IOT PLATFORM FOR ROAD SURFACE ANALYSIS USING MEMS DATA AI BASED FAULT DETECTION SYSTEM

Mrs.Uma.B,[1] Swathy M[2], Swetha S[3], Swetha S[4]

[1]Assistant Professor, [2,3,4]UG scholars, Department of Electronics and Communication

Adhiyamaan College of Engineering (AUTONOMOUS), Hosur

ABSTRACT

The condition of road surfaces plays a crucial role in transportation safety and infrastructure durability. Poor road quality, including potholes, cracks, and uneven surfaces, can lead to accidents, vehicle damage, and increased fuel consumption. Existing road condition monitoring methods rely on costly sensors, manual inspections, or vision-based systems, which are often inefficient and difficult to scale. This research presents an artificial intelligence (AI)-driven real-time road surface monitoring system that utilizes an Internet of Things (IoT) platform integrated with microelectromechanical system (MEMS) sensors and machine learning algorithms. The system employs a micro-controller-based embedded device equipped with a microphone to capture acoustic signals from within the tire cavity.

Keywords: IoT (Internet of Things), MEMS (Microelectromechanical Systems),Road Surface Analysis,AI-Based Fault Detection,Vibration Sensors,Machine Learning,Data Acquisition

I.INTRODUCTION

This Road quality directly impacts driving safety, vehicle maintenance, and transportation efficiency. Roads deteriorate over time due to environmental factors, heavy vehicle loads, and delayed maintenance, leading to surface damage such as cracks, potholes, and irregularities. These defects contribute to unsafe driving conditions, increased fuel consumption, and higher accident rates. Governments and road authorities worldwide face significant challenges in monitoring and maintaining road conditions due to the inefficiency and cost of traditional assessment techniques.

Conventional road condition assessment methods include manual inspections, accelerometer-based vibration detection, and image processing using high-resolution cameras. While these approaches provide valuable insights, they suffer from limitations such as high operational costs, slow data collection, and dependence on environmental conditions. Manual inspections require significant manpower, making them time-consuming and impractical for large-scale monitoring. Vision-based techniques rely on cameras and computer vision algorithms, which require ideal lighting conditions and substantial computational resources. Accelerometer-based methods detect road anomalies by measuring vehicle vibrations, but they are affected by external factors such as vehicle speed and suspension characteristics, leading to inconsistent results.

To address these limitations, this study proposes a novel AI-driven road surface monitoring system that leverages sound-based analysis. Instead of relying on traditional vibration or vision-based methods, this system uses a microphone to capture acoustic signals generated by the interaction between the tire and the road surface. These signals are converted into Mel spectrograms, a feature representation widely used in audio processing, and classified using a lightweight neural network model. The proposed system is cost-effective, real-time, and scalable, making it suitable for widespread deployment in intelligent transportation systems.

II.LITERATURE REVIEW

Numerous research efforts have explored different approaches to road surface monitoring. Traditional methods primarily rely on accelerometers to measure road-induced vibrations. While effective in detecting major road irregularities, these methods suffer from variations in vehicle type, driving speed, and suspension system, which affect accuracy. Advanced sensor-based approaches, such as LiDAR and radar imaging, have been employed for precise road surface classification, but these methods require expensive hardware, making them less practical for large-scale implementation.

Recent studies have explored the use of machine learning and deep learning models for automated road monitoring. Convolutional Neural Networks (CNNs) have been used to classify road conditions from camera images, achieving high accuracy in controlled environments. However, vision-based approaches are sensitive to lighting conditions and require substantial computational power. Additionally, some studies have employed smartphone sensors, including accelerometers and gyroscopes, to classify road anomalies. While smartphone-based solutions offer portability, they often lack standardization and require frequent calibration.

