iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** I **Month of publication:** January 2026

DOI: https://doi.org/10.22214/ijraset.2026.77124

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue I Jan 2026- Available at www.ijraset.com

Survey Paper on Enhancing Damage and Collapse Alert System for Bridges

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Bridges are among the most essential components of modern transportation infrastructure, enabling the movement of people, goods, and services across regions. As these structures age and traffic loads continue to increase, the risk of structural failures, undetected damage, and collapse rises significantly. Traditional manual inspection techniques are time-consuming, labor-intensive, and incapable of identifying early-stage damage in real time.

This creates a critical need for automated, intelligent, and continuous monitoring systems capable of predicting potential failures before they lead to catastrophic incidents. The rapid advancement of the Internet of Things (IoT) and sensor-based technologies has transformed the way structural health monitoring (SHM) is implemented globally. Sensors such as accelerometers, vibration sensors, water-level detectors, pressure transducers, and crack sensors allow for precise measurement of structural behavior under real-world environmental and load conditions.

These sensors, combined with microcontrollers and wireless communication modules, make it possible to collect high-frequency data and transmit it instantly to cloud platforms for analysis. The proposed "Enhancing Damage and Collapse Alert System for Bridges" integrates multiple sensing technologies, automated threshold-based event detection (ETTA), GSM- based alert transmission, and cloud-based data visualization. The system not only monitors critical parameters but also provides safety mechanisms such as automatic traffic barrier activation and immediate alert notifications to government authorities.

Abstract: The project focuses on detecting bridge health and preventing collapse using sensors. It monitors factors like cracks, vibrations, water level, and pressure to assess the bridge's condition. When danger is detected, the system automatically alerts nearby authorities such as police stations, PHCs, and transportation departments, and activates signals and barriers to stop traffic and prevent accidents. Using Structural Health Monitoring (SHM), the system provides real-time data to help engineers ensure safety, plan maintenance, and extend the bridge's lifespan. This enhances public safety, reduces accidents, and supports timely emergency response.
Keywords: IoT, Bridge Safety, Structural Health Monitoring, ETTA Algorithm, GSM Alerts, Cloud Monitoring.

I. INTRODUCTION

The project focuses on monitoring the health and safety of bridges using sensors to detect cracks, vibrations, water levels, and structural damage. When any abnormal condition such as excessive water flow, cracks, or risk of collapse is detected, the system automatically alerts nearby government offices like police stations, PHCs, and transportation departments. It also activates traffic signals and barriers up to 5 km before and after the bridge to prevent accidents, control traffic movement, and ensure quick emergency response and public safety.

The system is based on Structura Health Monitoring (SHM), which continuously collects and analyzes data from sensors installed at critical points on the bridge. This helps engineers assess structural integrity, schedule timely maintenance, and prevent major failures. The technology ensures early detection of damage caused by aging, corrosion, overloading, or floods, thereby contributing to safer transportation and reliable infrastructure.

Bridges play a vital role in economic development by supporting smooth transportation and connectivity. However, factors such as material deterioration, design defects, and increasing traffic loads can weaken their structure over time. Implementing this smart monitoring system helps in reducing the risk of sudden bridge failures, improves maintenance planning, and supports sustainable infrastructure management by combining modern IoT technology with safety automation.

II. LITERATURE SURVEY

In recent years, the use of IoT-based technologies for monitoring bridge safety and detecting structural failures has gained significant attention among researchers. Several studies have explored the integration of sensors, wireless communication, and data analytics to ensure timely detection of damages and prevention of accidents. Development of bridge diagnosis system by using sensor network Miduki Nakayama, Harutoshi Ogai, Jong-In Cheon, Ming-Yuan Hsieh, Hiroshi Inujima, Noriyoshi Yamauchi. The Graduate school of Information, Production and Systems, Waseda University 2-7 Hibikino, Wakamatsu-ku, Kitakyushu-shi, Fukuoka 808-0135, Japan Wireless IoT monitoring system in Hong Kong–Zhuhai–Macao bridge and edge computing for anomaly detectionXiaoyou Wang, Wanglin Wu, Yao Du, Jiannong Cao, Qianyi Chen, Yong XiaIEEE Internet of Things Journal 11 (3), 4763-4774, 2023 An IoT-based road bridge health monitoring and warning systemAbdul- Rahman Al-Ali, Salwa Beheiry, Ahmad Alnabulsi, Shahed Obaid, Noor Mansoor, Nada Odeh, Alaaeldin MostafaSensors 24 (2), 469, 2024 From these studies, it is evident that IoT and smart sensing technologies play a vital role in improving bridge safety, early fault detection, and disaster prevention. However, integrating flood monitoring, crack detection, and automatic alert systems into a single platform remains a crucial area of development — which this proposed system aims to address effectively.

