

Automated Height Monitoring And Damage Detection System For Rural Bridge Infrastructure

Sudha M S¹, Pragna N², Sahana N P³, Nisarga M⁴, Hemalatha R⁵

¹ Department of ECE, RR Institute of Technology, Karnataka, India.

² Department of ECE, RR Institute of Technology, Karnataka, India.

³ Department ECE, RR Institute of Technology, Karnataka, India.

⁴ Department ECE, RR Institute of Technology, Karnataka, India.

⁵ Department ECE, RR Institute of Technology, Karnataka, India.

*Corresponding Author Email (hemalathar884@gmail.com)

Abstract

Ensuring the safety of rural bridge infrastructure is challenging due to limited monitoring systems and delayed maintenance practices. This paper presents a compact and cost-effective automated system capable of detecting both vehicle height violations and damage anomalies in real time. The proposed approach integrates an ultrasonic sensing unit for measuring vehicle clearance and a piezoelectric sensing mechanism for monitoring vibration patterns associated with structural stress or damage. A microcontroller-based processing unit analyzes the acquired data and initiates immediate response actions such as visual alerts, audible warnings, and mechanical barrier control. The system is designed to operate reliably under varying environmental conditions while maintaining low power consumption and minimal maintenance requirements. Experimental evaluation using a prototype setup demonstrates consistent performance, fast response time, and accurate detection capabilities. The proposed solution offers a practical and scalable approach for improving safety in rural transportation networks without requiring complex infrastructure.

Keywords- rural bridge safety; ultrasonic height detection; piezoelectric vibration sensing; Arduino microcontroller, embedded systems.

1. Introduction

Bridges in rural areas play a key role in connecting villages, farms, and nearby towns. However, these bridges often suffer from poor maintenance, lack of monitoring, and absence of modern safety systems, making them vulnerable to damage and accidents. The existing systems have several disadvantages. Manual inspections are slow, require more labor, and may miss early signs of damage. Static warning boards are not effective in real-time situations, especially during heavy rainfall when water levels rise suddenly. As a result, problems like high water levels and damage often go unnoticed until they become serious. The main problem is the lack of an automated system that can monitor water levels and detect structural issues continuously. This leads to accidents, delayed maintenance, and reduced bridge lifespan. To overcome this, an Automatic Height Variation and Damage Detection System is proposed. It uses ultrasonic sensors to measure water levels and gives warnings through alarms or lights when the level becomes unsafe. Piezoelectric sensors are used to detect vibrations and stress, helping identify early

structural damage. A microcontroller like Arduino processes the data and controls the system. The proposed system has several advantages. It provides realtime monitoring, reduces human effort, detects problems early, improves safety, and is cost-effective and easy to install in rural areas. In this system offers a reliable and efficient solution for improving rural bridge safety by combining monitoring, early warning, and damage detection.

2. Related Work

Several studies have investigated structural health monitoring systems for improving infrastructure safety. Vibration-based damage detection methods are widely used to identify structural faults through dynamic response analysis [2], [4]. The use of piezoelectric sensors has proven effective in capturing structural vibrations and detecting early-stage damage [6].

Wireless sensor networks and IoT-based monitoring approaches enable real-time data acquisition and remote

supervision of bridge conditions [3], [7], [12]. These systems improve monitoring efficiency and reduce the need for manual inspection. In addition, smart sensing technologies provide reliable and continuous assessment of structural integrity [10].

Previous research also highlights that integrating multiple sensing techniques enhances detection accuracy and system reliability [1], [5], [11]. These approaches form the foundation for developing efficient and automated bridge monitoring systems.

Recent advancements in bridge monitoring have focused on wireless sensor networks for continuous and real-time structural assessment [11], [12]. Survey studies highlight the effectiveness of distributed sensing systems in improving reliability and reducing maintenance efforts [13]. Piezoelectric-based sensing techniques have also been widely applied for accurate detection of structural stress and damage [14]. In addition, IoT-based monitoring systems enable remote supervision and enhance overall system efficiency [15].

3. Materials and Methods

The proposed system consists of two main modules: height monitoring and damage detection. The overall structure is illustrated using block diagrams and flowcharts.

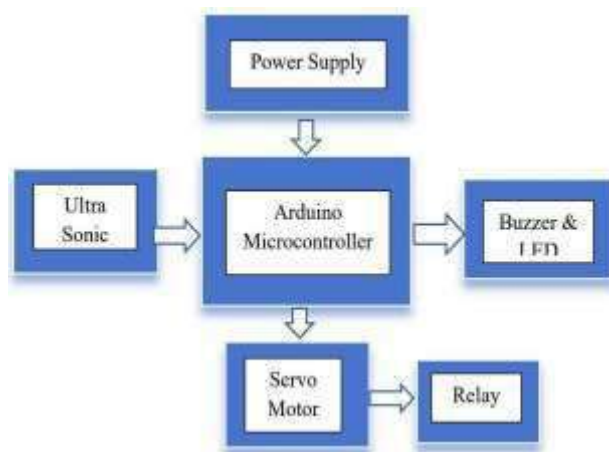


Fig 1.1:Block Diagram of Bridge Height Variant

Figure 1.1 illustrates the overall working of the bridge height variation system, showing how different components interact to ensure safety. The ultrasonic sensor continuously measures the water level by sending and receiving sound waves, and the measured data is transmitted to the Arduino microcontroller. The controller acts as the main processing unit, where the received values are compared with a predefined safe threshold.