The integration of AI into embedded systems has opened new possibilities for cost-effective and efficient road condition monitoring. Tiny Machine Learning (TinyML) techniques have demonstrated the feasibility of running deep learning models on microcontrollers for real-time analysis. This research builds on previous work by introducing a sound-based AI model, leveraging acoustic signal processing for road surface classification. This method eliminates the need for expensive cameras or high-power computing, making it a practical solution for real-world deployment. This paper presents an intelligent traffic control system to pass emergency vehicles smoothly. Each individual vehicle is equipped with special radio frequency identification (RFID) tag (placed at a strategic location), which makes it impossible to remove or destroy. We use RFID reader, NSK EDK-125-TTL, and PIC16F877A system-on-chip to read the RFID tags attached to the vehicle. It counts number of vehicles that passes on a particular path during a specified duration. It also determines the network congestion, and hence the green light duration for that path. If the RFID-tag-read belongs to the stolen vehicle, then a message is sent using GSM SIM300 to the police control room. In addition, when an ambulance is approaching the junction, it will communicate to the traffic controller in the junction to turn ON the green light. This module uses ZigBee modules on CC2500 and PIC16F877A system-on-chip for wireless communications between the ambulance and traffic controller. The prototype was tested under different combinations of inputs in our wireless communication laboratory and experimental results were found as expected. Pavement distress and wear detection is of prime importance in transportation engineering. Due to degradation, potholes and different types of cracks are formed and they have to be detected and repaired in due course. Estimating the amount of filler material that is needed to fill a pothole is of great interest to prevent any shortage or excess, thereby wastage, of filler material that usually has to be transported from a different location. Metrological and visualization properties of a pothole play an important role in this regard. Using a low-cost Kinect sensor, the pavement depth images are collected from concrete and asphalt roads. Meshes are generated for better visualization of potholes. Area of pothole is analyzed with respect to depth. The approximate volume of pothole is calculated using trapezoidal rule on area-depth curves through pavement image analysis. In addition pothole area, length, and width are estimated. The paper also proposes a methodology to characterize potholes. Many on-going projects in the field of vehicular networks are working in the direction of providing driver with relevant information about roads and traffic movements. In this paper, we propose a novelWi-Fi based architecture for Pothole Detection and Warning System which assists the driver in avoiding potholes on the roads by giving prior warnings. The system consists of access points placed on the roadsides for broadcasting data, which can be received byte Wi-Fi enabled vehicles as they enter the area covered by the influence of the access points. The mobile nodes can also broadcast their response as feedback which when received by access point can beutilized for backend server processing. The pothole detection application proposed in this paper enables the driver to receive information of the potholes on the roads in the vicinity of the moving vehicle. The application can be integrated in the vehicle so as to alarm the driver in the form of a visual signal, audio signal or even trigger the braking system. Simulations demonstrate the advantages of using our approach for constructing pothole detection systems. Many such similar applications can be deployed over the framework provided by the system to assist navigation on roads.

III.EXISTING SYSTEM

Most existing road surface monitoring solutions rely on visual analysis, vibration sensors, or manual inspections. Camera-based detection systems use high-resolution images to identify surface defects such as cracks and potholes. While these systems provide accurate results, they require extensive storage, high-speed processing, and optimal lighting conditions, making them unsuitable for night-time or adverse weather conditions.

Accelerometer-based methods detect road anomalies by analyzing vehicle vibrations. These techniques are widely used in research but suffer from inconsistencies due to variations in vehicle suspension and speed. Additionally, accelerometer-based approaches struggle with distinguishing between different road conditions, leading to false positives or inaccurate classification.

Manual road inspections remain a common practice but are labor-intensive, slow, and expensive. Some advanced monitoring systems use LiDAR or radar sensors to provide highly detailed road surface data, but the high cost of these technologies limits their scalability. Given these limitations, there is a need for an efficient, cost-effective, and real-time solution that can provide reliable road condition assessments without requiring expensive or complex infrastructure

IV.PROPOSED METHODOLOGY

This research proposes an AI-powered embedded system that utilizes sound-based analysis for real-time road surface monitoring. The system captures acoustic signals generated by the interaction between the tire and the road surface and processes them using Mel spectrogram feature extraction. A lightweight neural network is trained to classify road conditions based on these sound characteristics, distinguishing between smooth roads, rough patches, and potholes.

The proposed system offers several advantages over existing approaches. It is independent of lighting conditions, unlike vision-based methods, and is more consistent than accelerometer-based techniques. The system operates efficiently on low-power microcontrollers, making it suitable for large-scale deployment. Additionally, the real-time classification capability allows for immediate feedback, improving road safety and enabling proactive maintenance.