III. ALGORITHM – EVENT TRIGGERED THRESHOLD MODEL (ETTA)

The Event-Triggered Threshold Algorithm (ETTA) is a well-known, existing algorithm used in IoT-based monitoring and Wireless Sensor Networks (WSNs). It operates by continuously sensing environmental parameters (like vibration, strain, or water level) and only triggering an action when the sensor readings exceed a predefined threshold. This minimizes power consumption, ensures real-time decision-making, and supports automated alert systems — making it a perfect match for your Bridge Health Monitoring System.
Working Principle Sensors continuously capture real-time data (vibration, water level, tilt).
Microcontroller (Arduino) compares each reading to a threshold limit.
If the data crosses that limit, an event is triggered:
Servo barrier is activated. Alert is sent via GSM module.
Data is uploaded to the cloud (Salesforce). Otherwise, the system remains in monitoring mode, conserving resources.

A. Algorithm Steps

1) *Step 1: System Initialization*
a) Start the system.
b) Initialize all modules:
- Arduino Microcontroller
- Water Level Sensor
- Accelerometer Sensor
- Servo Motor
- GSM/Wi-Fi Module
- Cloud Interface (Salesforce)

c) Set the threshold values:
- WL_threshold → Maximum safe water level
- VIB_threshold →Maximum safe vibration/tilt level

2) *Step 2: Continuous Data Acquisition*
a) Continuously read data from sensors:
b) WL = read(Water_Level_Sensor)
c) VIB = read(Accelerometer_Sensor)
d) Store the readings temporarily in Arduino memory.

3) *Step 3: Data Filtering & Preprocessing*
4) *Step 4: Event Detection*
a) Water Level Monitoring)
IF (WL_avg > WL_threshold) THEN
Trigger_Event("High Water Level")

b) Vibration / Tilt Monitoring) IF (VIB_avg > VIB_threshold)
THEN
Trigger_Event("Bridge Vibration or Collapse Detected")

5) Step 5: Event-Triggered Actions

When an event is triggered:

a) Activate Servo Motor:
- Lower the barrier to stop vehicles.

b) Send Notifications via GSM Module:
- Alert nearest Government Departments (PWD, Police, PHC).

c) Upload Real-Time Data to Cloud:
- Update the current bridge condition on the Salesforce cloud dashboard.

d) Display Alert Message on LCD / Public Display:
- "Warning: Bridge Unsafe — Use
Alternate Route."

6) Step 6: Normal Monitoring Mode

If no thresholds are crossed:

a) System remains in low- power, monitoring mode.
b) Continues periodic data sensing and logging.

7) Step 7: End

IV. MATHEMATICAL MODEL

Let S(t) represent bridge structural health at time t.

A. Sensor Parameters

- V(t) – vibration
- W(t) – water level
- C(t) – crack displacement

B. Risk Function

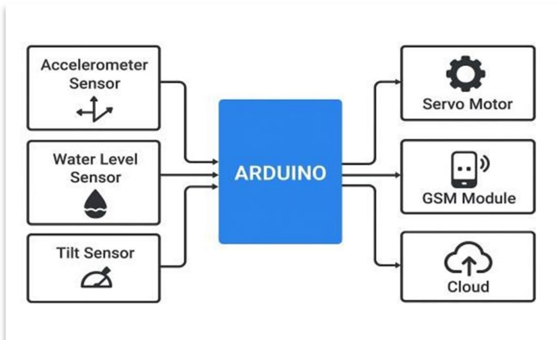
- $R(t) = \alpha V(t) + \beta W(t) + \gamma C(t)$
- Collapse predicted if:
- $R(t) \geq$ Threshold

