less than 3 seconds from the sensor reading to the notification. This enabled the swift distribution of information about water level changes, providing individuals sufficient time to react to potential flooding situations, as illustrated in Fig. 6.

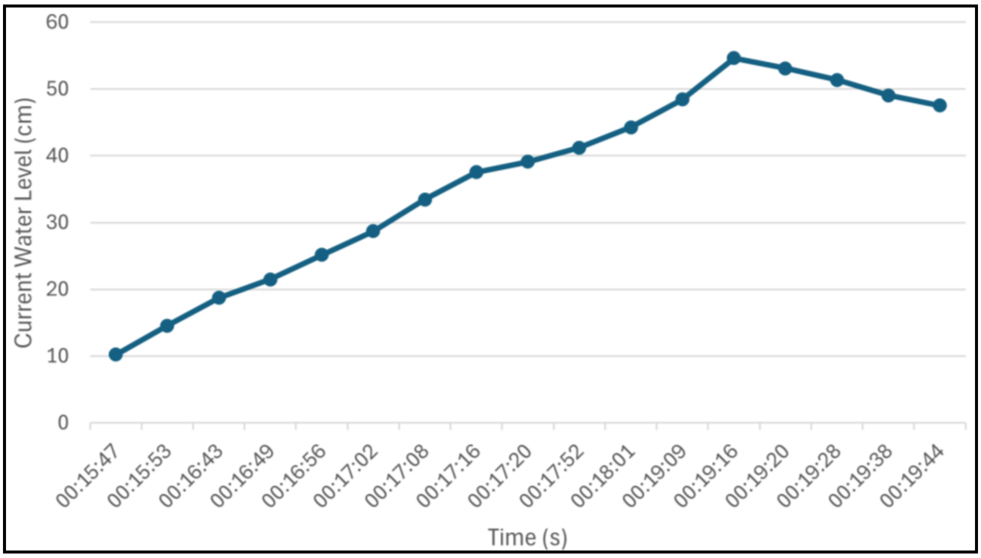


Fig. 6 Graphical representation of water level trends over time

The system's ability to handle varying rates of water level fluctuations was a crucial aspect of its performance. The sensor accurately detected both incremental increases and abrupt surges in water levels, providing precise measurements and triggering alerts at appropriate times. The notification system was carefully designed to exclude minor variations, ensuring that users received alerts only for significant changes. This aided in reducing false alarms and preserving the system's reliability in real-world applications. The system demonstrated its efficacy as a reliable tool for early flood warning. The system enhanced flood preparedness and response via real-time monitoring, visualisation of water levels, and prompt notifications. The integration of the ultrasonic sensor with the Blynk IoT platform proved effective in monitoring water levels and providing critical data to users, positioning it as a vital tool for flood-prone communities.

5. Conclusion

This study emphasises the efficacy of IoT technology in monitoring escalating water levels and providing prompt alerts for flood readiness. The system effectively monitored and communicated water rise velocity in real time using an ESP32 microcontroller, HC-SR04 ultrasonic sensor, and Blynk IoT platform. Testing validated the system's precision and capacity to elicit prompt responses. Although the prototype demonstrated efficacy, prospective improvements may encompass supplementary sensors (e.g., temperature or turbidity) and enhanced scalability for wider applications, including urban flood management. This project illustrates the capability of IoT-based solutions in alleviating flood risks and enhancing community resilience.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Mohamad Aidil Adan;* ***solve the governing equation:*** *Mohamad Aidil Adan, Afishah Alias;* ***data collection:*** *Mohamad Aidil Adan;* ***analysis and interpretation of results:*** *Mohamad Aidil Adan, Afishah Alias;* ***draft manuscript preparation:*** *Mohamad Aidil Adan, Afishah Alias. All authors reviewed the results and approved the final version of the manuscript.*

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