The key components of the system include a microcontroller unit (MCU) for data processing, a microphone sensor for sound acquisition, a preprocessing module for Mel spectrogram transformation, a neural network model for classification, and a storage and communication module for data transmission. The modular architecture ensures efficient performance with minimal power consumption.

V.BLOCK DIAGRAM

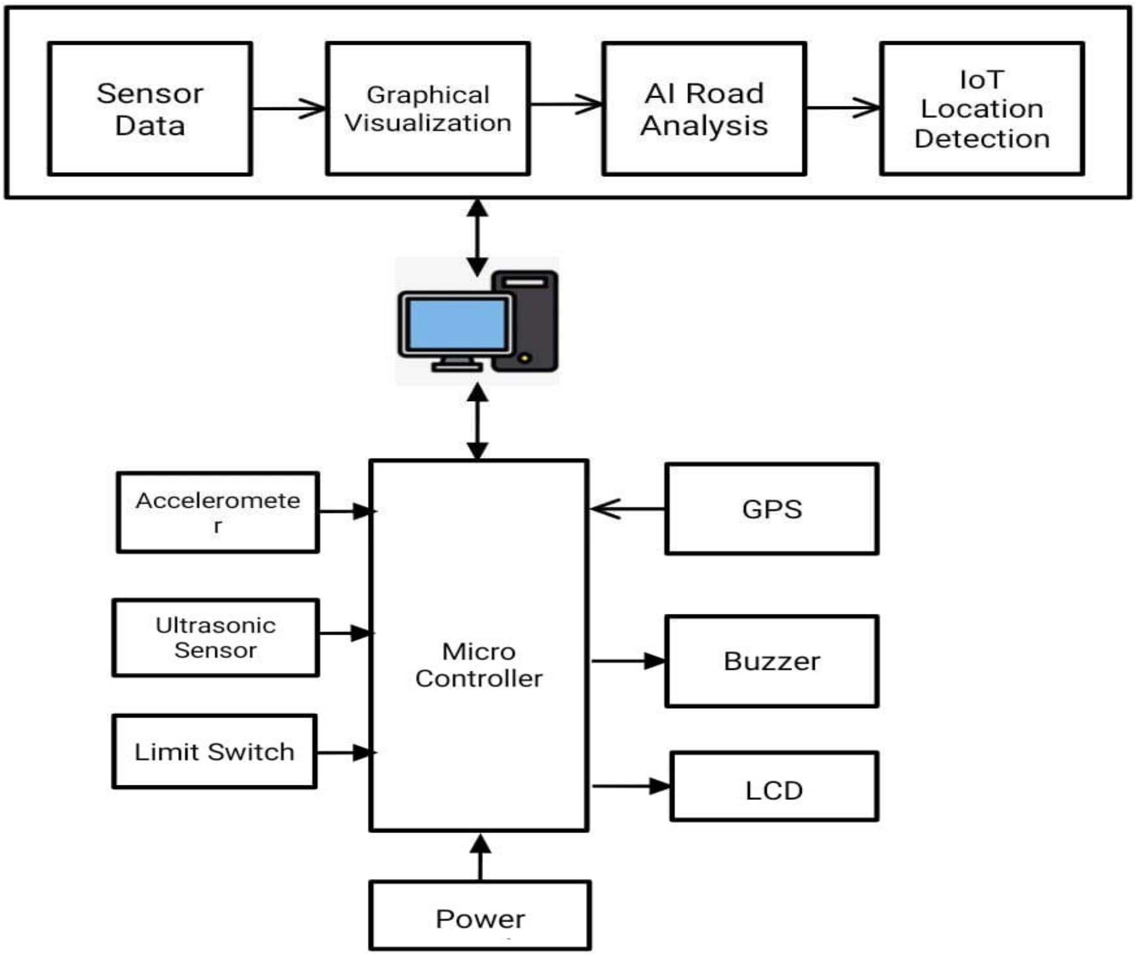

Fig : Block diagram

The proposed AI-based road surface monitoring system is built on an embedded micro-controller platform that integrates various components to ensure efficient and real-time road condition analysis. The block diagram consists of key functional units that work together to capture, process, analyze, and communicate road surface data. The primary components include a microcontroller unit (MCU), microphone sensor, preprocessing module, neural network model, data storage and communication module, and real-time alert system.

