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IoT-Based Multi-Sensor Dam Monitoring and Automated Disaster Management System

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Abstract- ***This work presents an IoT-based framework for observing dam conditions and assisting with early disaster response. The proposed arrangement gathers environmental and structural readings such as reservoir level, water inflow and discharge, rainfall, temperature, and indicators of structural behaviour. Sensor observations are sent to a central platform, where they can be processed and used for operational decisions. The system was assessed using simulated and real operating situations to examine measurement accuracy, response behaviour, warning delivery, and consistency. Cloud storage and data analysis are included so that unusual changes in the monitored values can be identified and conditions related to flooding or structural stress can be examined. The evaluation showed that the framework could follow changes in the monitored conditions and issue warnings when important limits were reached. Remote access also allows personnel to check dam status without remaining at the installation, which can be useful when rapid decisions are required.***

The system also has some practical limitations. Reliable communication is needed to transfer sensor readings, especially at remote locations. The sensors require regular inspection and calibration to maintain accurate operation. The proposed system can support dam monitoring and emergency response, while future improvements can include better prediction methods and additional analytical features.

Index Terms- ***Dam Management, Disaster Monitoring, Early Warning System, Flood Prediction, IoT, Real- Time Monitoring, Smart Sensors, Water Resource***

I. INTRODUCTION

Water-resource management has become increasingly important as climate conditions vary, populations grow, and demand for water continues to rise. Dams are used for storage, irrigation, electricity generation, and flood regulation, but poor supervision can create serious risks, including overflow, structural damage, and consequences for communities located downstream. For this reason, dependable and continuous observation is important for safe dam operation. Conventional inspection practices commonly depend on personnel visiting the site and collecting measurements at intervals. Such an approach may not provide enough warning when conditions change quickly. Heavy rainfall, a rapid increase in reservoir level, or unusual structural loading can develop in a short period, leaving little time for manual intervention. An automated monitoring arrangement can reduce this delay by collecting measurements continuously and informing responsible personnel when important changes occur. IoT technology is suitable for this type of application because sensors distributed around the dam can gather several parameters and communicate their readings to a central system. The information can then be examined against normal operating conditions and predefined limits. Remote access is another advantage because operators can observe current conditions without being physically present at the dam. Dam safety is also affected by factors such as severe weather, seismic activity, and gradual deterioration of infrastructure. Considering these conditions along with sensor measurements can provide a more complete view of possible hazards. At the same time, practical issues such as communication failures, sensor accuracy, and maintenance must be considered when designing a dependable monitoring solution. This work therefore develops an integrated framework for continuous dam observation, automated warning, and remote supervision with the objective of supporting safer operation and reducing disaster-related risk.

In addition to environmental factors, disaster risks associated with dams can also be influenced by external conditions such as extreme weather events, seismic activity, and aging infrastructure. These factors may increase the likelihood of dam failure or overflow, leading to floods and widespread damage. Although the use of modern technology is helpful, there are still issues with regard to reliability, accuracy, and connectivity, especially in the case of remote or harsh environments. These issues need to be addressed in order to improve monitoring systems and ensure that the data collected is accurate and reliable. This study proposes to design and evaluate an integrated dam management and disaster monitoring system that makes use of real-time data collection and analysis to improve safety and reduce risk and enhance water resource management.

II. PROPOSED METHODOLOGY

The proposed system is designed as an IoT-enabled monitoring and control framework for observing dam

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conditions and initiating predefined actions when the measured parameters move beyond their acceptable operating ranges. The methodology combines sensor acquisition, local processing, condition assessment, alert generation, and gate control within a continuous monitoring cycle. Initially, the controller initializes all sensing and output modules. The water-level sensor measures the variation in the reservoir level, while the rainfall sensor identifies the occurrence or intensity of rainfall. Environmental parameters such as temperature and humidity can also be acquired to provide additional information about the surrounding conditions. The collected readings are periodically updated so that the system operates with the latest available data.

After acquisition, the sensor values are evaluated against the threshold limits configured for the prototype. The reference implementation specifically uses threshold-based water-level evaluation and also considers rainfall status while controlling the gate state.

