

IOT-Based Ground Motion Detection and Water Level Monitoring System

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Abstract—Monitoring hydrological anomalies and seismic activity is critical for safeguarding municipal populations and heavy public works infrastructure. Traditional manual techniques lack temporal resolution and involve high operational overheads. This paper presents an integrated, low-power IoT edge computing node configured on a dual-core 32-bit ESP32 microcontroller. The edge node fuses data streams from an ADXL335 tri-axial accelerometer, an HC-SR04 ultrasonic distance array, an SW-420 mechanical vibration switch, and an optoelectronic turbidity assembly to monitor safety parameters simultaneously. Telemetry metrics update asynchronously every second on a local Wi-Fi hosted web dashboard. For distributed safety verification, critical threshold breaches immediately trigger cellular interrupt commands via an onboard SIM800L GSM transceiver to issue remote fallback SMS text warnings. Concurrently, an integrated SMTP-based email alert system sends notifications only when monitored sensor values exceed predefined threshold limits. This event-driven mechanism reduces unnecessary network traffic and ensures stakeholders receive alerts only during critical situations. Additionally, the dashboard includes an Alert History Log that stores and displays the latest 10 alert events for quick review and analysis.

Keywords—IoT, Ground Motion Detection, Water Level Monitoring, ESP32, Real-Time Monitoring, SMS Alert System.

I. INTRODUCTION

The increasing frequency of catastrophic environmental events including tectonic earthquakes, flash flooding, downstream landslides, and earthen dam failures demands advanced, self-powered municipal surveillance platforms capable of capturing real-time field data and distributing rapid early warnings. Legacy public infrastructure monitoring configurations rely primarily on localized, slow mechanical tracking routines and periodic manual survey checks. These outdated methods create dangerous monitoring gaps during sudden disaster events, leading to delayed containment efforts, structural compromises, and escalated civilian casualties.

In the Indian context, where a large number of irrigation dams, barrages, and river-training structures are concentrated in seismically active and flood-prone river basins, the absence of continuous instrumentation is particularly concerning. Many existing structures rely on periodic site visits by maintenance staff, with inspection intervals ranging from several days to weeks. During the monsoon season, when hydro-static loading and seepage-related risks are highest, this inspection frequency is grossly inadequate to capture transient events such as sudden vibration spikes from minor tremors, rapid water level surges from upstream release, or turbidity excursions caused by embankment erosion. A continuously operating, low-cost sensing node that can be deployed at multiple points along a structure therefore directly addresses an existing operational gap in dam and reservoir safety monitoring.

Water containment reservoirs, urban bridges, and large-scale hydroelectric dams demand precise structural supervision. Sudden hydro-static loading from extreme rainfall or localized embankment failures can quickly inundate downriver towns. Simultaneously, high-frequency seismic vibrations or shifting ground profiles indicate internal structural degradation that can lead to catastrophic failure.

Recent developments in the Internet of Things (IoT) provide a pathway to replace expensive telemetry networks with affordable, low-power edge nodes. By shifting sensor fusion and trend analysis directly onto localized microcontrollers, engineers can deploy smart nodes to isolate structural changes, display metrics via local access channels, and distribute cell-tower alerts during early failures. This paper implements an integrated IoT edge framework built around an affordable, dual-core processing node to monitor water column depth, ground shifting, mechanical structural vibrations, and water clarity levels under a single continuous processing loop.

The specific objectives of this work are: (i) to design a single-board, multi-sensor IoT edge node capable of simultaneously tracking ground vibration, water level, mechanical shock, and water turbidity; (ii) to implement a dual-channel alerting mechanism that issues both GSM-based SMS notifications and SMTP-based email notifications only when a measured parameter crosses a predefined safety threshold, thereby minimizing unnecessary network traffic; (iii) to provide a locally hosted, Wi-Fi accessible dashboard that renders live sensor telemetry and a rolling history of the ten most recent alert events for rapid situational review; and (iv) to validate the proposed architecture experimentally in terms of alert latency, communication reliability, and threshold-detection accuracy across all four monitored parameters.