V. METHODOLOGY

1) Requirement Analysis – The first step involves identifying key safety parameters of the bridge such as cracks, vibrations, and water levels. Appropriate sensors and communication modules are selected to ensure reliable data collection and real- time monitoring.
2) System Design – The system architecture is designed to integrate hardware components including sensors, microcontroller, GSM module, and automatic barrier control. Data flow, alert mechanisms, and communication links are structured for smooth operation.
3) Sensor Installation – Sensors are strategically placed at crucial points on the bridge to detect cracks, measure vibrations, and monitor water levels. Proper calibration ensures high accuracy in data collection.
4) Data Transmission – The GSM module facilitates wireless communication between sensors and the central monitoring system, enabling continuous real-time data transfer and remote supervision.
5) Alert and Control Mechanism – In case of critical readings or structural risks, the system automatically sends alerts to nearby Police Stations, PHCs, and Transportation Departments. Simultaneously, barriers and traffic signals are activated to prevent vehicles from crossing the bridge.

6) Monitoring Interface – A digital interface displays live bridge condition data and warning messages, helping engineers and authorities take immediate action when abnormalities are detected.
7) Testing and Deployment – The system undergoes testing to ensure sensor accuracy, communication reliability, and timely alert generation. After validation, it is deployed on bridges for continuous real- time monitoring and performance evaluation..

VI. SYSTEM ARCHITECTURE



The system architecture of the proposed IoT-Based Bridge Health and Collapse Detection System is designed to provide real-time structural monitoring, early warning, and automated control using a combination of sensors, microcontroller, wireless communication, and cloud integration.

The architecture consists of four main layers:
1) Sensing Layer
2) Processing Layer
3) Communication Layer
4) Application/Cloud Layer

Each layer works together to continuously monitor the health of the bridge and take automatic actions when abnormal conditions such as excessive vibration, cracks, or high water levels are detected.

a) Sensing Layer

This is the data collection layer where various sensors are deployed on the bridge structure to measure physical It includes: parameters.

- Accelerometer Sensor – Measures vibration and tilt. It detects sudden acceleration changes, which may indicate a potential collapse or structural instability.
- Water Level Sensor – Monitors the water level beneath the bridge. If water level exceeds a predefined threshold, it indicates a flood or high-pressure flow risk. All these sensors generate real-time analog signals proportional to their respective parameters.

b) Processing Layer

The Arduino Microcontroller serves as the central processing unit in the system.

- It continuously collects sensor data and processes it.
- It compares the real-time readings against threshold limits predefined in the program (based on safe bridge operating conditions).
- When an abnormal reading is detected (vibration or water level exceeds limit), the microcontroller triggers an event using the Event-Triggered Threshold Algorithm (ETTA).

Functions performed at this layer:

a) Data acquisition from sensors. 2.Threshold comparison and event triggering.
b) Controlling connected devices like servo motors and LCD display.
c) Communication Layer

This layer ensures data transmission and system connectivity between field devices and the cloud.

- Wi-Fi or GSM Module is used to send processed data from the Arduino to the cloud in real time.
- GSM Module is responsible for sending SMS alerts or notifications to concerned authorities such as the Public Works Department (PWD), Police Station, and Hospitals (PHC).

c) Application / Cloud Layer

This is the decision-making and visualization layer.

It includes cloud-based platforms such as Salesforce Cloud where all real-time data from the bridge is stored, analyzed, and visualized.

Functions:

- Stores continuous sensor data for long- term analysis.
- Provides a dashboard view of bridge health conditions.
- Generates real-time alerts and reports. This layer helps government departments and engineers to remotely monitor bridge health, analyze performance trends, and plan maintenance operations efficiently.

Actuation and Control Mechanism When an event is triggered by the processing layer:

- The Servo Motor automatically closes or opens barriers to control traffic movement.
- LCD Display or Signal Lights warn travelers within 5 km of the bridge.
- Alert Notifications are sent instantly to authorities.

This ensures timely action to prevent accidents and loss of life.

VII. CONCLUSION

As previously there were no forecasted notifications of bridge health, proposed system will send notifications to specified authorities . Accelerations from sensors distributed over the bridge will be analysed using an accelerometer. The environmental conditions will be taken into considerations during updating health of structure. The water level sensor will monitor the level of water that will be displayed using Arduino board. The overall data will be analyse on the cloud Finally, the Bridge diagnosis system using sensor network and sensor module is introduced. Furthermore, predictive insights obtained through continuous monitoring help engineers plan maintenance activities, extend the lifespan of bridges, and ensure public safety. Overall, this project presents a unified, intelligent, and highly scalable solution for modern bridge safety management.

