iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** III **Month of publication:** March 2026

DOI: https://doi.org/10.22214/ijraset.2026.77858

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

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 III Mar 2026- Available at www.ijraset.com

Early Fault Identification of Two-Wheeler Wheel Fasteners Using Mechanical Vibrations

Thangapandian P[1], Kishore S[2], Sreejay A[3], Mohanraj P[4], Deepasri R[5]
Rathinam Technical Campus, India

Abstract: Fastener loosening in two-wheeler wheels is a major safety risk that can cause instability and accidents if not detected early, making manual inspection methods unreliable during actual riding conditions. To address this issue, this project introduces a vibration-based early fault detection system using a MEMS accelerometer to continuously monitor wheel vibration patterns, where loosened fasteners produce abnormal signatures compared to properly tightened conditions. These vibration signals are processed by an ESP32 microcontroller, which analyzes the data in real time using threshold-based detection to identify potential loosening. Once abnormal vibrations are detected, the system activates a buzzer and relay module to alert the rider immediately, while a GSM module sends an SMS notification to a registered mobile number for remote awareness. Experimental results validate that vibration monitoring is an effective and low-cost method for early identification of wheel fastener faults, providing a reliable and easily installable solution that enhances two-wheeler safety through preventive maintenance and real-time fault detection.

I. INTRODUCTION

A. Background Information of the Study

Two-wheelers such as motorcycles and scooters are among the most commonly used modes of transportation, particularly in developing countries like India. Their affordability, fuel efficiency, compact design, and ease of maneuverability make them highly preferred for daily commuting. With the rapid growth of urbanization and increasing traffic congestion, the number of two-wheelers on roads has significantly increased over the past decade. However, despite their convenience and economic advantages, rider safety remains a critical concern, especially in relation to mechanical failures that occur during vehicle operation.

One of the most overlooked yet dangerous mechanical issues in two-wheelers is wheel fastener loosening. Wheel bolts or nuts are responsible for securely holding the wheel assembly to the vehicle structure. During regular riding conditions, wheels are subjected to continuous mechanical vibrations, dynamic loading, braking forces, uneven road surfaces, and environmental stresses. Over time, these factors can gradually reduce the clamping force of fasteners, leading to loosening. If such loosening is not detected at an early stage, it may result in wheel wobbling, misalignment, instability, abnormal vibration amplification, or in extreme cases, complete wheel detachment. Such failures can cause severe road accidents, leading to injury or loss of life.

Traditionally, wheel fasteners are inspected manually during periodic service or maintenance intervals. However, this method has significant limitations. Manual inspection depends heavily on human attention, consistency, and scheduled servicing. Loosening of fasteners may occur between service intervals, and the rider may remain unaware of the developing fault until it becomes critical. Moreover, modern riding conditions involving high-speed travel and rough road usage further increase the risk of unnoticed mechanical degradation. Therefore, reliance solely on periodic manual checks is insufficient to ensure continuous safety.

With advancements in sensor technology and embedded systems, real-time monitoring of mechanical parameters has become feasible and cost-effective. Vibration analysis is widely used in mechanical engineering for fault detection in rotating machinery, structural health monitoring, and predictive maintenance applications. Changes in vibration signatures often indicate developing mechanical faults. Similarly, loosening of wheel fasteners produces distinct vibration patterns due to reduced clamping stiffness and increased micro-movements in the wheel assembly. By capturing and analyzing these vibration characteristics, early-stage loosening can be identified before catastrophic failure occurs.

In this context, the present project proposes an ESP32-Enabled Vibration Monitoring System for Early Detection of Wheel Fastener Loosening in Two-Wheelers. The system utilizes a MEMS accelerometer mounted near the wheel hub to continuously measure mechanical vibrations during vehicle operation. The sensor data is processed by an ESP32 microcontroller, which analyzes vibration signals using predefined threshold algorithms derived from calibrated baseline conditions. When abnormal vibration levels indicating potential fastener loosening are detected, the system immediately alerts the rider through an onboard buzzer and simultaneously sends an SMS notification via a GSM communication module.

