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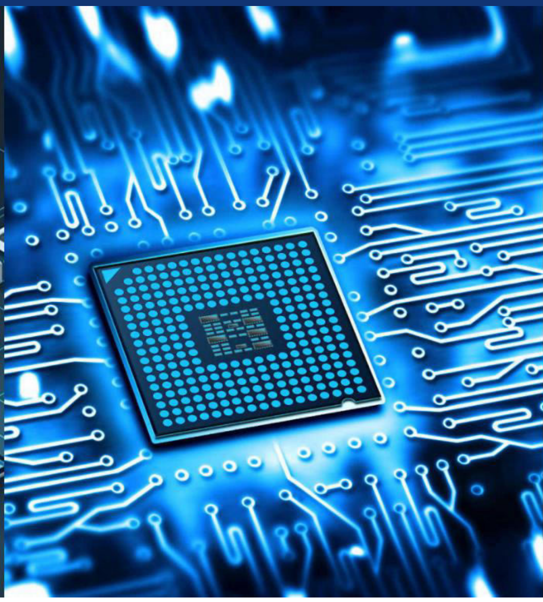


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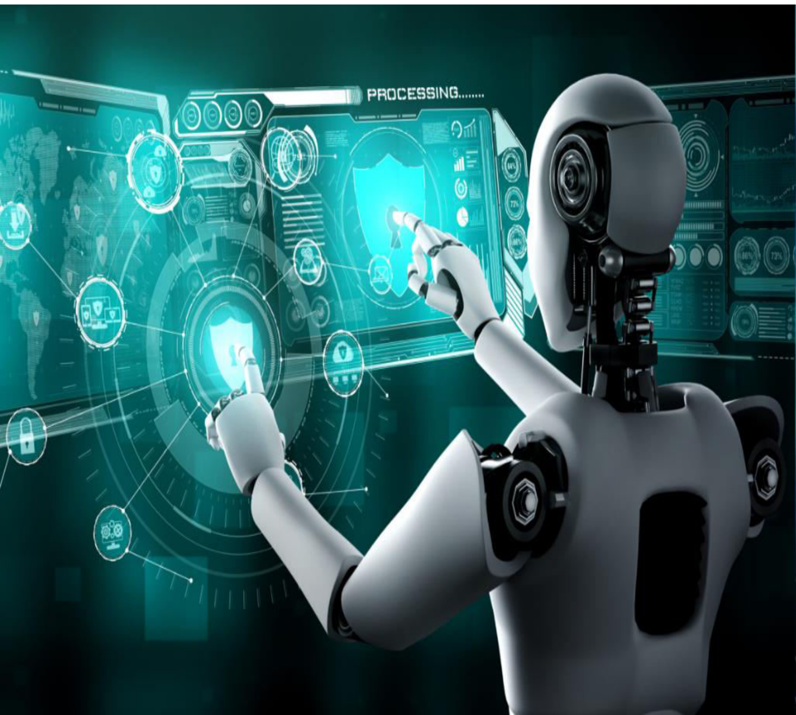