If the water level remains within the safe limit, the system continues normal operation without any alerts. However, when the level exceeds the set limit, the microcontroller immediately activates safety mechanisms. A buzzer provides an audible warning, and an LED gives a visual indication to alert nearby users. At the same time, a servo motor is triggered to close the barrier, preventing vehicles from accessing the bridge.

Thus, Figure 1.1 clearly represents the coordination between sensing, decision-making, and control actions, enabling a quick and effective response to rising water levels and improving overall bridge safety.

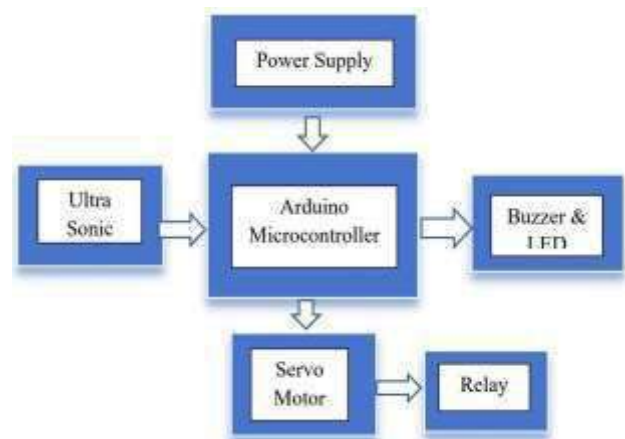


Fig 1.2:Block Diagram of Bridge Damage Detection System

A regulated power supply provides stable and continuous energy to all components of the system. A piezoelectric sensor is used to sense vibrations and stress by converting mechanical pressure into electrical signals. These signals are sent to an Arduino microcontroller, where they are analyzed in real time and compared with predefined threshold values.

Under normal conditions, the system operates without any alerts. However, if unusual vibrations or stress levels are detected, the system immediately responds. A buzzer gives an audible warning, while an LED display shows the status of the bridge, indicating whether it is safe or damaged.

This setup offers a simple and efficient way to monitor bridge health automatically and detect potential issues at an early stage, as shown in Fig. 1. Figure 2 further illustrates how the sensing and alert mechanisms work together. The sensor continuously sends data, and the controller triggers alerts only when necessary, reducing false alarms and improving reliability.

The working flow of the proposed bridge monitoring system is shown in Fig.1.3, which explains both height detection and damage detection processes.

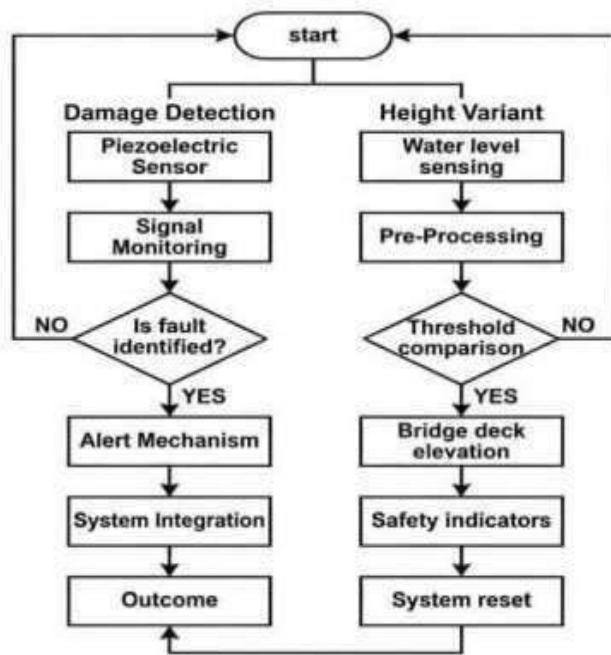


Fig 1.3:Flowchart of Height Variant & Damage Detection System

In the damage detection process, the piezoelectric sensor monitors vibrations and identifies abnormal conditions. If unusual patterns are detected, alerts are triggered. Simultaneously, the ultrasonic sensor measures water level and compares it with a predefined limit; if exceeded, warnings are activated and the barrier is controlled using a servo motor.

The system then resets and continues the cycle, ensuring real-time and continuous operation. Both processes run in parallel, enabling efficient monitoring and automatic decision-making with minimal human intervention, as shown in Fig.1.3.