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 III Mar 2026- Available at www.ijraset.com

The proposed solution operates automatically in real time without requiring rider intervention. It integrates mechanical vibration analysis with embedded electronics and wireless communication, thereby combining principles of mechanical engineering and IoT-based monitoring. The compact and modular design allows easy retrofitting to existing motorcycles and scooters with minimal structural modification. By enabling continuous monitoring and early warning, the system aims to reduce dependency on manual inspection, minimize human error, and significantly enhance rider safety.

Thus, this study focuses on developing a reliable, low-cost, and efficient vibration-based wheel fastener monitoring system that contributes to accident prevention and promotes smart safety integration in two-wheeler vehicles.

II. METHODOLOGY

1) To develop the proposed system, the first and most important step is to understand the vibration behavior of wheel fasteners under normal and loosened conditions. The mechanical vibration characteristics of the wheel assembly are studied to identify how loosening affects vibration signatures.
2) The suitable MEMS accelerometer sensor is selected for capturing real-time vibration data from the wheel hub region. The mounting position of the sensor is carefully determined to ensure accurate detection of vibration variations caused by fastener loosening.
3) The ESP32 microcontroller is selected as the main processing unit. It is interfaced with the accelerometer to collect analog vibration signals and convert them into digital data using its internal ADC (Analog-to-Digital Converter).
4) The firmware is developed for the ESP32 to continuously monitor vibration signals and compare them with predefined safe threshold values. These threshold values are obtained by recording baseline vibration data from a properly tightened wheel fastener condition.
5) The alert system is integrated into the design. A buzzer and optional relay module are connected to the microcontroller to provide immediate audible warning when abnormal vibration levels are detected.
6) A GSM communication module is incorporated to enable wireless notification. When a fault condition is identified, the ESP32 sends a command to the GSM module, which transmits an SMS alert to a registered mobile number.
7) The complete system is assembled on a compact hardware platform. All components, including the accelerometer, ESP32, buzzer, GSM module, and power supply unit, are integrated and enclosed in a protective casing suitable for vehicle installation.
8) After assembly, calibration and testing are carried out under different riding conditions. The system is tested with properly tightened fasteners and intentionally loosened fasteners to verify accuracy, reliability, and false alarm reduction.
9) Based on the prototype performance, necessary modifications and optimization are performed to improve sensitivity, power management, and overall system stability before final implementation.

III. LITERATURE SURVEY

R. K. Sharma & S. Verma (2023) explained a real-time vibration threshold detection system for identifying loosened fasteners. Their study shows that early-stage bolt loosening produces detectable vibration spikes. The system activates alerts when unsafe limits are crossed. Experimental testing under dynamic loading conditions proved the effectiveness of threshold-based monitoring.

Kumar & S. Reddy (2023) introduced an IoT-enabled condition monitoring framework for two-wheeler safety. Their work integrates vibration sensors, microcontrollers, and wireless modules for real-time fault detection. The system provides mobile alerts and improves rider safety through predictive monitoring.

H. Singh & P. Jain (2022) developed a smart vibration monitoring system using MEMS sensors for early fault detection in automobiles. The study highlights noise filtering and predefined threshold comparison for identifying structural abnormalities. Their low-cost design supports embedded automotive applications.

K. Murali & M. Prakash (2021) presented an IoT-based vehicle safety monitoring system using the ESP32 microcontroller. The system integrates sensors and GSM communication for real-time alerts. Their research validates the reliability of ESP32 in automotive safety applications.

J. Park & L. Chen (2021) focused on MEMS accelerometer-based loosening detection in rotating assemblies. The authors demonstrated that changes in vibration amplitude and frequency indicate early-stage mechanical instability. Their compact sensing approach supports wheel fastener monitoring.

N. S. Vyas & H. Arun (2020) studied bolt loosening using vibration amplitude and frequency characteristics. Their experimental analysis shows measurable vibration differences between tight and loose conditions. Threshold classification methods were proposed for fault identification.