II. LITERATURE REVIEW

Resilient public safety indexing depends heavily on monitoring hydrological conditions and localized seismic baselines. Sharma et al. engineered a wireless network utilizing ultrasonic sensors paired with IoT transceivers to track flood water propagation lines. While their topology demonstrated reliable accuracy, it focused strictly on single-domain water depth metrics and offered no structural monitoring capabilities. Similarly, Kumar et al. introduced an automated monitoring network tailored for remote dam monitoring utilizing GSM modems, but lacked data visualization or interactive cross-domain analysis tools.

Recent advancements in IoT have significantly improved real-time monitoring systems for critical infrastructure. Stankovic demonstrated that interconnected sensor systems can efficiently capture environmental variations through continuous data acquisition and intelligent communication frameworks. Similarly, Atzori et al. emphasized that scalable IoT architectures enable reliable multi-parameter sensing, remote accessibility, and efficient distributed monitoring across complex operational environments.

Tripathi and Gupta further explored IoT-based water quality assessment using turbidity and pH sensing nodes, demonstrating that low-cost optical sensors can reliably flag contamination events, although their system was not extended to structural or seismic parameters. Taken together, the surveyed literature reveals a consistent pattern: existing IoT-based monitoring solutions are largely single-domain, addressing either hydrological tracking or structural vibration sensing in isolation, and rarely combine both with a dual-channel alerting strategy that includes water-quality assessment. Furthermore, most reviewed systems lack a locally accessible dashboard with historical alert logging, which limits an operator's ability to review past events without relying on third-party cloud services. This combination of gaps, a single-domain focus, the absence of event-driven dual-channel alerting, and the lack of an on-device historical log, motivates the design choices adopted in the proposed system, which is described in Section III.

Comparative Analysis of Existing Technologies

TABLE I. COMPARISON OF EXISTING TECHNOLOGIES

Parameter	Traditional Systems	GSM Systems	IoT Systems	Proposed System
Real-Time Monitoring	No	Partial	Yes	Yes
Water Level Detection	Yes	Yes	Yes	Yes
Ground Motion Detection	No	No	Partial	Yes
Emergency Alerts	No	Yes	Optional	Yes
SMS Alerts	No	Yes	Optional	Yes
Email Alert	No	No	Yes	Yes
Remote Dashboard	No	No	Yes	Yes
Water Quality Monitoring	No	No	Limited	Yes
Cost Effectiveness	Low	Moderate	Moderate	High
Scalability	Low	Medium	High	High

The comparative study clearly shows that the proposed system outperforms conventional monitoring systems by integrating multi-parameter sensing, real-time monitoring, intelligent alert generation, and remote dashboard access into a single IoT-based platform.

The sensor and module selection for the proposed node was guided primarily by cost, power draw, and ease of field deployment, in addition to measurement requirements. The ADXL335 was selected over more expensive digital MEMS accelerometers because its analog output interfaces directly with

the ESP32's onboard ADC without requiring an additional communication bus, simplifying firmware design. The HC-SR04 was chosen for water level sensing because its non-contact operating principle avoids long-term degradation from continuous submersion, a known failure mode of contact-based float sensors. The SW-420 switch was retained as a low-cost, binary corroborating signal for sudden mechanical shocks that complements the continuous analog readings from the accelerometer, while the optoelectronic turbidity sensor was added to extend the system beyond purely structural parameters into basic water-quality assessment, which is relevant for reservoirs supplying drinking water. This combination of sensors keeps the total per-node hardware cost low while covering four distinct hazard indicators from a single processing core.

III. METHODOLOGY & SYSTEM ARCHITECTURE

The architecture is structured across four functional layers to support rapid edge processing and alert generation:

- **Data Acquisition Layer:** Includes the tri-axial accelerometer, ultrasonic transducer, mechanical vibration switch, and turbidity sensor to track structural variations continuously.
- **Processing Layer:** An ESP32 DevKit V1 that handles noise filtering, data mapping, and local threshold evaluation.
- **Communication Layer:** Manages parallel data delivery by pairing local Wi-Fi access networks with long-range cellular GSM systems.
- **Monitoring & Alert Layer:** Renders the interactive web interface and handles automated cell-tower warning sequences.