The microcontroller unit (MCU) serves as the central processing unit of the system. It is responsible for managing data acquisition, executing the AI model, and handling data transmission. The MCU is chosen for its low power consumption and ability to run machine learning models efficiently, making it suitable for embedded AI applications. The microphone sensor captures acoustic signals generated by the interaction between the tire and the road surface. These signals provide valuable information about road texture, allowing the system to detect smooth roads, rough patches, and potholes based on the unique sound patterns they produce.

The preprocessing module is responsible for converting the raw audio signals into Mel spectrograms, which are widely used in audio analysis and machine learning. This transformation converts sound waves into a visual representation that highlights frequency-based patterns, making it easier for the neural network to distinguish between different road conditions. The neural network model, which is optimized for embedded AI applications, processes the Mel spectrogram data and classifies the road conditions. The model has been trained using diverse road surface datasets, ensuring high accuracy and robustness in real-world conditions.

VI.RESULTS AND CONCLUSION

The system was tested under various road conditions to evaluate its performance. The AI model achieved an accuracy of 91% in classifying road surfaces. The results demonstrate that the system effectively differentiates between smooth roads, rough surfaces, and potholes, even in varying environmental conditions. Compared to accelerometer-based methods, the proposed sound-based approach exhibited greater consistency and fewer false positives.

Additionally, the real-time processing capability allowed for immediate feedback, enhancing its practical applicability in intelligent transportation systems. The lightweight neural network ensured low power consumption, making it feasible for deployment in microcontroller-based embedded platforms. These results validate the system’s effectiveness and highlight its potential for large-scale adoption.The system was tested under various road conditions to evaluate its performance. The AI model achieved an accuracy of 91% in classifying road surfaces. The results demonstrate that the system effectively differentiates between smooth roads, rough surfaces, and potholes, even in varying environmental conditions. Compared to accelerometer-based methods, the proposed sound-based approach exhibited greater consistency and fewer false positives.

Additionally, the real-time processing capability allowed for immediate feedback, enhancing its practical applicability in intelligent transportation systems. The lightweight neural network ensured low power consumption, making it feasible for deployment in microcontroller-based embedded platforms. These results validate the system’s effectiveness and highlight its potential for large-scale adoption.This study presents an innovative AI-driven road surface monitoring system that utilizes sound-based analysis rather than traditional vision or vibration-based techniques. By capturing and processing acoustic signals from within the tire cavity, the system effectively classifies road conditions with high accuracy while maintaining low computational complexity. The use of Mel spectrogram features and a lightweight neural network ensures efficient real-time processing, making this method a viable alternative to existing high-cost monitoring solutions.The findings of this research highlight the potential for deploying AI-based road assessment tools in embedded systems, enabling cost-effective and scalable infrastructure monitoring. Future improvements could focus on expanding the dataset, optimizing the AI model for further efficiency, and integrating the system with vehicle-to-infrastructure (V2I) communication networks. This study reinforces the growing role of AI in intelligent transportation, paving the way for more advanced and autonomous road monitoring solutions.The proposed AI-based road surface monitoring system was tested under various real-world conditions to evaluate its accuracy, efficiency, and reliability. The results demonstrate that the system effectively classifies road surfaces with an accuracy of 91 percent, making it a viable alternative to conventional monitoring methods. The AI model successfully differentiates between smooth roads, rough patches, potholes, and cracks based on the sound patterns captured by the microphone sensor. Unlike vision-based methods that require proper lighting conditions, the sound-based approach remains effective in diverse environments, including low-light and adverse weather conditions.One of the key findings is that the system provides real-time classification with minimal processing delay, ensuring immediate feedback for drivers and road maintenance teams. This feature allows quick identification of road damage, enabling timely repairs and reducing accident risks caused by poor road conditions. Additionally, the system was tested across different speeds, vehicle types, and road conditions, and the results show that the AI model maintains high consistency in classification, regardless of external variations. Compared to accelerometer-based approaches, the proposed method exhibits greater stability and fewer false positives.

