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IOT-Based Headwater Detector System

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Abstract: *The tragic headwater surge incident at Jeram Air Putih, Kemaman, which resulted in the loss of ten lives, has underscored the urgent necessity for real-time, technology-enhanced monitoring systems in high-risk recreational water areas. This research introduces a comprehensive Internet of Things (IoT)-based Headwater Monitoring System (HMS) designed to rectify the shortcomings of the manual observation techniques currently utilized in 39 identified high-risk regions throughout Malaysia. The system's architecture features a distributed network of environmental sensors, including ultrasonic level sensors, pressure transducers, and flow rate meters, strategically positioned at critical upstream sites. These sensors connect to edge computing units for initial data filtering and compression before wirelessly transmitting the information to a centralized cloud-based analytics platform using LoRaWAN and cellular IoT protocols (NB-IoT/LTE-M). Real-time hydrological data is analyzed through anomaly detection algorithms and threshold-based decision models, facilitating the prompt identification of sudden water level increases or flash flood indicators. When critical events are detected, the system activates automated alerts through a multi-channel communication framework, which includes SMS, mobile applications, and integration with local siren systems, aimed at informing authorities, emergency responders, and nearby residents. Field tests conducted under various rainfall conditions validate the system's responsiveness, energy efficiency, and scalability. This IoT-driven HMS represents a significant improvement in disaster risk reduction strategies, bolstering early warning capabilities and operational preparedness in flood-prone recreational areas.*

Key Words: *Headwater phenomenon; Flood phenomenon; Water Detection; Monitoring using Internet of Thing (IoT)*

I.INTRODUCTION

The recent incident at Jeram Air Putih in Kemaman, Terengganu, which tragically claimed ten lives, has led authorities to designate 39 recreational sites along waterfalls and rivers throughout Malaysia as high-risk areas for water-related dangers. This event highlights the critical necessity for a systematic and technologically advanced method to monitor surges in headwater, especially in locations that attract public visitors.

Currently, the monitoring of headwater events is largely conducted through manual techniques that depend on human observation and sound cues to identify unusual water flow. Although this traditional approach has been in use, it is fundamentally constrained: it requires significant labor, lacks scalability, does not provide real-time information, and results in considerable delays in detecting threats and initiating responses.

To address these shortcomings, this paper introduces an innovative Headwater Monitoring System (HMS) that leverages Internet of Things (IoT) technology. The aim of this system is to offer a thorough and automated solution that facilitates continuous environmental monitoring, real-time data communication, and intelligent alert distribution. It is engineered to identify early indicators of headwater accumulation and to issue timely alerts to nearby residents and relevant authorities. By incorporating environmental sensors and automated alarm systems at key upstream sites, this IoT-based HMS allows for real-time monitoring and situational awareness. The early-warning system ensures that those at risk can take appropriate measures such as evacuating to safer areas or ceasing activities well before dangerous water conditions arise. This forward-thinking strategy not only improves public safety but also significantly shortens response times during emergencies.

II.MATERIAL AND METHODS

The proposed IoT-based Headwater Monitoring System (HMS) is developed using a comprehensive engineering framework that includes hardware selection, sensor deployment strategies, data communication systems, and real-time analytics for detecting anomalies and generating alerts. This methodology is divided into four key phases: system design, deployment of sensor nodes, data transmission and processing, and the dissemination of alerts.

The HMS features a modular design that promotes scalability and resilience in challenging outdoor conditions, utilizing primary hardware components such as ultrasonic water level sensors for non-contact measurement of water surface elevation and flow rate sensors for real-time velocity assessment. Microcontroller units like ESP8266 serve as data acquisition nodes with local preprocessing capabilities, while solar panels with battery storage provide a reliable power supply for autonomous operation. Sensors are strategically placed at critical upstream locations identified through hydrological studies to ensure early detection of rising water levels before they impact populated areas. Each sensor node is protected by weatherproof enclosures to endure harsh weather and debris during surges. Data is collected at regular intervals and the information relayed to a cloud platform for real-time visualization using Node-red application and processing. Edge computing is utilized at the node level for initial data filtering and anomaly detection.