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 III Mar 2026- Available at www.ijraset.com

M. S. Alavi & T. Ahmed (2020) described embedded safety alert systems for two-wheelers. The research explains the integration of buzzer alerts and vibration detection modules to prevent mechanical failures. Their work supports electronic safety enhancements in motorcycles.
T. S. Lopez & R. Diaz (2019) presented embedded fault detection techniques using real-time vibration analysis. The study discusses threshold algorithms and signal processing methods for early fault detection. Their microcontroller-based system proves effective for preventive maintenance.
A. S. Rao & R. Gupta (2019) explained the working principles and applications of accelerometers in mechanical fault detection. The authors discussed sensor placement, filtering, and sampling techniques for accurate vibration monitoring.
D. Zhu & Y. Wang (2018) proposed wireless sensor-based fault diagnosis in rotating machinery. Their research highlights vibration signal processing and real-time GSM reporting for predictive maintenance applications.
Robert Bosch GmbH (2018) in the Bosch Automotive Handbook provided comprehensive information on automotive sensors, diagnostics, and vibration behavior in vehicles. The handbook supports the design of sensor-based safety monitoring systems.
Rao, S. S. (2017) in the book Mechanical Vibrations explained vibration theory and fault diagnosis methods. The text describes how loosened bolts alter vibration signatures in mechanical systems.
L. Brown & T. Robinson (2017) analyzed the impact of road-induced vibrations on fastener integrity in automobiles. Their study shows that continuous vibration reduces bolt preload over time and recommends real-time monitoring.
Z. Wang & H. Liu (2014) described MEMS-based sensor technology for mechanical fault detection. The study explains calibration, sensitivity, and microcontroller integration for portable monitoring systems.

IV. RESULTS AND DISCUSSIONS:

A. *Testing and Experimental Analysis*

As the project mainly focuses on early detection of loosened wheel fasteners using vibration patterns, the testing was concentrated on vibration signal monitoring and threshold evaluation. The vibration sensor (MPU6050) mounted near the wheel fastener region was interfaced with ESP32 for real-time data acquisition. The analysis considered vibration amplitude variations under normal and loosened bolt conditions. The experimental setup used for testing the wheel fastener monitoring system is shown in Figure 1

FIG 1 Experimental Setup of Wheel Fastener Monitoring System

No complex structural simulation was carried out, since the focus was on real-time embedded monitoring and IoT alert mechanism. Following processes were carried out for experimental validation of the system:

B. *Sensor Calibration and Data Monitoring*

Sensor calibration is an important step in vibration-based monitoring systems to ensure accurate and reliable readings. The MPU6050 sensor was calibrated to eliminate offset errors and environmental noise. Baseline vibration readings were recorded when the wheel fasteners were properly tightened.
Under normal conditions:

- Vibration amplitude remained within safe threshold limits.
- No abnormal spikes were observed.
- The system status displayed “NORMAL” on the LCD.

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 III Mar 2026- Available at www.ijraset.com

When bolts were intentionally loosened:
- Sudden spikes in vibration amplitude were detected.
- Irregular waveform patterns were observed.
- Threshold values were exceeded.

The ESP32 continuously monitored these values and compared them with predefined limits for fault classification.

C. *Threshold Condition and Alert Mechanism:*
Choosing appropriate threshold values is essential for meaningful fault detection. If the threshold is too low, false alarms may occur. If it is too high, early-stage loosening may not be detected.
For boundary conditions of testing:
- The wheel assembly was subjected to manual rotation and road-simulated vibration.
- Loosening was gradually introduced to study vibration variation.
- Threshold values were programmed in ESP32 firmware.

When the vibration level crossed the safe limit:
- Buzzer alert was activated.
- Warning message was displayed on LCD.
- IoT alert mechanism (GSM/Wi-Fi) was triggered.

The system successfully differentiated between normal riding vibration and abnormal loosening vibration.

D. *Post-Processing and Observations*
After testing under multiple conditions, the system response was analyzed. The observed results indicate:
1) Clear increase in vibration amplitude during bolt loosening.
2) Fast response time of ESP32 in triggering alerts.
3) Stable operation under continuous monitoring.
4) Minimal false triggering during normal riding simulation.

The vibration pattern under loose condition showed irregular spikes compared to stable waveform in tight condition. The early-stage loosening was successfully identified before complete mechanical failure.