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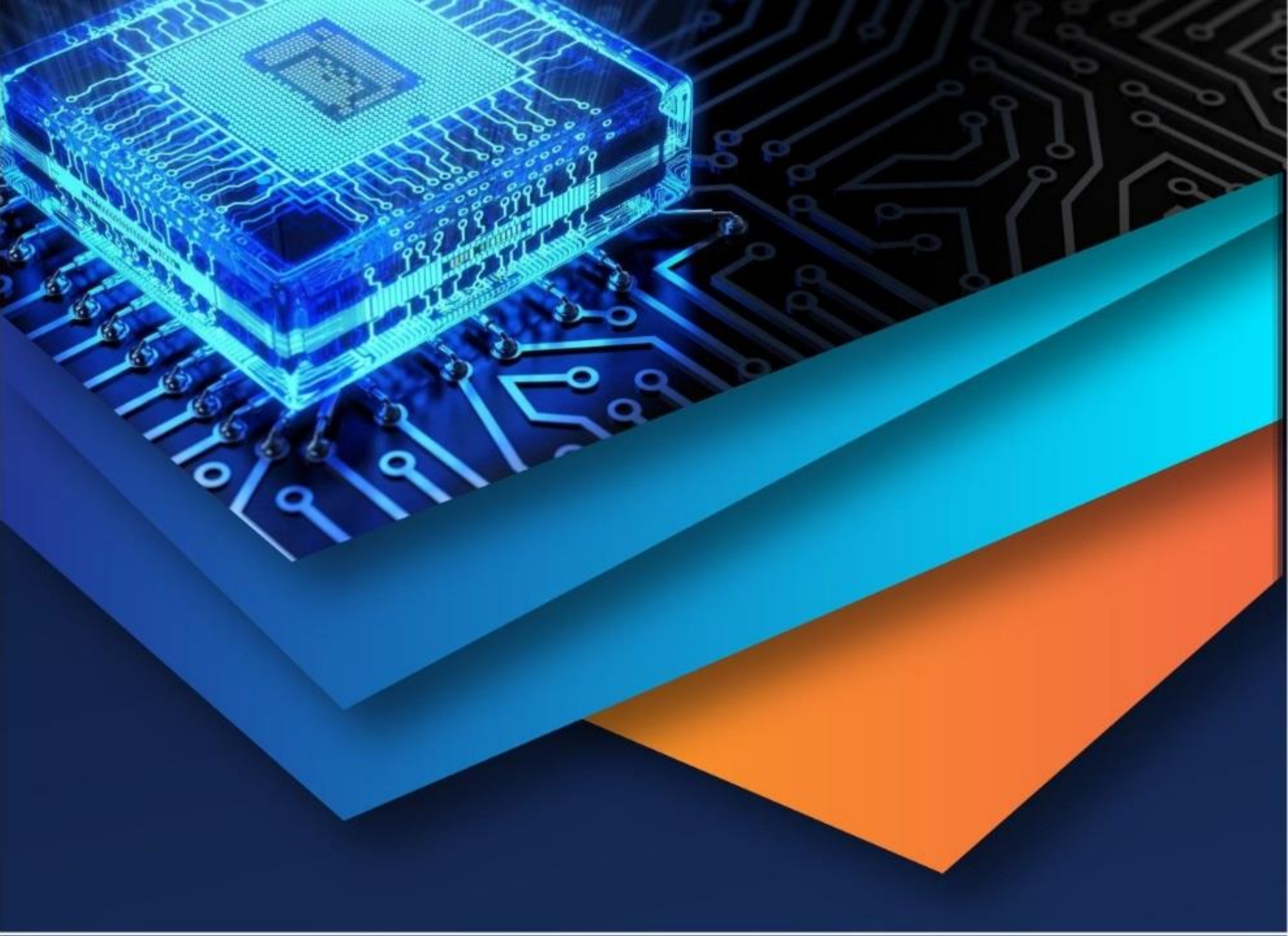

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