The cloud-based backend features a detection algorithm that utilizes both rule-based and machine learning techniques to examine time-series data for any irregularities, such as unexpected increases in water levels or flow rates. When certain thresholds are surpassed or risk patterns are detected, an automated alert system is activated. These alerts are communicated through various channels, including SMS and mobile app notifications directed at the public and local authorities, integration with public sirens and LED display systems located at recreational areas, and web-based dashboards that enable emergency services to monitor multiple zones simultaneously. Furthermore, the initial deployment of the system occurs at a pilot site identified as high-risk to assess its performance. Key parameters, including sensor precision, communication delays, energy efficiency, and rates of false alarms, are thoroughly examined. Regular calibration procedures are implemented to maintain sensor accuracy across different environmental conditions.

The block diagram of the system is as shown in Figure 1 below.

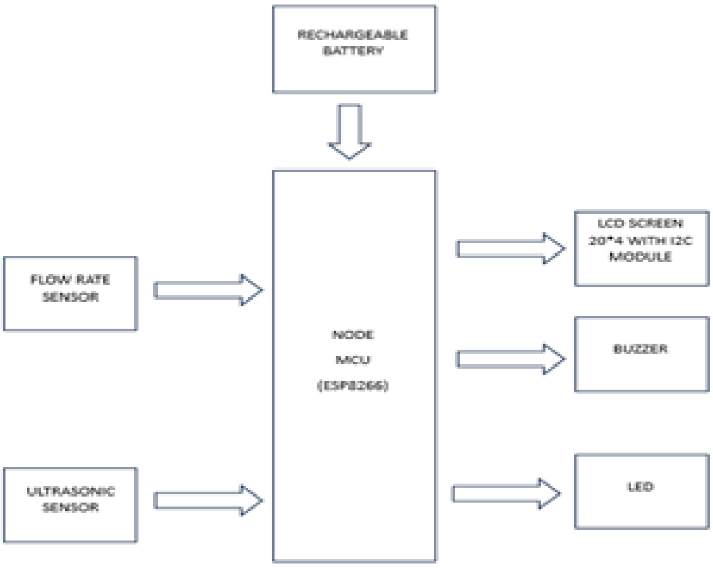

Figure 1: Block Diagram of the System

A. Node MCU (ESP8266)

Figure 2: Microcontroller

The Node MCU ESP8266 is a development board that incorporates the ESP8266 Wi-Fi module, aimed at facilitating the development of Internet of Things (IoT) projects. This board offers a user-friendly platform with integrated Wi-Fi capabilities, making it easier for developers to prototype their ideas. The ESP8266 module is a cost-effective, energy-efficient, and highly integrated Wi-Fi chip that allows devices to connect to Wi-Fi networks and communicate online. Specifically designed to enhance the programming experience with the ESP8266 module, the Node MCU ESP8266 development board includes a microcontroller, General Purpose Input/Output (GPIO) pins, flash memory, and various communication interfaces, all within a compact and practical design. This board serves as an accessible hardware platform for connecting sensors, actuators, and other components, enabling developers to build IoT applications without requiring extensive expertise in electronics or low-level programming.

B. Buzzer

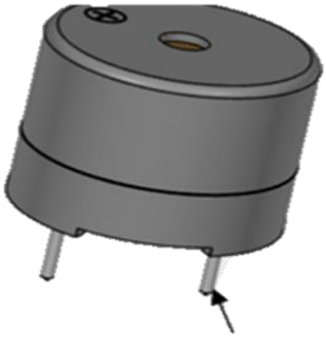

Figure 3: Buzzer

The buzzer serves as an auditory warning system that activates when water levels or flow rates exceed critical limits. Controlled by the ESP8266 microcontroller, it delivers a prompt and loud signal to alert nearby residents of potential flood hazards, ensuring that individuals are informed even in the absence of smartphone alerts. Furthermore, the sound pattern of the buzzer can be modified to reflect varying degrees of urgency, thereby improving community safety by providing a clear and comprehensible warning.

C. Light Emitting Diode (LED)

Figure 4: LED

In this system, the use of LEDs facilitates the indication of various safety levels through distinct colours. A green LED denotes that conditions are safe, implying that no urgent action is necessary. Conversely, a yellow LED acts as a warning, suggesting a state of caution where users should remain vigilant for possible changes. A red LED signifies danger, indicating a critical situation that may necessitate immediate intervention. This color-coded LED system offers users a straightforward and rapid visual representation of the current conditions, allowing for quick comprehension at a glance.