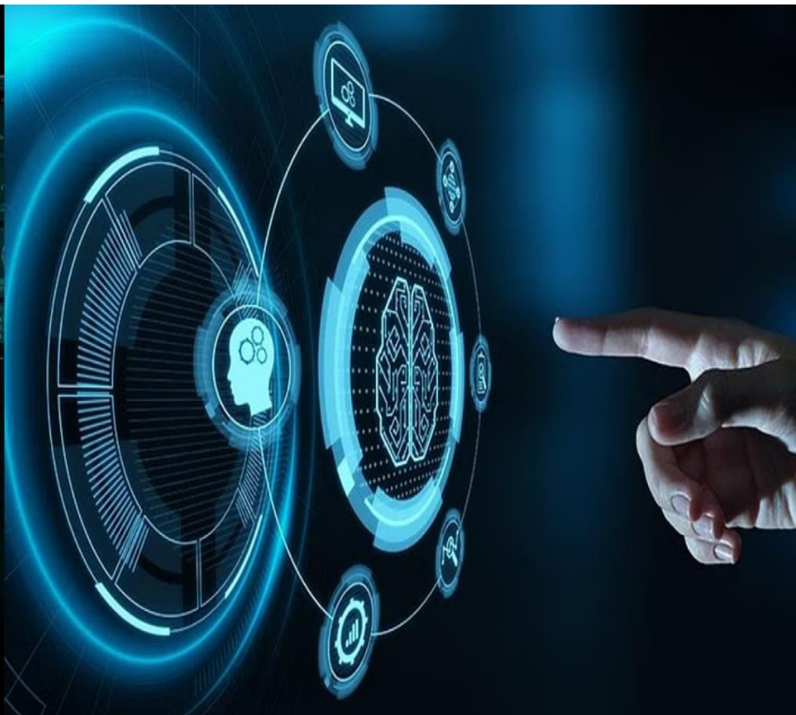

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Enhancing Damage and Collapse Alert System for Bridges

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ABSTRACT: Bridge safety has become a serious concern in recent years due to increasing traffic load, environmental conditions, and aging structures. During our study, it was noticed that many bridge failures occur not because of sudden damage, but due to small issues that are not detected at the right time. These minor problems gradually become major risks.

In this project, we developed an IoT-based damage and collapse alert system to continuously monitor bridge conditions. The system uses sensors such as an accelerometer, vibration sensor, and load sensor to collect real-time data related to tilt, vibration, and weight. This data is processed using a microcontroller and compared with predefined safety limits.

During implementation, threshold values such as vibration greater than 2.5g, tilt beyond 15 degrees, and load exceeding 120% of the safe capacity were defined. Whenever these values were exceeded, the system generated alerts and sent notifications through Telegram and SMS.

During testing, the system achieved an accuracy of approximately 92–95%. The system responded quickly and generated alerts within 1–2 seconds, which can help in preventing accidents.

From the results, it can be concluded that the system is simple, cost-effective, and suitable for real-world applications, especially in areas where continuous monitoring is difficult.

KEYWORDS: Bridge Monitoring, Internet of Things (IoT), Structural Health Monitoring, Real-Time Alert System, Vibration Detection, Load Monitoring, Smart Infrastructure, Early Warning System

I. INTRODUCTION

Bridges play a significant role in transportation systems as they connect different places and make travel easier. However, several bridges today are under constant stress due to heavy traffic and changing environmental conditions. Over time, this can weaken the structure and increase the risk of failure.

In traditional systems, bridge inspection is done manually by engineers at certain intervals. From our understanding, this method has some limitations because it does not provide continuous monitoring. There is always a possibility that small damages may go unnoticed between inspections.

To solve this problem, we decided to design a system that can monitor bridge conditions in real time. By using IoT technology, it is possible to collect data continuously and detect problems at an early stage.

The main goal of our project is:
- To monitor bridge conditions continuously
- To detect abnormal situations like vibration, tilt, and overloading
- To send alerts immediately when risk is detected
- To reduce the need for manual inspection

This project mainly focuses on practical implementation rather than only theoretical analysis.

II. LITERATURE REVIEW

In recent years, several techniques have been developed for monitoring the structural health of bridges. Early approaches mainly focused on vibration-based analysis, where changes in vibration patterns were used to identify structural damage. These methods were effective for detecting major faults but were not very efficient in identifying early-stage damage [1].

Later, wireless sensor networks were introduced to improve monitoring by collecting data from multiple locations on the bridge. These systems provided better coverage, but they lacked real-time alert mechanisms, which limited their usefulness in emergency situations [2].

With the advancement of technology, cloud-based monitoring systems were developed to store and analyze large amounts of structural data. While these systems improved accessibility and data management, they were dependent on stable internet connectivity and sometimes introduced delays in data processing [3].

Recent research has also explored the use of machine learning techniques for predicting structural failures. These approaches analyze historical data to identify patterns and forecast potential risks. However, they require high computational power and large datasets, making them less suitable for low-cost implementations [4].

IoT-based monitoring systems integrate sensors with communication technologies to provide real-time monitoring and alert generation. These systems are more practical and cost-effective, making them suitable for real-world applications [5], [6].