Based on the evaluation, the operating condition is classified into three levels:

1) **Normal Condition:** All monitored parameters remain within their specified safe range. The current readings and gate status are displayed, and the system continues monitoring.
2) **Warning Condition:** One or more parameters approach a predefined limit. The system records the condition and generates a warning so that the operator can be informed before the situation becomes critical.
3) **Critical Condition:** A monitored parameter reaches or exceeds its critical threshold. The system activates the emergency indication mechanism and initiates the programmed gate-control action. Depending on the configured operating logic, the gate actuator is commanded to move to the required position for controlled water release.

Following each action, the sensors continue to acquire new readings. When the monitored condition returns to the configured safe range, the controller updates the gate state according to the control rules and resumes normal monitoring. Thus, the methodology operates as a closed monitoring-and-response loop rather than as a one-time decision process.

Methodology Steps

1) Initialize the microcontroller, sensors, communication modules, display, alert unit, and gate actuator.
2) Collect real-time readings from the water-level, rainfall, temperature, and humidity sensors.
3) Validate and update the current sensor values.
4) Compare the measured values with the predefined threshold limits.
5) Determine whether the dam condition is **normal, warning, or critical**.
6) Display and record the current operating status.
7) Generate a warning or notification when the readings approach a critical range.
8) Activate the emergency response when the critical condition is reached.
9) Operate the dam gate according to the programmed threshold-based control logic.
10) Continue acquiring sensor data and repeat the decision cycle.

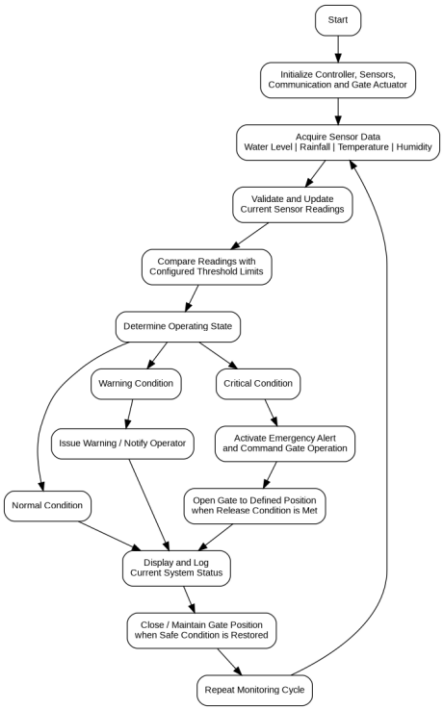


Fig. 1. Flowchart of the proposed multi-sensor monitoring and threshold-based dam control methodology.

Fig. 1 presents the operational flow of the proposed IoT-based dam monitoring system. The process begins with the initialization of the controller, sensing units, communication modules, and gate actuator. The system then continuously collects data related to water level, rainfall, temperature, and humidity. These readings are processed and compared with the predefined threshold values to identify the current operating condition of the dam.

Based on the evaluation, the condition is categorized as normal, warning, or critical. Under normal conditions, the system continues regular monitoring and updates the current status. When the

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measured values approach the specified safety limits, a warning is generated to support timely attention. If a critical threshold is reached, the system activates the required alert mechanism and performs the programmed gate-control action. After each cycle, updated sensor readings are obtained again, allowing the system to continuously reassess the dam condition and respond to changing environmental conditions.

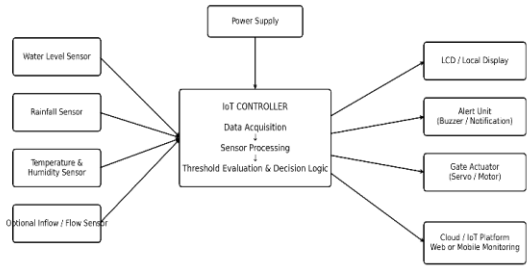


Fig. 2. Block diagram of the proposed IoT-based dam monitoring and control system.

The proposed architecture is organized around a central IoT controller that receives information from multiple sensing units and determines the operating condition of the dam. The water-level sensor provides the primary measurement required for observing changes in reservoir level, while the rainfall sensor supplies information about changing weather conditions. Temperature and humidity measurements provide supporting environmental data, and an additional inflow sensor may be incorporated when required. The controller collects these inputs, processes the readings, and evaluates them using the predefined threshold limits.