D. Liquid Crystal Display (LCD) I2C 20x4

Figure 5: Liquid Crystal Display (LCD) I2C 20x4

LCD represents a widely utilized display technology in electronic devices for visual representation. This technology operates by employing liquid crystals that manipulate light to present various forms of information, including text, numbers, and symbols. In the context of microcontroller applications, LCDs serve the purpose of conveying information to users, such as readings from sensors or the status of systems. Their popularity stems from their affordability, ease of integration with microcontrollers, and capability to display multiple characters or lines simultaneously. Furthermore, an LCD equipped with I2C (Inter-Integrated Circuit) technology enhances the simplicity of wiring by minimizing the number of necessary connections and facilitating communication through just two data pins, thereby making it particularly suitable for compact and efficient design implementations.

E. IOT (NODE-RED)

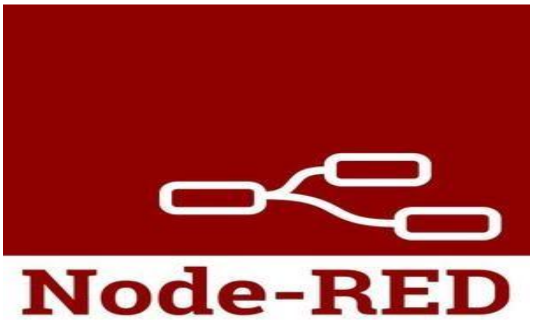

Figure 6: Node-red application

Node-RED serves as a flow-based development platform designed for the interconnection and automation of hardware devices, APIs, and online services. It features a user-friendly visual interface that enables users to easily drag and drop nodes, which symbolize various actions or processes, to establish workflows known as flows. Each node functions as a distinct block of code or a specific operation, such as gathering data from a sensor, processing that information, or issuing alerts. This tool is particularly popular in Internet of Things (IoT) initiatives, as it facilitates straightforward integration among diverse hardware and software services. Additionally, Node-RED accommodates a broad spectrum of protocols, rendering it ideal for constructing intricate IoT systems that require smooth interaction among multiple components.

B. Flow Rate Sensor

Figure 7: Flow Rate Sensor

A flow rate sensor is an instrument designed to quantify the speed at which a water, traverses through channel. It operates by sensing variations in fluid velocity, subsequently translating these readings into a comprehensible flow rate, typically measured in liters per minute (LPM) or gallons per minute (GPM). These sensors play a vital role across numerous sectors, such as water treatment, HVAC systems, and chemical processing, by ensuring operational efficiency and safety through the provision of real-time data that facilitates the monitoring and regulation of fluid dynamics, helps avert overflow situations, and sustains optimal system performance.

C. Ultrasonic Sensor

Figure 8: Ultrasonic Sensor

Ultrasonic sensors operate by emitting high-frequency sound waves to gauge the distance to the water level, subsequently calculating the duration it takes for these waves to return after reflecting off the water's surface. This time-of-flight method enables the determination of distance, which is then converted into a measurement of the water level. Typically, the sensor comprises a transmitter that generates the sound waves and a receiver that captures the returning echo. By understanding the speed of sound in air, the sensor can precisely calculate the distance from itself to the water surface, thereby offering real-time information for monitoring water levels. This technique is particularly effective for ongoing, non-contact measurements, making it suitable for uses such as tank surveillance or flood detection.

III.RESULT

The conditions of water level and velocity are classified into three condition safety categories. Green (Safe), Yellow (Warning), and Red (Danger). In the Green category, characterized by a water level below 15% and a velocity under 15 m/s, the system functions normally without activating any alarms. When conditions shift to Yellow, indicated by a water level ranging from 15% to 20% and a velocity between 15 m/s and 20 m/s, a buzzer is triggered to issue a warning, accompanied by an immediate alert sent to the owner's mobile device. In the Red category, where the water level surpasses 20% or the velocity exceeds 20 m/s, the system activates a buzzer to signal a critical situation and dispatches a high-priority notification to the owner, necessitating urgent intervention. By establishing these thresholds for both water level and velocity, the system facilitates the prompt identification and communication of abnormal conditions, enabling swift responses from the owner or relevant authorities, thereby contributing to effective water resource management and enhancing the safety of the community. Prompt response from the owner or relevant authorities, thereby aiding in effective water resource management and enhancing community safety.