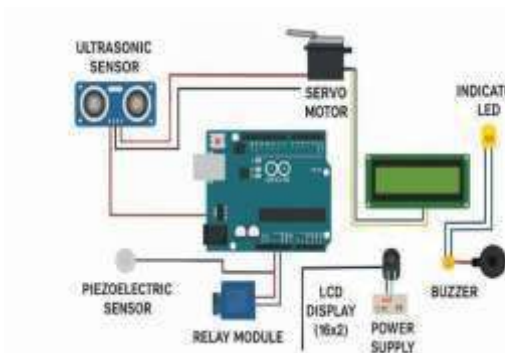


Fig 2:Circuit Diagram of the Proposed System

The circuit integrates an ultrasonic sensor, piezoelectric sensor, Arduino microcontroller, servo motor, buzzer, and LED indicators. The ultrasonic sensor measures clearance and provides digital input, while the piezoelectric sensor generates analog signals based on vibrations. The Arduino processes these inputs and controls the outputs. A servo motor operates the barrier during height violations, and alerts are given through the buzzer and LED. A regulated power supply ensures stable operation.

4. Results and Discussion

The prototype was tested under simulated conditions, demonstrating effective operation of both height monitoring and damage detection modules. The ultrasonic sensor accurately detected water level variations and triggered timely alerts when unsafe limits were exceeded, showing low response time and reliable performance. The piezoelectric sensor successfully identified abnormal vibrations caused by structural defects, and the microcontroller accurately distinguished between normal and critical conditions.

Both modules operated simultaneously without interference, ensuring continuous monitoring. The alert system provided clear notifications, while the system maintained low power consumption, stability, and adaptability through adjustable thresholds. Additionally, consistent performance across different test scenarios highlights its reliability for real-time applications in rural environments.

Overall, the system demonstrates efficient integration of sensing and control mechanisms, making it a dependable solution for enhancing safety and monitoring bridge conditions. It enables timely detection of risks and ensures quick response through automated alerts. The system maintains stable performance under varying conditions, proving its reliability. Its low-cost design and adaptability make it suitable for rural deployment.



Fig3.1BridgeNormalState

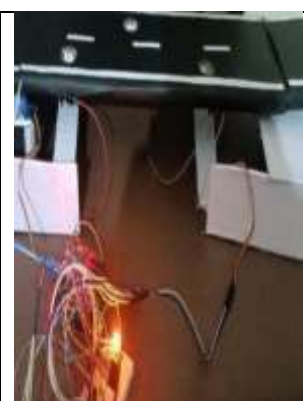


Fig3.2BridgeHeightIncrease

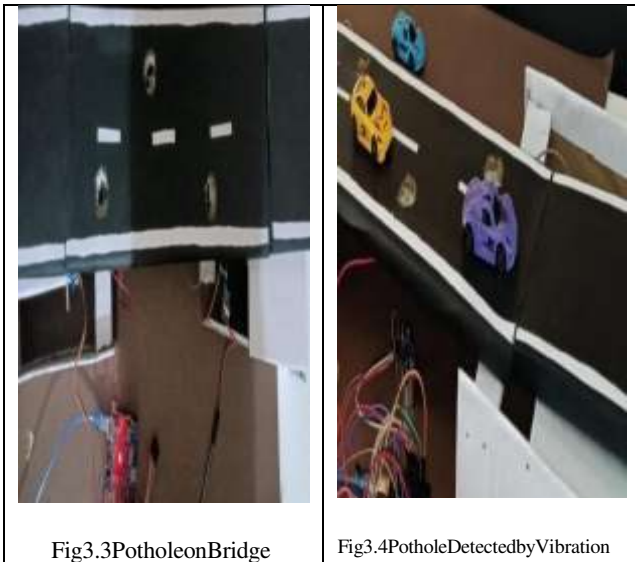


Fig3.3 Pothole on Bridge

Fig3.4 Pothole Detected by Vibration

Overall, the results confirm that the proposed system effectively performs its functions of detecting high water levels, adjusting to environmental changes like flooding, and identifying structural damage at an early stage. Its accuracy, quick response, and afford ability make it a useful solution for improving the safety and reliability of rural bridges.

Future Scope

The system can be enhanced by integrating wireless communication technologies such as GSM or LoRa for real-time alert transmission. The use of solar power can improve reliability in remote areas. Advanced techniques like Artificial Intelligence can be applied for accurate damage classification, while cloud storage can support data analysis and maintenance planning. The system can be further scaled for larger bridges by incorporating additional sensors and enabling remote monitoring through digital modeling.

5. Conclusion

The system provides a cost-effective solution for improving bridge safety through continuous monitoring of water levels and structural conditions. By integrating height sensing and vibration analysis, it enables early detection of potential risks and ensures timely response. The results demonstrate reliable performance, fast operation, and accurate detection. The design is simple, economical, and suitable for rural deployment, with scope for further enhancements to improve functionality and scalability.

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