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.2026.78148

www.ijraset.com

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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

Railway Track Crack Detection Systems: A Review of Recent Technologies for Intelligent Railway Infrastructure Monitoring

Sandra Jose[1], Dr. K Sathishkumar[2]
[1]*PhD Research Scholar,* [2]*Assistant Professor, Erode Arts and Science College, Erode, Tamil Nadu*

Abstract: ***Railway transportation is one of the most widely used modes of transportation worldwide, making railway infrastructure safety a critical concern. Structural defects such as cracks, fractures, and wear in railway tracks can cause catastrophic train derailments if not detected early. Traditional railway inspection techniques rely heavily on manual monitoring and periodic inspection vehicles, which may fail to identify small defects in real time. Recent advances in sensor technologies, computer vision, machine learning, and Internet of Things (IoT) systems have enabled the development of automated railway track crack detection systems. This review paper examines recent research developments in railway track crack detection technologies, including sensor-based systems, ultrasonic testing, computer vision techniques, robotic inspection systems, and deep learning approaches. The study analyzes the advantages and limitations of existing methods and highlights emerging trends such as artificial intelligence-driven monitoring systems and autonomous inspection robots. The findings suggest that integrating multiple technologies, particularly deep learning and IoT-enabled sensing systems, can significantly improve railway safety through early defect detection and predictive maintenance.***

Keywords: Railway track monitoring, crack detection, railway safety, machine learning, IoT, computer vision.

I. INTRODUCTION

Railway networks are essential components of modern transportation systems and support the movement of passengers and freight across large geographical areas. Ensuring the structural integrity of railway tracks is therefore critical for safe operations. Track defects such as cracks, fractures, corrosion, and misalignment can compromise railway safety and potentially lead to derailments or service interruptions.

Conventional railway track inspection methods mainly rely on manual inspection performed by maintenance personnel or scheduled inspection vehicles. These approaches are time-consuming, labor-intensive, and susceptible to human error. Consequently, researchers have focused on developing automated crack detection systems capable of continuously monitoring railway infrastructure. Recent advancements in sensing technologies, machine learning algorithms, and intelligent monitoring systems have enabled more efficient railway inspection techniques. Artificial intelligence and computer vision methods can analyze visual data captured from cameras, while sensor-based monitoring systems can detect structural anomalies in rails. According to recent studies, integrating machine learning and computer vision techniques significantly enhances the detection of rail defects and improves railway maintenance efficiency.

This paper reviews recent research developments in railway track crack detection systems and discusses the technological advancements that support intelligent railway infrastructure monitoring.

II. TRADITIONAL RAILWAY TRACK INSPECTION METHODS

Historically, railway track inspection has been conducted through manual observation or specialized inspection vehicles equipped with diagnostic instruments. Maintenance workers visually examine tracks to identify cracks, wear, or misalignment. However, these traditional methods suffer from several limitations, including limited coverage, slow inspection speed, and the inability to detect small structural defects. Ultrasonic inspection systems have also been used in railway maintenance. These systems generate ultrasonic waves that propagate through the rail structure and detect internal flaws based on signal reflections. Although ultrasonic testing is effective for detecting internal cracks, it often requires expensive equipment and trained personnel for operation.

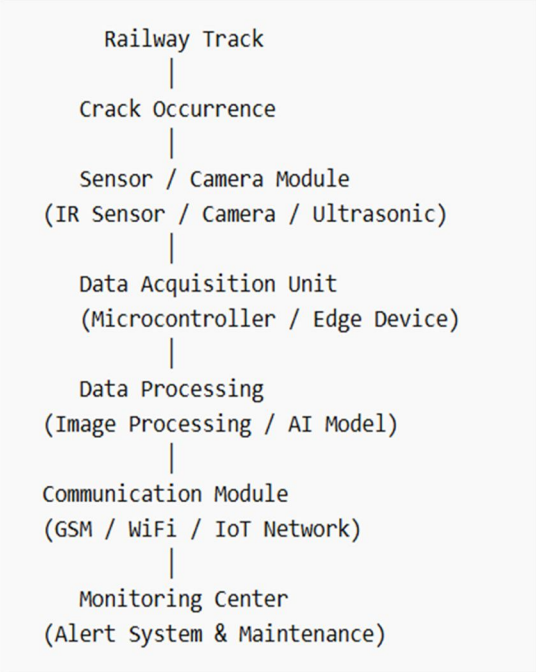
The increasing complexity of railway networks has therefore motivated the development of automated detection technologies capable of performing real-time monitoring.