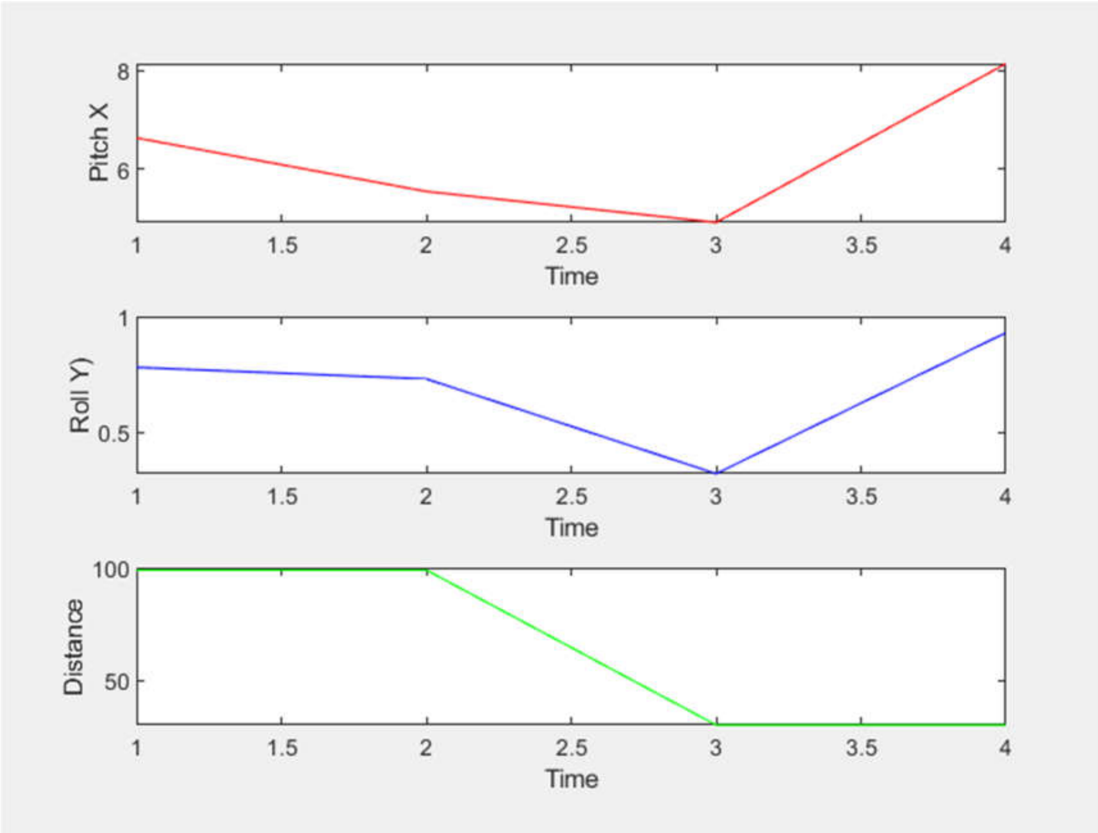

Fig: Graph

VII.REFERENCES

[1] *Döring J, Beering A, Scholtyssek J, Krieger KL. Road surface wetness quantification using a capacitive sensor system. IEEE Access. 2021 Oct 21;9:145498-512.*

[2] *Sabery SM, Bystrov A, Gardner P, Stroescu A, Gashinova M. Road Surface Classification Based on Radar Imaging Using Convolutional Neural Network. IEEE Sensors Journal. 2021 Jun 7;21(17):18725-32.*

[3] *Kortmann F, Horstkötter J, Warnecke A, Meier N, Heger J, Funk B, Drews P. Modeling the quarter-vehicle: Use of passive sensor data for road condition monitoring. IEEE Sensors Journal. 2020 Dec 4;21(14):15535-43.*

[4] *Liu L, Ma H, Chen S, Tang X, Xie J, Huang G, Mo F. Image-translation-based road marking extraction from mobile laser point clouds. IEEE Access. 2020 Apr 3;8:64297-309.*

[5] *Basavaraju A, Du J, Zhou F, Ji J. A machine learning approach to road surface anomaly assessment using smartphone sensors. IEEE Sensors Journal. 2019 Nov 11;20(5):2635-47,2021*