Based on the study of existing methods, it is clear that there is a need for a simple, reliable, and real-time monitoring system that can provide early warnings. The proposed system in this work aims to address these limitations by combining IoT technology with an efficient alert mechanism.

We also came across IoT-based systems that connect sensors with mobile applications. These systems are closer to real-world applications, but many of them are still in development stages and are not widely used yet [7], [9]. Based on our analysis, we found that most systems have one or more limitations such as high cost, lack of real-time alerts, or complexity. Therefore, in our project, we focused on developing a simple, low-cost, and real-time alert system that can be easily implemented.

III. METHODOLOGY

To develop this system, we used a combination of sensors, a microcontroller, and communication modules. Our goal was to create a system that is simple but effective.

Components Used
- Accelerometer (to detect tilt and movement)
- Vibration sensor (to detect unusual vibrations)
- Load sensor (to measure weight and overloading)
- Arduino/NodeMCU (for processing data)
- GSM/Wi-Fi module (for sending alerts)

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Working of System

The system works step by step as follows:

1. Sensors are placed on the bridge structure
2. These sensors continuously collect real-time data
3. The data is sent to the microcontroller
4. The microcontroller compares the values with predefined thresholds
5. If any value exceeds the limit:

- The system identifies it as a risk
- An alert is generated immediately

6. Notifications are sent to users through Telegram or SMS
7. The data can also be stored for future analysis

Some variations in sensor readings were observed during initial testing, which were corrected through calibration.

Alert System

In our project, the alert system plays a key role. During testing, it was noticed that whenever abnormal conditions were created (like increasing load or vibration), the system quickly sent alerts.

This ensures that authorities can take action immediately and prevent accidents.

IV. SYSTEM ARCHITECTURE

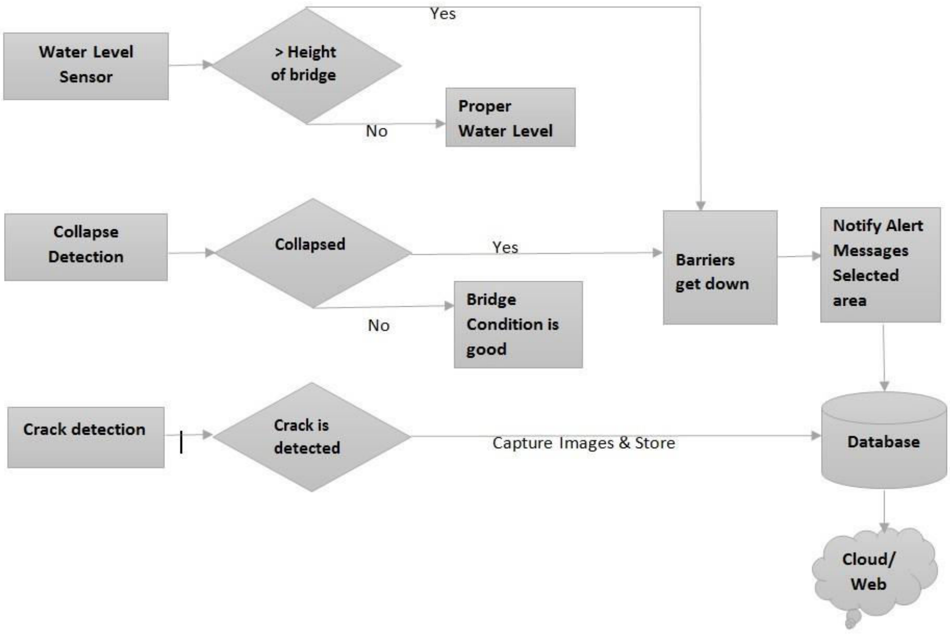

Fig 1: System Architecture of Proposed Bridge Monitoring System

In our project, the system architecture is designed using multiple sensors, a microcontroller, and communication modules. The accelerometer, vibration sensor, and water level sensor are placed on the bridge structure to continuously monitor parameters such as tilt, vibration, load, and water level. The collected data is processed using a NodeMCU/Arduino controller and compared with predefined threshold values. If any abnormal condition is detected, the system generates an alert and sends it to users through GSM or Wi-Fi modules.