V. WORKING
Initially, power is supplied to the ESP32 microcontroller through a regulated power source. The MPU6050 vibration sensor continuously measures vibration signals in three axes (X, Y, Z) near the wheel fastener assembly.
The analog/digital vibration data is transmitted to ESP32, where it is processed in real-time. The microcontroller compares the incoming vibration values with predefined threshold limits.
If the vibration remains within the safe range:
1) The system displays normal condition.
2) No alert is triggered.

If abnormal vibration spikes occur due to loosened fasteners:
- The threshold is exceeded.
- The buzzer alarm is activated.
- Alert message is displayed.
- IoT module sends notification for safety action.

The entire system operates continuously during vehicle movement, ensuring early identification of mechanical faults. The main objective of the system is to prevent accidents caused by undetected wheel bolt loosening and to enhance two-wheeler rider safety through real-time vibration monitoring.

VI. CONCLUSION
The proposed system for early fault identification of two-wheeler wheel fasteners using mechanical vibrations has been successfully designed and implemented. By using vibration monitoring through MEMS sensors and ESP32 microcontroller, the system effectively detects abnormal vibration patterns caused by loosened wheel bolts. This approach helps in reducing the risk of accidents caused by undetected mechanical failures and improves rider safety.

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 III Mar 2026- Available at www.ijraset.com

The following are the conclusions from the evaluation and testing carried out on the system:

The vibration-based monitoring system successfully differentiates between normal and loosened bolt conditions by analyzing vibration amplitude variations.

The MPU6050 sensor effectively captures vibration spikes generated during early-stage bolt loosening, ensuring timely fault identification.

The ESP32 microcontroller processes real-time vibration data accurately and triggers alert mechanisms without significant delay.

The buzzer and display alert system provides immediate warning to the rider when unsafe vibration thresholds are exceeded.

The integration of IoT/GSM communication enables remote alert notification, enhancing preventive maintenance and safety awareness.

The system operates reliably under simulated road vibration conditions with minimal false triggering.

The proposed setup is compact, cost-effective, and suitable for integration into two-wheeler wheel assemblies for real-time safety monitoring.

Overall, the developed system proves that vibration-based monitoring is an effective method for early detection of wheel fastener loosening, contributing to improved vehicle safety and preventive maintenance in two-wheelers.

REFERENCES

[1] R. K. Sharma & S. Verma (2023, Real-Time Vibration Threshold Detection for Loosened Fasteners.
[2] Kumar & S. Reddy (2023), IoT-Enabled Condition Monitoring for Two-Wheeler Safety Systems.
[3] H. Singh & P. Jain (2022), Smart Vibration Monitoring System for Early Fault Detection in Automobiles.
[4] K. Murali & M. Prakash (2021), IoT-Based Vehicle Safety Monitoring Using ESP32 Microcontroller.
[5] N. S. Vyas & H. Arun (2020), Analysis of Bolt Loosening Using Vibration Amplitude and Frequency Characteristics.
[6] J. Park & L. Chen (2021), MEMS Accelerometer-Based Loosening Detection in Rotating Mechanical Assemblies.
[7] M. S. Alavi & T. Ahmed (2020), Design of Safety Alert Systems for Two-Wheelers Using Embedded Electronics.
[8] T. S. Lopez & R. Diaz (2019), Embedded Fault Detection Techniques Using Real-Time Vibration Analysis.
[9] S. Rao & R. Gupta (2019), Application of Accelerometers for Mechanical Fault Detection.
[10] D. Zhu & Y. Wang (2018), Wireless Sensor-Based Fault Diagnosis in Rotating Machinery.
[11] Robert Bosch GmbH (2018), Bosch Automotive Handbook (10th Edition).
[12] Rao, S. S. (2017), Mechanical Vibrations.
[13] L. Brown & T. Robinson (2017), Impact of Road-Induced Vibrations on Fastener Integrity in Automobiles.
[14] W. Zhang & Q. Sun (2016), Advanced Signal Processing Methods for Vibration-Based Mechanical Diagnostics.