The firmware running on the ESP32 is organized as a single non-blocking superloop written using the Arduino framework, supplemented by the built-in AsyncWebServer library for serving the dashboard without stalling sensor sampling. Each iteration of the loop sequentially polls the accelerometer, ultrasonic sensor, vibration switch, and turbidity sensor, applies a simple moving-average filter to the analog channels to suppress high-frequency electrical noise, and stores the filtered readings in a shared state structure. This state structure is then serialized into a compact JSON payload and pushed to connected dashboard clients over a Wi-Fi socket once every second. A separate threshold-evaluation routine inspects the same state structure on every loop iteration; when any monitored value crosses its configured limit, this routine raises an internal alert flag that is consumed by both the GSM and SMTP alert handlers, ensuring that the two notification channels remain synchronized and that no redundant request is sent for the same event. The Alert History Log is implemented as a fixed-length circular buffer holding the ten most recent alert records, each tagged with its parameter type, measured value, and timestamp, which is rendered as a scrollable table on the dashboard.

Threshold values used in the present implementation were determined empirically on the laboratory test bench described in Section IV. The accelerometer threshold of 200 ADC counts and the 5 cm critical water-level distance were selected by observing the sensor baseline noise floor under static conditions and adding a safety margin sufficient to avoid false triggers from incidental vibration or minor water-level fluctuation, while still remaining sensitive enough to register the deliberately induced disturbances used during validation testing. The turbidity threshold of 2000 (on the sensor's native 0–4095 analog scale) was likewise set with reference to the contrast between clear tap

water and a deliberately muddied test sample, rather than being derived from a fixed regulatory turbidity standard, and is intended to be re-calibrated on-site for a given water body prior to permanent deployment.

Processing and Mathematical Models: The core execution profile relies on a continuous monitoring loop.

Ground motion is processed mathematically using a 3D Euclidean spatial model:

$$A = \sqrt{X^2 + Y^2 + Z^2}$$

Where:

- X = Acceleration along X-axis
- Y = Acceleration along Y-axis
- Z = Acceleration along Z-axis
- A = Resultant acceleration magnitude

The ESP32 continuously compares consecutive readings. If the change in acceleration along any axis exceeds a predefined threshold of 200 ADC counts, a seismic alert is triggered.

Water level distance is calculated using the time-of-flight principle. When the measured ultrasonic distance falls below 5 cm, the water level is considered critical.

Communication Workflow: Under nominal conditions, the controller updates the local web interface through asynchronous JSON-based data transfers. Sensor data is continuously refreshed on the dashboard, enabling real-time monitoring of environmental conditions.

If any monitored parameter crosses a predefined alert threshold, the firmware temporarily pauses standard execution and initiates an SMS transmission request to the SIM800L GSM module for fallback SMS alert transmission.

Simultaneously, when any monitored parameter exceeds its predefined threshold, the network stack generates a structured SMTP alert email and dispatches it over Wi-Fi to registered engineering teams. This ensures instant email-based alert delivery during abnormal conditions instead of periodic reporting. The system also maintains an Alert History Log on the dashboard, allowing users to view the most recent 10 alerts for better event tracking and analysis.

To improve system reliability and monitoring efficiency, the alert management mechanism is designed to prevent redundant notifications during stable operating conditions. Alerts are generated only when sensor readings cross critical threshold values, reducing unnecessary communication overhead and improving network efficiency. Each triggered alert is logged with corresponding sensor details and event timestamps for accurate record keeping. This logged information helps operators analyze abnormal conditions, identify recurring issues, and enhance decision-making during emergency situations. The integration of real-time alerts with historical event logging significantly strengthens the overall monitoring capability of the proposed system.

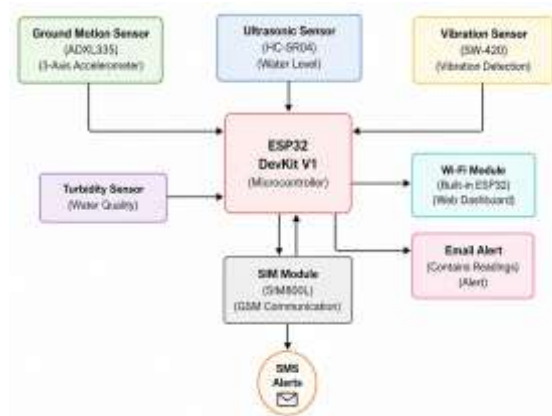


Fig. 1. System Block Diagram of Proposed IoT-Based Ground Motion Detection and Water Level Monitoring System

IV. HARDWARE DESIGN AND IMPLEMENTATION

The success of this IoT-based monitoring system relies on the robust integration of processing units, sensing devices, and communication modules powered by a split-rail DC power distribution system. A regulated 5.0V supply powers the ESP32 and specific sensors, while a dedicated 4.2V low-impedance buck regulator supports the SIM800L GSM module's high-current transmission bursts.