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III. ARCHITECTURE OF AN AUTOMATED RAILWAY CRACK DETECTION SYSTEM

Figure 1: General Architecture of Railway Track Crack Detection System



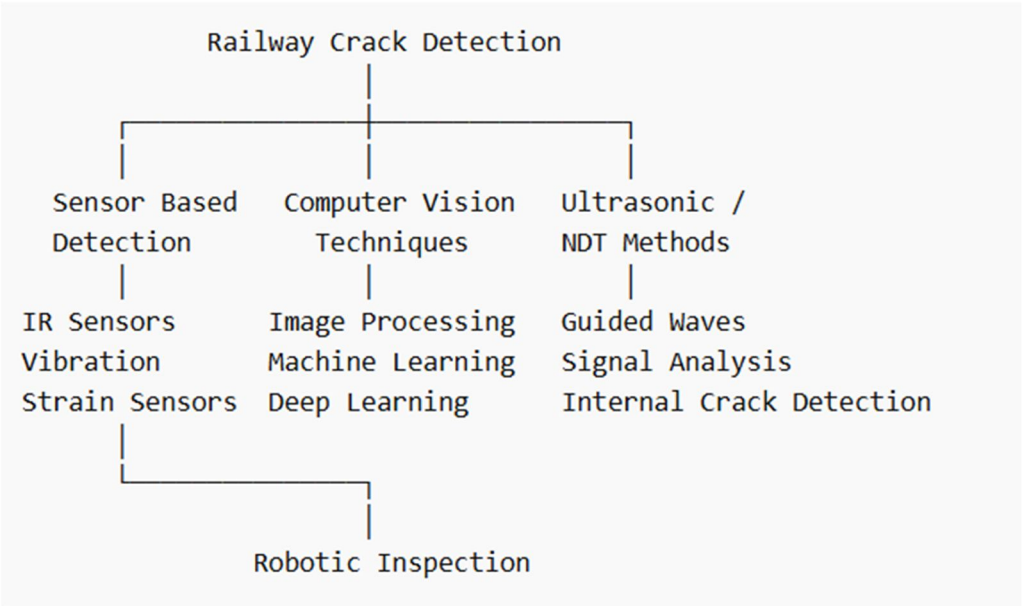
A. *Explanation*

The typical railway crack detection system consists of:

1) Detection unit – sensors or cameras used to identify track defects
2) Processing unit – microcontroller or embedded processor that analyzes the collected data
3) Communication module – transmits information to monitoring stations
4) Control center – receives alerts and initiates maintenance actions.

IV. CLASSIFICATION OF RAILWAY CRACK DETECTION METHODS

Figure 2: Classification of Detection Techniques



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V. SENSOR-BASED RAILWAY CRACK DETECTION SYSTEMS

Sensor-based systems represent one of the earliest approaches for automated railway crack detection. These systems typically use infrared sensors, vibration sensors, or strain sensors to identify irregularities in the railway track structure.

Recent research has proposed embedded sensor systems that continuously monitor railway tracks and transmit defect information to maintenance teams. For instance, one study introduced a railway crack detection system using infrared sensors integrated with a microcontroller and wireless communication module to detect surface cracks and transmit alerts to remote monitoring platforms.

Another approach uses flexible sensors and IoT-based networks to detect track bending or cracking. Sensor data is transmitted to centralized monitoring systems where anomalies can be analyzed and maintenance actions scheduled accordingly.

Sensor-based methods are relatively cost-effective and suitable for large-scale deployment; however, their detection capability may be limited for small or complex cracks.

VI. ULTRASONIC AND NON-DESTRUCTIVE TESTING TECHNIQUES

Non-destructive testing methods play a significant role in modern railway inspection systems. Ultrasonic guided wave testing is widely used to detect internal cracks that are not visible on the rail surface.

Recent research proposes AI-optimized ultrasonic detection systems that analyze reflected wave signals to identify crack locations more accurately. These systems evaluate wave dispersion characteristics and signal energy variations to determine defect locations within railway tracks.