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V. EXPERIMENTAL SETUP

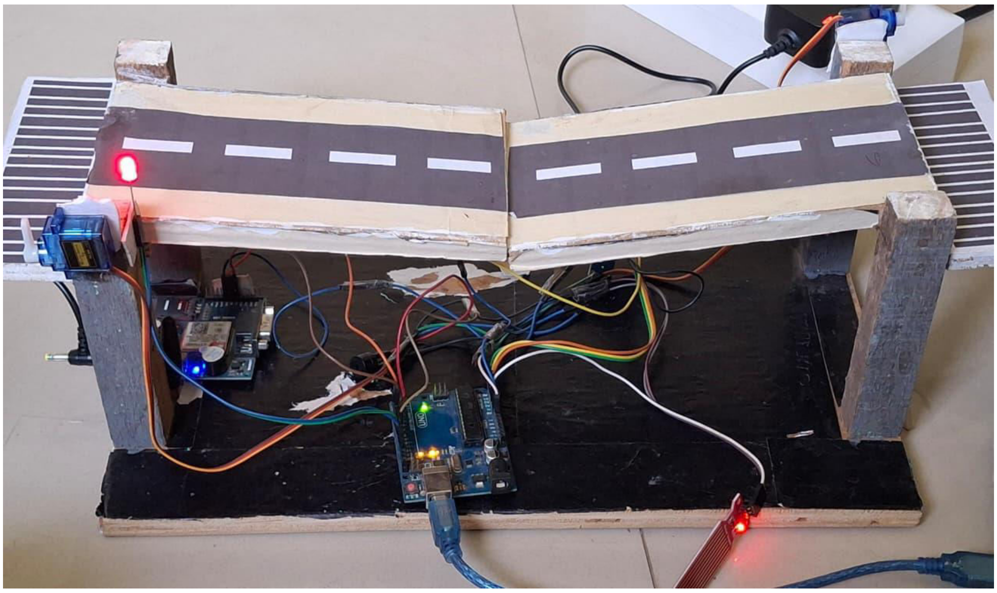

Fig 2: Prototype Model of Bridge Monitoring System

The prototype model of the system was developed using a small-scale bridge structure. Sensors were mounted at critical points of the model to measure real-time conditions. The microcontroller unit was connected with all sensors and communication modules. The testing was performed multiple times to ensure consistency of the results under different conditions. During testing, different scenarios such as increased vibration, water level and load were created to evaluate system performance.