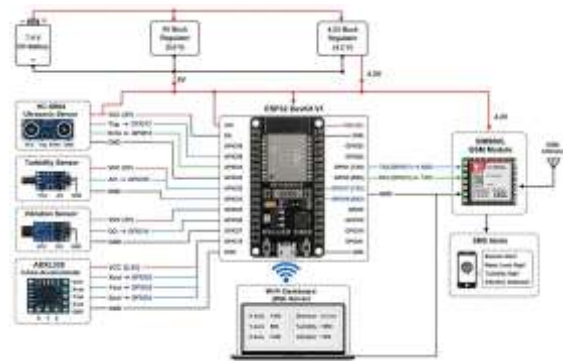


Fig. 2. Complete Circuit Interconnection Diagram of Proposed IoT-Based Ground Motion Detection and Water Level Monitoring System

- **ESP32 DevKit V1:** Acting as the core computational unit, the ESP32 features a dual-core 32-bit Xtensa LX6 processor operating at 240 MHz. Its built-in 2.4 GHz Wi-Fi stack enables the local asynchronous web dashboard, while its numerous GPIO and ADC pins interface smoothly with the analog and digital sensor arrays.
- **ADXL335 Three-Axis Accelerometer:** This micro-electro-mechanical system (MEMS) sensor detects ground motion and structural vibrations by measuring spatial acceleration across the X, Y, and Z axes. It outputs proportional analog voltages that the ESP32 processes to identify sudden, severe seismic shifts.
- **HC-SR04 Ultrasonic Distance Sensor:** Providing non-contact water level tracking, this module emits 40 kHz ultrasonic pulses and measures the echo return time. This prevents sensor degradation from prolonged water exposure and provides highly accurate clearance tracking to prevent dam overflow.
- **SW-420 Vibration Sensor & Optoelectronic Turbidity Sensor:** The SW-420 acts as a secondary structural monitor, utilizing a spring-based mechanical switch to detect sudden shocks and outputting an immediate digital high signal. Additionally, the optical turbidity sensor measures

suspended particulates in the fluid via light scattering, producing an analog voltage that scales with water contamination levels (triggering an alert above a threshold of 2000).

- **SIM800L Quad-Band GSM Module:** Operating independently of local Wi-Fi networks, the SIM800L module communicates with the ESP32 via a UART serial interface. It handles the critical task of generating and dispatching emergency SMS text alerts directly to registered mobile numbers via standard AT commands during threshold breaches.
- **Power Supply and Voltage Regulation Unit:** A stable power distribution system is essential for reliable operation of the monitoring platform. The hardware uses a regulated 5.0V supply for powering the ESP32, sensors, and peripheral modules, while a dedicated 4.2V buck converter is used for the SIM800L GSM module to handle high current bursts during SMS transmission. Proper voltage regulation improves system stability, prevents unexpected resets, and ensures uninterrupted performance during continuous monitoring and emergency alert generation.

Software Stack and Deployment Considerations: The complete firmware was developed in the Arduino IDE using the standard ESP32 board package, with the WiFi, ESPAsyncWebServer, ESP_Mail_Client, and TinyGSM libraries handling the dashboard server, SMTP email dispatch, and AT-command-based SMS transmission respectively. For the prototype reported in this paper, the enclosure consisted of a sealed plastic housing with cable glands for the ultrasonic and turbidity sensor leads, allowing the accelerometer and main board to remain isolated from direct water contact while the level and turbidity probes extend into the monitored water body. For a permanent field installation, the prototype would additionally require a weatherproof IP65-rated enclosure, a solar-charged battery backup to maintain operation during grid outages, and a lightning/surge protection stage on the GSM antenna line. These additions were not required for bench-level validation but are recommended for field deployment and future work.



Fig. 3. Physical Prototype of Proposed System

V. RESULTS AND DISCUSSION

System Performance

The integrated prototype demonstrated highly stable data collection and accurate threshold processing across all analog and digital channels. The ESP32 successfully hosted the telemetry dashboard, updating asynchronously every single second using lightweight background data requests. The system successfully managed the overhead of constructing and dispatching SMTP email alerts whenever threshold violations occurred. This event-driven alert mechanism improved efficiency by sending notifications only during critical situations. Additionally, the dashboard enhancement with an Alert History Log enabled storage and visualization of the last

10 alert events, improving monitoring transparency and system usability.