Another study developed a hierarchical classification model for analyzing rail flaw images obtained from ultrasonic inspection equipment. The proposed artificial intelligence model improves the classification accuracy of rail defects and assists maintenance engineers in identifying structural failures more effectively.

Despite their high accuracy, ultrasonic inspection systems require specialized equipment and are often deployed through dedicated inspection vehicles rather than continuous monitoring platforms.

VII. COMPUTER VISION AND IMAGE PROCESSING APPROACHES

Computer vision techniques have become increasingly popular for railway track inspection due to their ability to analyze large volumes of visual data automatically. Cameras installed on inspection vehicles or autonomous robots capture images of railway tracks, which are then processed using image analysis algorithms. Machine learning models can identify crack patterns, surface defects, and structural irregularities in the captured images. A recent comparative study on rail damage recognition highlights that machine vision-based approaches significantly improve defect detection accuracy compared to traditional inspection methods.

Furthermore, deep learning models such as convolutional neural networks (CNNs) have demonstrated strong performance in railway defect classification tasks. Advanced models can automatically extract features from images and classify different types of rail defects.

VIII. DEEP LEARNING AND ARTIFICIAL INTELLIGENCE FOR CRACK DETECTION

Artificial intelligence has significantly transformed railway infrastructure monitoring in recent years. Deep learning techniques enable automated defect detection by analyzing large datasets of railway images and sensor data.

Recent research has proposed deep learning frameworks for detecting railway cracks and squats using image processing techniques combined with pattern recognition algorithms. These systems process captured track images, identify defect features, and generate real-time alerts for maintenance teams.

Another study implemented real-time railway defect detection using the YOLOv8 deep learning architecture, demonstrating high detection accuracy for various types of track defects.

The integration of deep learning models with embedded systems allows railway monitoring systems to operate autonomously with minimal human intervention.

IX. ROBOTIC AND AUTONOMOUS RAILWAY INSPECTION SYSTEMS

Robotic inspection systems have been developed to automate railway track monitoring tasks. These robots are equipped with sensors, cameras, and communication modules that allow them to travel along railway tracks and inspect structural conditions.

Some robotic systems use Arduino-based embedded controllers combined with crack detection sensors and wireless communication modules. These systems can transmit real-time defect information to monitoring centers and help maintenance teams identify the precise location of track defects.

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Autonomous railway inspection robots offer several advantages, including continuous monitoring, improved safety for maintenance workers, and increased inspection efficiency.

X. COMPARISON OF EXISTING CRACK DETECTION TECHNIQUES

Detection Method	Technology Used	Advantages	Limitations	Typical Applications
Sensor-Based Detection	IR sensors, vibration sensors, strain sensors	Low cost, easy deployment	Limited detection accuracy for complex cracks	Basic railway monitoring systems
Ultrasonic Testing	Ultrasonic guided waves, signal analysis	High accuracy for internal defects	Expensive equipment, requires skilled operators	Railway inspection vehicles
Computer Vision	Cameras, image processing	Detects surface cracks automatically	Sensitive to lighting and environmental conditions	Automated track inspection
Deep Learning Methods	CNN, YOLO models	High accuracy, automated feature extraction	Requires large datasets	Intelligent railway monitoring
Robotic Inspection Systems	Mobile robots with sensors and cameras	Continuous monitoring, reduced human risk	High development cost	Smart railway infrastructure

XI. CHALLENGES IN RAILWAY CRACK DETECTION

Despite technological advancements, several challenges remain in railway crack detection systems:

1) Environmental noise affecting sensor accuracy
2) Poor lighting conditions affecting image-based detection
3) Limited datasets for training AI models
4) Integration challenges with existing railway infrastructure
5) High installation costs for large-scale monitoring systems

Addressing these challenges requires interdisciplinary research involving artificial intelligence, sensor technologies, and smart infrastructure systems.