After the condition is determined, the controller distributes the result to different functional units. The LCD provides the current sensor values and system status locally, whereas the alert unit is activated when a warning or critical situation is identified. For conditions requiring water release or a change in gate position, the control logic sends a command to the servo-based gate actuator. The IoT communication module transfers the monitored information to a cloud platform, allowing the system status to be observed through a web or mobile interface. This arrangement creates a continuous cycle in which sensor measurements are repeatedly acquired, evaluated, and converted into monitoring or control actions.

III. IMPLEMENTATION

The implementation diagram illustrates the integration of the sensing, processing, communication, and control modules used in the proposed system. The controller acts as the central processing unit and receives the measurements obtained from the water-level, rainfall, and environmental sensing units. Each incoming value is periodically processed and evaluated against the configured operating limits. The current condition is then made available through the local display and can also be transmitted through the IoT communication interface for remote observation.

When the measured parameters remain within the acceptable range, the system continues its regular monitoring cycle. If a value approaches or exceeds the assigned threshold, the controller changes the system status and activates the corresponding response. The alert unit provides an immediate indication of an abnormal condition, while the gate actuator receives a control signal whenever the programmed logic requires a change in gate position. The actuator can therefore represent the opening, closing, or holding action defined by the threshold evaluation. By connecting sensing, decision-making, notification, and actuation in a single loop, the implementation enables continuous observation of the prototype and reduces dependence on repeated manual checking.

The implementation diagram shows the hardware setup of the proposed IoT-based dam monitoring and control system. The NodeMCU (ESP8266) acts as the central controller that receives data from all the sensors. The water level sensor placed in the reservoir measures the current water height, while the rainfall sensor detects the presence and intensity of rainfall. The DHT11 sensor monitors temperature and humidity to provide supporting environmental information. All the sensor outputs are conditioned and supplied to the NodeMCU for processing.

The LCD display presents real-time values of water level and rainfall status. When any parameter crosses the predefined threshold, the alert unit consisting of buzzer and LED is activated to notify the nearby personnel. Based on the threshold evaluation, the controller sends a command to the servo motor, which operates the gate mechanism (OPEN or CLOSE). The NodeMCU connects to the internet through its built-in Wi-Fi and uploads the data to a cloud platform (such as Blynk/ThingSpeak). The user can view live data and alerts on a web dashboard or mobile application from any remote location.

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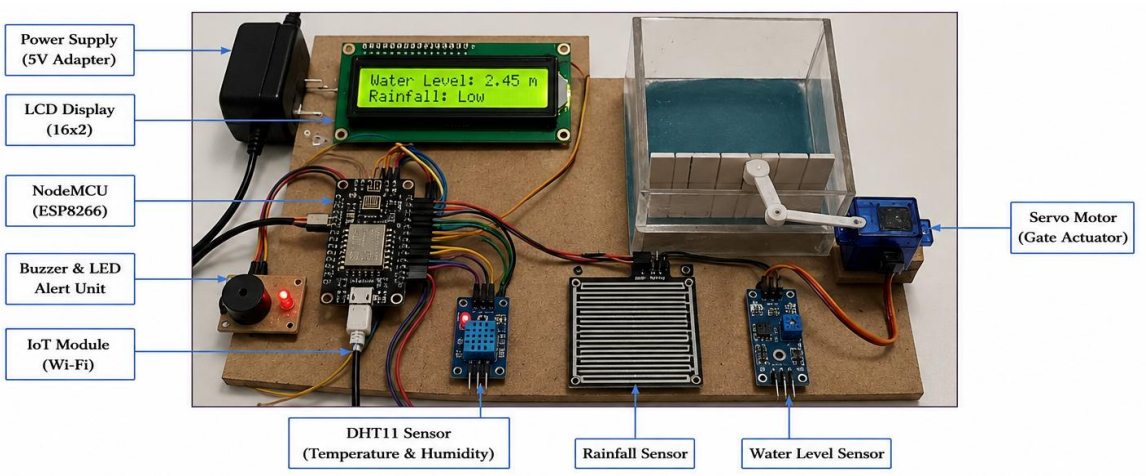


Fig. 3. Implementation diagram of the proposed system.