Table 1: Result after testing

PARAMETER	Water Level >20% Water Velocity >20m/s	Water Level >15% Water Velocity >15m/s	Water Level <15% Water Velocity <15m/s
LCD Display	Danger	Warning	Safe
Buzzer	On	On	Off
LED	Red On	Yellow On	Green On
SMS Notification	Sent	Sent	Not Sent

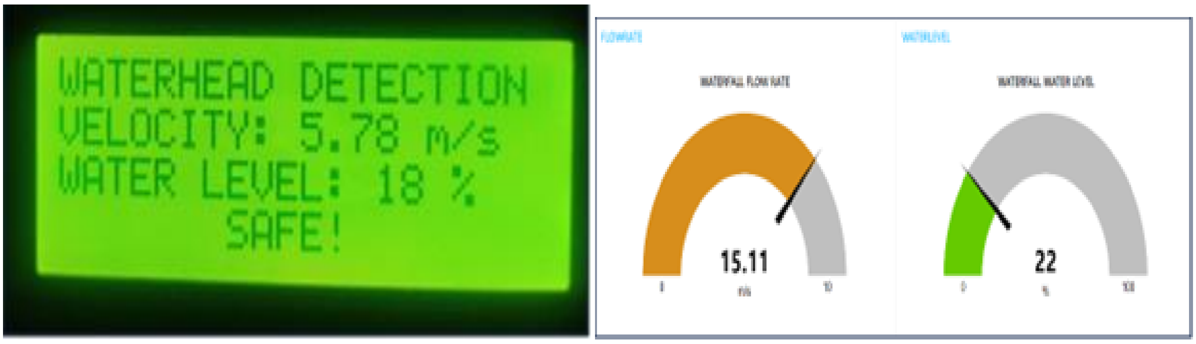

Figure 9: Safe Condition

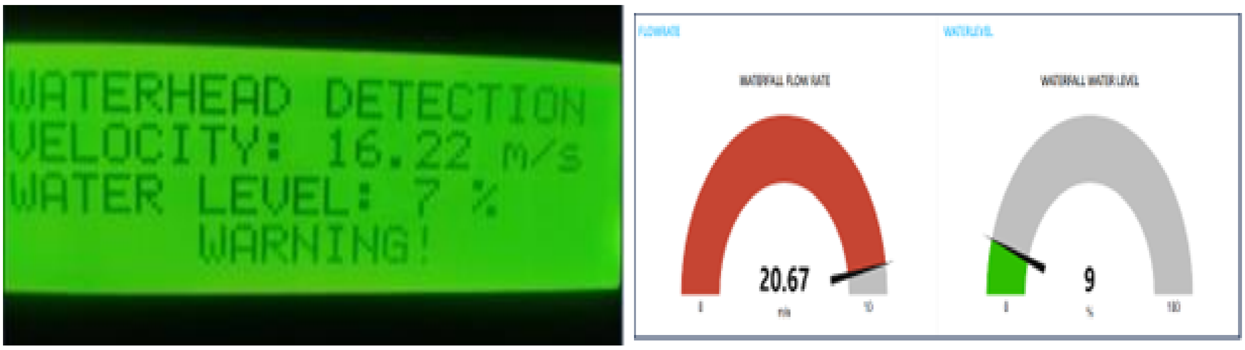

Figure 10: Warning Condition

Figure 11: Danger Condition

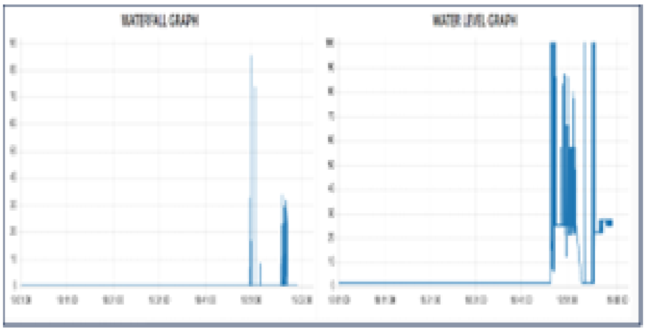

Figure 12: Recorded Data for Water Level and water velocity

The graph illustrating the relationship between water level and water velocity offers essential insights into the fluid dynamics present in various systems. Our collected data systematically documented and plotted this relationship to elucidate the characteristics of flow. The graph demonstrated how velocity varies in response to changes in water level, providing a clear representation of the hydraulic conditions. For example, at elevated water levels, velocity may increase due to a greater volume of water driving movement, or it may decrease if the system undergoes flow expansion or turbulence. This information is vital for forecasting water flow behavior in both natural and engineered settings, such as rivers, reservoirs, or drainage systems. The significance of this graph is underscored by its capacity to guide decisions related to flood management, resource distribution, and infrastructure design, emphasizing critical thresholds where velocity and water levels could lead to inefficiencies or risks within the system. These insights enhance real-time monitoring capabilities, refine predictive models for water management, and bolster the safety and effectiveness of water-related infrastructure.