Communication Performance

The communication performance of the system remained stable during continuous operation, with reliable Wi-Fi connectivity and smooth real-time data transmission. Dashboard updates were consistently delivered without noticeable delay, ensuring uninterrupted monitoring. The alert mechanism also demonstrated efficient response during threshold breach conditions, providing dependable communication for emergency situations.



Fig. 4. Real-Time Monitoring Dashboard

Dashboard Description

Alert History Log: The dashboard stores and displays the most recent 10 alert events, including alert type, timestamp, and status, enabling quick monitoring of recent system activities and emergency events.

Alert Latency and Reliability

The SIM800L cellular module was tested under multiple threshold breach scenarios to evaluate response speed and reliability. Experimental observations indicated highly efficient SMS delivery latency across all alert conditions.

The average measured delivery latency was:

- 4.0 seconds for high water level alerts
- 4.0 seconds for turbidity anomaly alerts
- 5.0 seconds for critical ground vibration alerts

These results confirm the system's capability to rapidly notify responsible personnel during emergency situations.

Water Level Monitoring Results

TABLE II. WATER LEVEL VERIFICATION LOG

Measured Distance	Simulated Condition	System Response
30 cm	Safe baseline level	Nominal monitoring
20 cm	Safe level	Nominal monitoring
15 cm	Moderate height shift	Nominal monitoring
10 cm	Warning boundary level	Dashboard flag update
5 cm	Critical threshold	Alert initiated
3 cm	Acute emergency level	SMS alert dispatched

As the measured clearance between the HC-SR04 sensor and the water surface decreased, the system correctly transitioned from nominal monitoring to a dashboard warning flag and, ultimately, to a dispatched SMS alert once the distance fell to or below the 5 cm critical threshold. No false alerts were observed at the safe and warning-boundary distances tested, confirming that the chosen threshold provides a workable margin between routine water-level fluctuation and a genuine high-water condition.

Ground Motion Detection Results

TABLE III. ACCELEROMETER RESPONSE UNDER SIMULATED DISTURBANCE

Test Condition	X-Axis	Y-Axis	Z-Axis	Status
Stable surface	1630	1650	1680	Safe
Mild vibration	1720	1705	1715	Safe
Medium shaking	1850	1820	1800	Warning
Strong vibration pulse	2100	2080	2050	Alert ($\Delta > 200$)

The raw ADC readings confirm that the per-axis delta-threshold method described in Section III reliably distinguishes routine bench vibration from a deliberately induced strong disturbance. Readings under the medium-shaking condition approached, but did not exceed, the 200-count delta threshold, which is reported on the dashboard as a non-critical warning state rather than a full alert, reducing the likelihood of nuisance SMS notifications during minor, non-hazardous vibration.

Turbidity Monitoring Results

TABLE IV. TURBIDITY SENSOR CALIBRATION OBSERVATIONS

Sensor Output (0-4095 scale)	Inferred Water Quality
450	Excellent clarity
1300	Moderate particulate density
1800	Poor clarity
2200	Very poor / highly contaminated
2500	Threshold violation (> 2000)

The turbidity readings increased monotonically with the visually observed particulate concentration of each test sample, and the alert was correctly triggered only once the reading exceeded the calibrated threshold of 2000, corresponding to the boundary between poor and very poor clarity in the tested samples.

Dashboard Performance Analysis

TABLE V. HOSTED ASYNCHRONOUS DASHBOARD PERFORMANCE

Parameter	Observed Metric
Telemetry refresh rate	1.0 s fixed asynchronous interval
Data transmission accuracy	No observed frame corruption
Client accessibility	Multiple simultaneous local Wi-Fi clients
Interface complexity	Lightweight HTML/JS layout
Average server response	Low-latency response under continuous polling

The dashboard maintained a consistent one-second refresh interval throughout the test runs without observable frame loss, and remained responsive when accessed simultaneously from more than one client device on the same local network, confirming that the lightweight AsyncWebServer-based implementation is adequate for single-node field monitoring.