IV. RESULTS AND DISCUSSION

The developed prototype was evaluated by observing the response of the system under different sensor conditions. The water-level, rainfall, temperature, and humidity sensors provided input to the controller, which continuously processed the received values. During normal operating conditions, the measured parameters remained within the assigned limits, and the system maintained its regular monitoring state. The sensor readings and corresponding system status were updated through the display and IoT interface.

As the water level approached the specified threshold, the system changed from the normal monitoring state to a warning condition. This transition enabled the alert mechanism to indicate that the reservoir condition required attention. When the critical threshold was reached, the controller executed the predefined response and generated a control signal for the gate actuator. The prototype demonstrated that the gate operation could be linked directly to the evaluated sensor condition, allowing the opening or closing action to occur according to the implemented control logic.

V. EXPERIMENTAL OUTPUT

The experimental output can be presented as a set of operating conditions showing how the prototype responds when the sensor values change.

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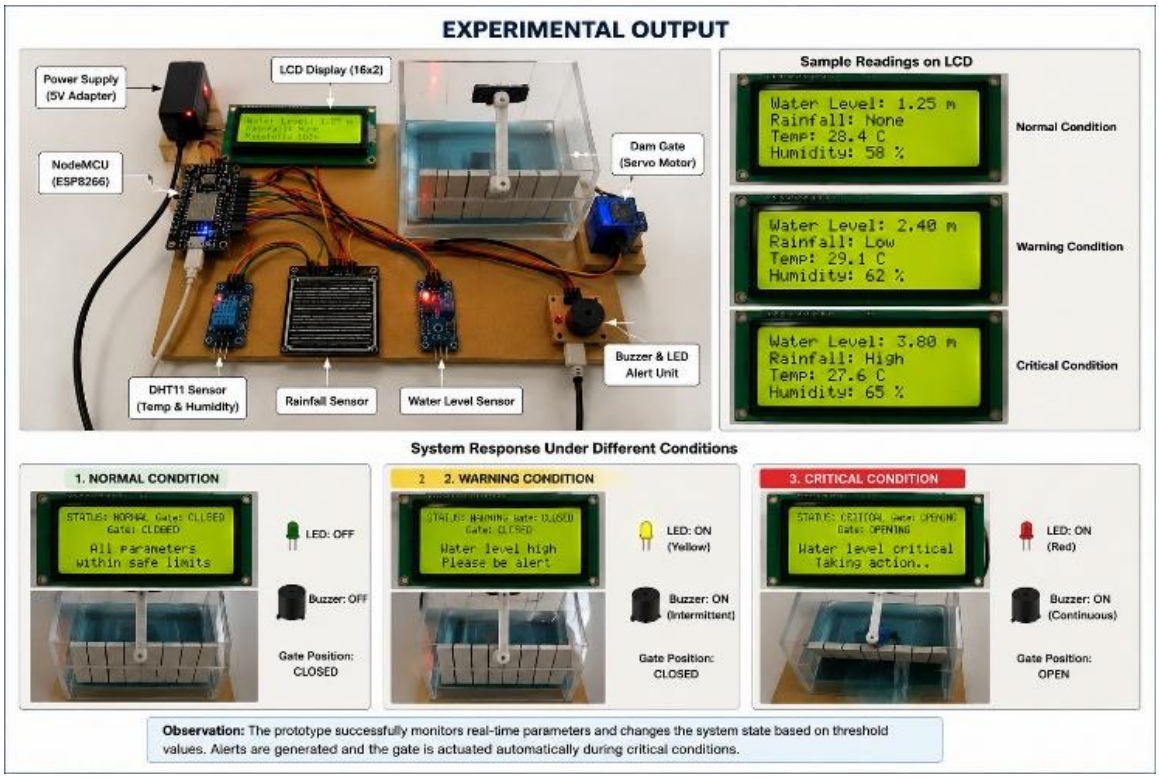


Fig. 4. Experimental output of the proposed IoT-based dam monitoring and automated gate control system.

During normal operation, the sensor readings stayed within the safe range, so the system continued monitoring without activating the emergency response. When the water level came close to the set limit, the system changed to the warning state and generated an alert. If the water level crossed the critical limit, the controller activated the alert unit and sent a command to the gate actuator to carry out the required action.