IV.DISCUSSION

The classification of water levels and velocities into three distinct safety categories Green, Yellow, and Red is essential for ensuring the operational efficiency of the system and averting severe failures. By establishing these thresholds, the system is equipped to monitor and address potential hazards proactively, thereby facilitating effective and safe management of water resources. The Green category signifies safe operational conditions, allowing the system to function at its best without immediate threats, while the Yellow and Red categories act as indicators for early warnings and emergency responses. These defined thresholds enable prompt interventions, thereby mitigating the risk of issues escalating into more hazardous or expensive scenarios. The correlation between water level and velocity, illustrated in the accompanying graph, offers vital insights into the fluid dynamics of the system. In the Green category, where both parameters remain within safe boundaries, the system operates smoothly. Conversely, a transition into the Yellow zone, characterized by elevated water levels and velocities, signals potential stress on the system. The triggering of a warning buzzer and immediate notification to the owner highlights the significance of early detection. This proactive alert mechanism ensures that any deviation from standard operations is swiftly communicated, empowering the owner to implement corrective measures before the situation deteriorates.

In the Red category, when the water level exceeds 20% or the velocity surpasses 20 m/s, the system is deemed to be in a critical condition, indicating an immediate requirement for intervention. A high-priority alert is dispatched to the owner, ensuring that necessary corrective actions are undertaken swiftly to prevent severe consequences such as flooding or structural failures. These classifications offer explicit guidance on the conditions under which the system experiences stress, enabling owners or relevant authorities to effectively prioritize their actions and allocate resources accordingly.

The graphical representation of water level in relation to velocity is crucial in this scenario, as it visually illustrates how variations in one parameter influence the other. Grasping this correlation is vital for forecasting system behavior across various conditions. For example, the graph revealed that at elevated water levels, the velocity may either rise or fall, contingent upon specific system factors such as flow expansion or resistance. This intricate understanding is essential for making well-informed decisions regarding water flow management, particularly in areas susceptible to flooding, reservoirs, or water treatment facilities.

The established data and thresholds are critical not only for ensuring operational safety but also for enhancing system performance. By proactively identifying potential challenges through real-time monitoring, the system can adjust its operations dynamically to maintain the safety and efficiency of water management. Consequently, these insights play a significant role in improving water resource management, reducing the likelihood of flooding, and ensuring that infrastructure remains robust and dependable. Ultimately, the integration of categorized thresholds with a comprehensive analysis of the relationships between water level and velocity equips stakeholders with the tools necessary to manage water systems more effectively, respond to emergencies promptly, and bolster the overall safety of water infrastructure.

V.CONCLUSION

In conclusion, the deficiencies identified in the current manual headwater monitoring system highlight critical shortcomings, including procedural inefficiency, delayed information acquisition, and a lack of real-time monitoring capabilities. These issues compromise the precision of detection, impede effective risk management, and leave communities vulnerable to sudden changes in headwater conditions without timely warnings. The absence of an efficient early warning system exacerbates the problem, resulting in inadequate preparedness time and increasing the risk of adverse consequences. To address these challenges and enhance the overall effectiveness of headwater monitoring and alerting processes, the implementation of a technologically advanced Headwater Monitoring System leveraging IoT technology is imperative. The proposed system aims to design a monitoring system for water velocity and water level, implement an alert messaging notification system through smartphones using IoT, and integrate an alarm system with a buzzer to provide timely warnings to communities. This technological advancement seeks to significantly improve. Community safety and preparedness in headwater-prone areas by overcoming the limitations of the existing manual monitoring approach.

VI.RECOMMENDATION

To improve the IoT-Headwater Detection System, the incorporation of cloud storage would facilitate real-time data collection and backup, thereby supporting sophisticated data analytics, machine learning, and trend analysis aimed at forecasting future water levels and assessing potential flooding hazards. The integration of real-time weather forecasting data would further enhance the system's predictive capabilities, enabling it to link water levels and flow rates with precipitation or storm events, thus providing timely alerts. The installation of cameras at strategic locations would yield real-time visual information regarding headwater conditions, allowing authorities and communities to monitor water levels, flow rates, and possible obstructions visually. Furthermore, the addition of a GPS module would enable the establishment of mobile or portable monitoring stations equipped with precise geolocation data, ensuring that water level measurements are accurately associated with specific locations, which is essential for comprehensive geographic monitoring and alert systems.

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