XII. FUTURE RESEARCH DIRECTIONS

Future railway monitoring systems are expected to incorporate advanced technologies such as:

1) Deep learning-based rail defect detection
2) Edge computing for real-time processing
3) Autonomous robotic inspection platforms
4) IoT-based predictive maintenance systems
5) Smart railway infrastructure integrated with AI monitoring

These technologies will enable more reliable railway monitoring and reduce the risk of railway accidents

XIII. CONCLUSION

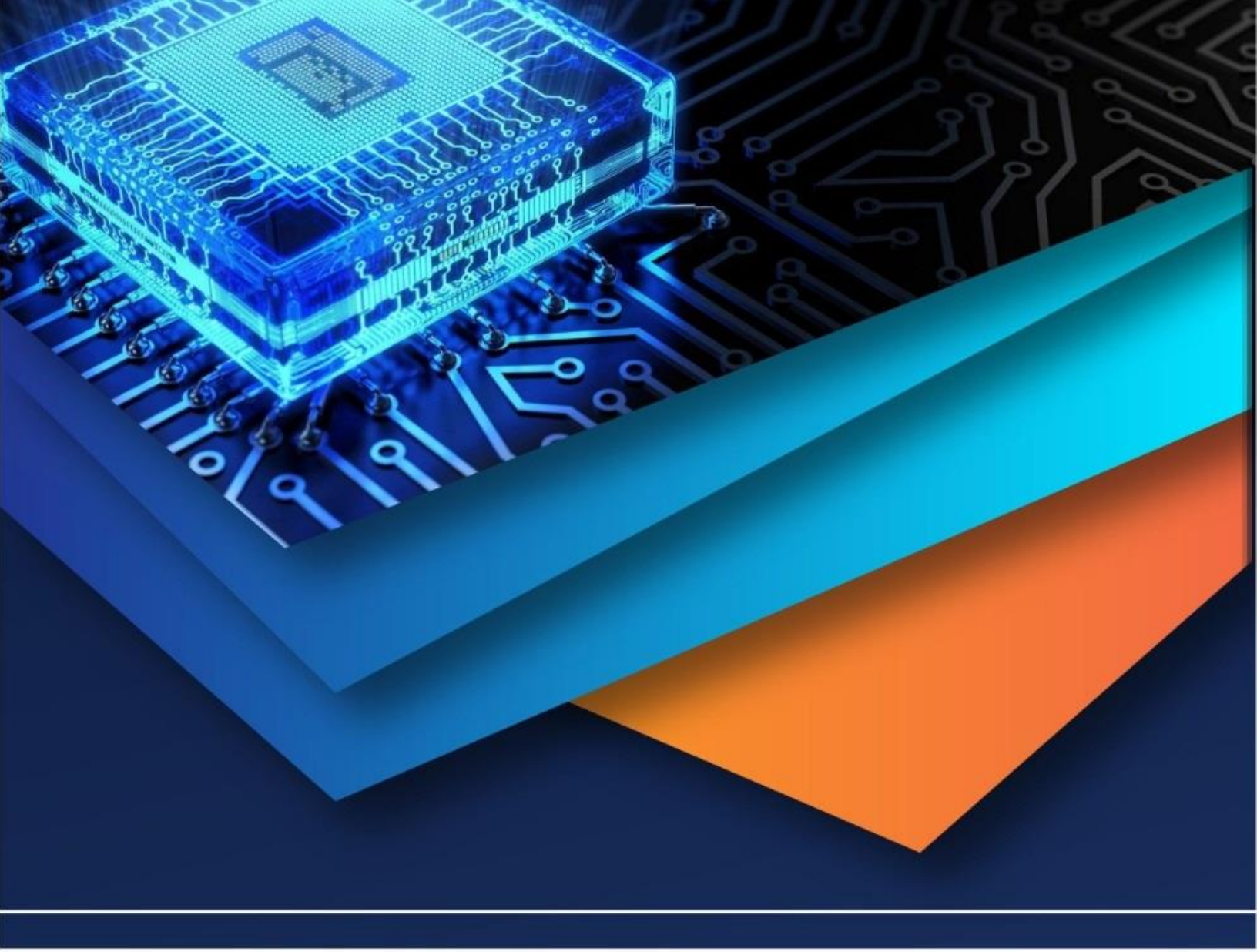
Railway track crack detection systems have evolved significantly with the advancement of sensor technologies, artificial intelligence, and IoT-based monitoring systems. Traditional manual inspection methods are gradually being replaced by automated systems capable of detecting track defects in real time. Sensor-based monitoring systems provide cost-effective solutions, while ultrasonic inspection methods enable detection of internal defects. Computer vision and deep learning techniques have further enhanced the accuracy and automation capabilities of railway monitoring systems. Future research should focus on integrating multiple detection technologies to develop intelligent railway infrastructure monitoring systems that ensure safe and reliable railway operations.

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