Table I. Observed System Response under Different Conditions

Test Condition	Water Level Range	Rainfall Status	System Status	Alert Response	Gate Action
Test 1	Below warning threshold	Low / None	Normal	Not activated	Closed / Maintained
Test 2	Approaching warning threshold	Moderate	Warning	Warning indication activated	Closed / Monitored
Test 3	Above critical threshold	High	Critical	Buzzer and visual alert activated	Opening command issued
Test 4	Returned to safe range	Reduced / Low	Normalized	Alert reset according to control logic	Closed / Safe position

The table summarizes the change in system status, alert response, and gate action for different monitored conditions.

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A. Serial Monitor Output

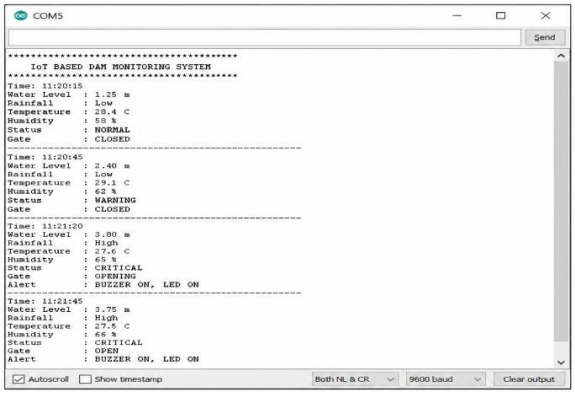


Fig. 5. Serial monitor output showing sensor readings, system status, and threshold-based gate control actions.

The serial monitor provides a direct view of the values received and processed by the controller during system operation. As shown in Fig. 5, the output displays the measured water level, rainfall status, temperature, humidity, identified operating condition, and gate response. When the sensor readings remain within the selected operating range, the system reports a normal condition and keeps the gate in its current safe position. As the measured water level approaches the configured limit, the status changes to a warning state, allowing the condition to be identified before reaching the critical level.

The serial monitor output displays the real-time readings from the sensors and the corresponding system actions. When all the parameters are within the predefined limits, the status is shown as NORMAL and the gate remains CLOSED. As the water level rises and approaches the threshold, the system changes the status to WARNING to indicate a potential risk while the gate is still closed. Once the water level crosses the critical threshold, the status becomes CRITICAL, the alert is activated (buzzer and LED ON), and the gate is instructed to OPEN. The output confirms that the controller correctly processes the sensor data, evaluates the condition, and performs the appropriate action.

B. Real-Time Parameter Values

The prototype was monitored continuously to record the sensor values during operation. Water level, rainfall, temperature, and humidity were measured at regular intervals. The controller processed each reading and compared it with the preset threshold values to identify the operating condition of the dam.

Table II presents the variation in sensor parameters recorded during real-time operation of the prototype. At lower water levels, the system remained in the normal state and maintained the gate in the closed position. As the water level increased and rainfall conditions changed, the controller identified a warning condition after the measured value approached the selected threshold.

Table II. Real-Time Sensor Parameter Results and Corresponding System Response

Observation	Water Level	Rainfall	Temperature	Humidity	System Condition	Gate Status
1	1.25 m	Low	28.4 °C	58%	Normal	Closed
2	1.80 m	Low	28.7 °C	60%	Normal	Closed
3	2.40 m	Moderate	29.1 °C	62%	Warning	Closed
4	3.10 m	High	28.3 °C	64%	Warning	Closed
5	3.80 m	High	27.6 °C	65%	Critical	Opening

The observed readings show the transition of the system from normal operation to warning and critical conditions as the monitored parameters change.

C. Threshold-Based System Response

The graph uses three conditions:

- **Normal condition:** Water level remains below the warning threshold and the system continues monitoring.
- **Warning condition:** Water level enters the intermediate range, causing the system to generate an alert while maintaining controlled gate operation.
- **Critical condition:** When the water level crosses the upper limit, the system activates the emergency response and performs the programmed gate operation.

Initially, the water level remains in the normal range and the system continues monitoring without generating an alert. When the level reaches the warning range, the controller changes the status and activates the warning indication. If the level crosses the critical limit, the system enters the critical state and sends the programmed command to the gate actuator.