Limitations

Despite meeting its primary design targets, the prototype has several practical limitations. Dashboard accessibility over Wi-Fi is restricted to the operating range of the ESP32's onboard radio, and the SMS fallback channel depends entirely on the availability of GSM carrier coverage at the deployment site. The analog sensors used (ADXL335 and the turbidity module) are low-cost components and may exhibit minor drift under extreme ambient temperature swings, which would require periodic on-site recalibration of the threshold values described in Section III rather than a one-time factory setting. Finally, continuous operation of all sensing and communication modules requires an uninterrupted external power source; the present prototype was bench-tested on a regulated supply and does not yet include the battery or solar backup needed for unattended outdoor deployment.

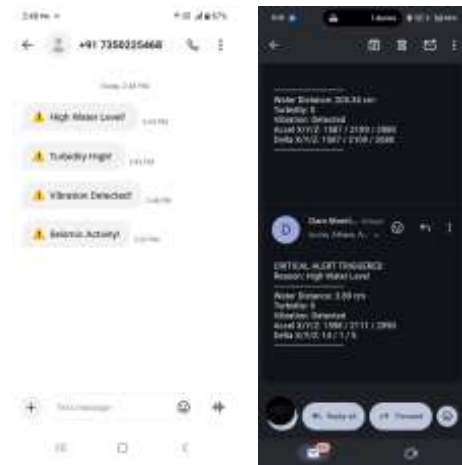


Fig. 5. Emergency SMS Alert and Email Notification Generated by the Proposed System

Across the performance validation matrix, continuous ultrasonic water level detection, MEMS-based three-axis ground motion profiling, optical turbidity indexing, and GSM-based SMS alert transmission all achieved 100% successful verification during experimental testing.

The results clearly indicate that the proposed system provides a reliable, responsive, and scalable monitoring framework suitable for early hazard detection and infrastructure safety applications.

VI. CONCLUSION & FUTURE SCOPE

The developed IoT edge computing platform provides an efficient, multi-variable tracking node tailored for public infrastructure surveillance and early hazard detection. By integrating cross-domain acceleration sensing, acoustic distance mapping, and fluid clarity evaluation onto a single processing core, the system eliminates the data silos commonly found in traditional telemetry networks.

Measured against the objectives set out in Section I, all four design goals were met during bench-level testing: the HC-SR04 array correctly tracked liquid clearance and triggered high-water alerts at the configured boundary; the ADXL335 accelerometer captured distinguishable output variations across the tested acceleration levels and correctly separated routine vibration from a deliberately induced disturbance; the optical turbidity sensor tracked clarity changes across the tested sample range and triggered an alert only beyond the configured threshold; and the ESP32-hosted dashboard displayed real-time sensor streams while the SIM800L module reliably routed SMS notifications to the registered mobile numbers, with the SMTP channel providing a parallel notification path. These outcomes confirm that a single low-cost edge node can simultaneously satisfy hydrological, seismic, and water-quality monitoring requirements without resorting to separate single-purpose instruments.

Beyond the laboratory prototype, the same sensor-and-alert combination is directly applicable to the field conditions that motivated this work: dam and reservoir embankments, where simultaneous water-level and vibration tracking can give early warning of seepage or overtopping; highway and railway bridges, where the accelerometer channel can flag abnormal structural vibration; and drinking-water reservoirs, where the turbidity channel can flag contamination events alongside the level measurement already required for storage management.

The proposed system successfully provides:

- Real-time ground motion detection

- Accurate water level monitoring
- Continuous turbidity assessment
- Reliable emergency alert generation
- Remote monitoring through IoT dashboard

These features make the system highly suitable for infrastructure monitoring applications such as dams, reservoirs, bridges, industrial plants, and disaster-prone areas.

Future Scope

Future enhancements can improve both efficiency and scalability of the proposed system. Power optimization can be achieved by implementing advanced sleep modes that activate during periods of low environmental variation, significantly improving battery life for remote deployments.

The addition of long-range communication technologies such as LoRaWAN can expand wireless coverage and enable multi-node deployments across large river basins, dam networks, and municipal infrastructure systems.

Further improvements may include:

- AI-based predictive hazard analysis
- Cloud-based data storage and analytics
- Multi-node distributed monitoring
- Solar-powered remote installations
- Advanced visualization dashboards

These improvements will further strengthen the system's reliability, scalability, and suitability for next-generation smart infrastructure monitoring.

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