VI. USER INTERFACE AND MONITORING

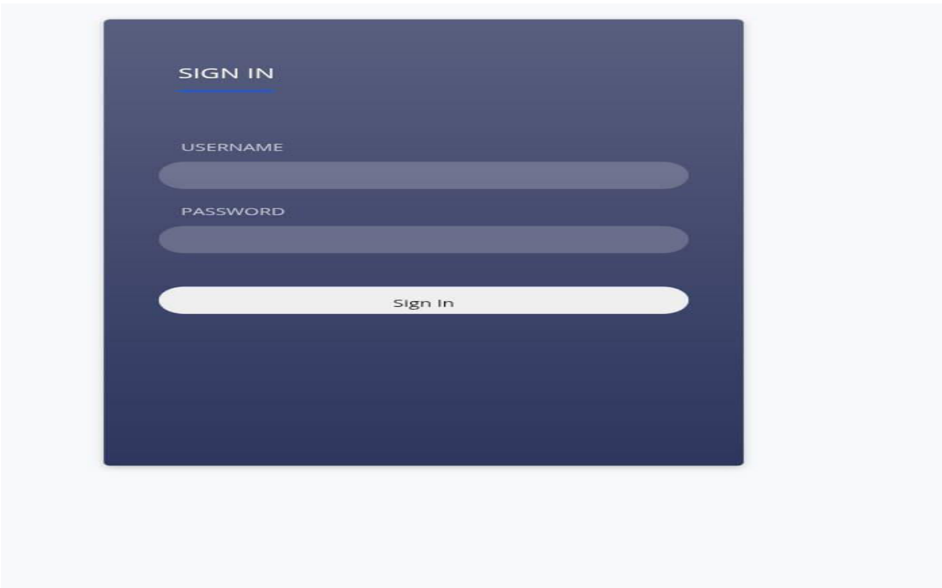

Fig 3: User Login Interface

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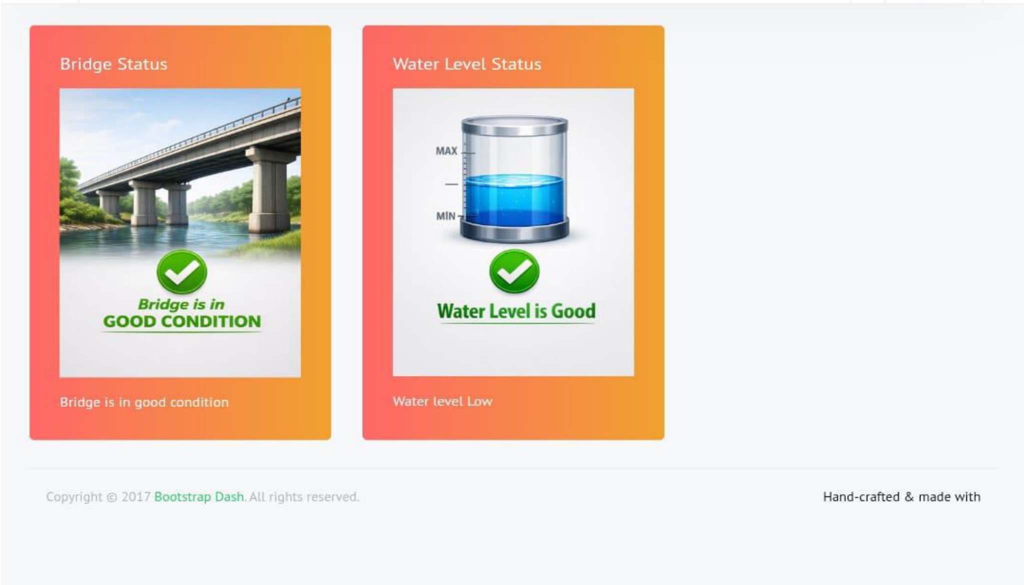

Fig 4: Monitoring Dashboard Showing Bridge Status

A web-based interface was developed to monitor bridge conditions in real time. The system includes a login page for secure access and a dashboard that displays bridge status and water level conditions. During testing, the dashboard successfully reflected real-time updates and indicated whether the bridge was safe or at risk.

VII. RESULTS AND DISCUSSION

Table 1: Performance Analysis of Proposed System

Parameter	Threshold Value	Observed Value	Status
Vibration	2.5g	2.8g	Alert
Tilt Angle	15°	16.5°	Alert
Load	120%	115%	Safe
Response Time	-	1.2 sec	Fast
System Accuracy	-	92–95%	Reliable

After implementing, the prototype was tested under different conditions such as vibration and load. It was noticed that the system detected abnormal situations correctly in most cases. Alerts were generated within 1–2 seconds when the values exceeded the limits. The system performance remained stable during testing, with an overall accuracy of approximately 92–95%.

VIII. FUTURE SCOPE

This system can be further enhanced by integrating advanced technologies such as artificial intelligence and machine learning. These technologies can be used to predict structural failures based on historical data patterns.

Future improvements may include:
- AI-based predictive maintenance systems
- Drone-based inspection for visual analysis
- Integration with 5G networks for faster communication
- Development of a dedicated mobile application with a dashboard interface

Such enhancements will improve accuracy, efficiency, and automation in bridge monitoring systems.

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IX. CONCLUSION

In this work, we focused on building a simple and practical bridge monitoring system using basic sensors and IoT technology. Instead of relying only on theoretical design, we created a working model and tested it under different conditions.

From the testing process, it was clear that the system can detect unsafe situations and provide alerts within a short time. One important benefit is that it reduces dependency on manual inspection and allows continuous monitoring.

Although the system is a prototype, it shows that such solutions can be useful for improving safety in real-world bridge structures. With further improvements, it can be expanded for larger applications.

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