The proposed system continuously monitors the water level of the dam using an ultrasonic sensor and classifies the condition based on predefined threshold values. According to the condition, the system

generates alerts and controls the gate automatically. Fig. 6 shows the variation of water level with time and the corresponding system response.

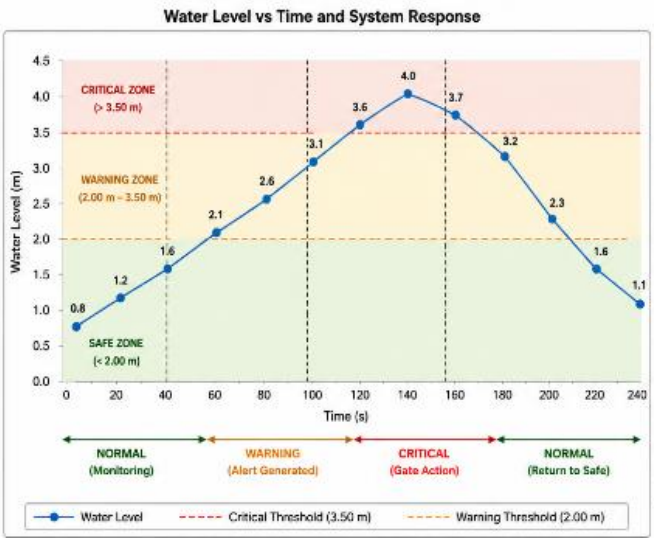


TABLE III. SYSTEM RESPONSE UNDER DIFFERENT CONDITIONS

Time (s)	Water Level (m)	Rainfall Status	System Condition	Alert Status	Gate Status
0	0.80	Low	Normal	OFF	Closed
20	1.20	Low	Normal	OFF	Closed
40	1.60	Low	Normal	OFF	Closed
60	2.10	Moderate	Warning	Buzzer ON LED ON	Closed
80	2.60	Moderate	Warning	Buzzer ON LED ON	Closed
100	3.10	High	Warning	Buzzer ON LED ON	Closed
120	3.60	High	Critical	Buzzer ON LED ON	Opening
140	4.00	High	Critical	Buzzer ON LED ON	Opening
160	3.70	High	Critical	Buzzer ON LED ON	Open
180	3.20	Moderate	Warning	Buzzer ON LED ON	Closing
200	2.30	Low	Warning	Buzzer ON LED ON	Closed
220	1.60	Low	Normal	OFF	Closed
240	1.10	Low	Normal	OFF	Closed

Fig. 6. Threshold-based water level variation with system response.

Fig. 6 illustrates the variation in water level and the corresponding response of the proposed monitoring system.

The graph therefore shows the complete sequence of operation, starting from regular monitoring, followed by warning generation and finally automated response during a critical condition. It demonstrates that the proposed prototype can continuously observe changes in water level and produce different actions based on the defined operating limits. The figure also supports the experimental results by clearly showing how threshold-based decision-making is used to connect real-time sensing with alert generation and gate control.

The water level gradually rises due to rainfall and inflow. When it crosses the warning threshold (2.00 m), the system changes the state to WARNING and activates the alert (buzzer and LED). When the water level exceeds the critical threshold (3.50 m), the system enters the CRITICAL state and sends a command to open the gate automatically. The graph and table confirm that the proposed system can monitor in real time, identify the risk level, generate alerts, and actuate the gate without manual intervention, which helps in effective dam monitoring and disaster management.

VI. CONCLUSION

The evaluation indicates that continuous sensing combined with automated control can support safer dam operation. Incoming measurements can be examined as they are received, allowing significant changes in reservoir conditions to be recognized without waiting for a manual inspection. When the measured level reaches a critical limit, the warning function informs the responsible users, while the programmed gate response can act automatically. The mobile interface also permits an operator to control the gates manually when a situation requires a decision based on current conditions. The application displays water level, operating status, and warning information, making it possible to supervise the installation from a remote location. Stored observations can be used later to examine changes over time and support planning. The system depends on reliable communication, and regular sensor maintenance and calibration are required for accurate measurements. For larger installations, additional communication and processing resources may be needed. Future work can include weather data and improved analysis methods to better identify possible risks. Overall, the proposed system combines sensor monitoring, automated response, and remote access to support safer dam operation and emergency preparedness.

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