IoT Framework for Realtime Speed and Road Condition Monitoring

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***Abstract*: The modern economy depends on a robust transportation network, with road conditions and vehicle speed playing critical roles in economic health and safety. This real-time IoT framework is designed to monitor road conditions and vehicle speed. An accelerometer mounted on a vehicle's rear axle captures vertical acceleration data, which is used to assessing road quality. Additionally, a hall effect sensor measures the vehicle's speed in real time. The framework comprises a hardware node that gathers and transmits sensor data to a remote monitoring system. This system processes the data and visually maps road conditions, offering an immediate and clear assessment of road quality. It also monitors vehicle speed to ensure adherence to speed limits, thereby enhancing road safety. While the system's performance relies on internet connectivity, it effectively tracks road conditions and promotes safer driving by raising awareness of speed limits.**

***Keywords*: Acceleration Signals, Monitoring Server, Speed Monitoring.**

1. Introduction

The modern economy relies heavily on a robust transportation network, where the quality of roads plays a crucial role. Deterioration in road conditions can lead to significant negative impacts on both the economy and the quality of life for citizens. Poor road quality is directly linked to an increase in car accidents and casualties, with estimates indicating that over 31 percentage of crash costs are associated with inadequate road conditions. In 2021, a report from the American Automobile Association (AAA) highlighted that one in ten vehicles suffered substantial damage from potholes, resulting in an average repair cost of around 600 per vehicle, totaling approximately 26.5 billion in damages. To mitigate these issues, highway authorities are increasingly focused on enhancing pavement quality. However, effective road maintenance is challenging without a reliable monitoring system to assess road conditions accurately. Timely monitoring is essential for identifying early signs of road degradation, allowing authorities to take proactive measures to reduce repair costs and improve safety. Recent advancements in electronic devices and Microelectromechanical Systems (MEMS) sensors have opened new avenues for road condition monitoring. MEMS accelerometers can be attached to vehicles to capture vertical acceleration data, which can then be processed to estimate road quality. The integration of Internet of Things (IoT) technology allows for automated data transmission and analysis, enhancing the efficiency of road condition monitoring systems.

2. System Modelling

Figure 1 shows the step-by-step process of road condition monitoring. Begin by assessing the power requirements of all system components, including sensors, microcontrollers, and communication devices, to determine their total energy needs.

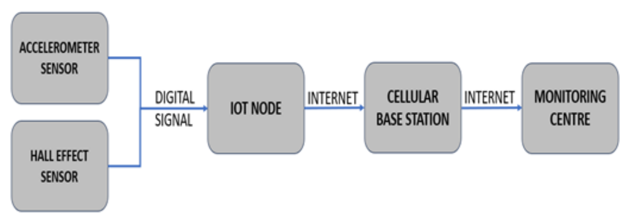


Fig. 1. Block diagram of IoT framework

Perfect for Internet of Things applications, the ESP32 is a multipurpose microcontroller with integrated Bluetooth and Wi-Fi. It can connect to a variety of sensors and devices because to its dual-core processor and numerous GPIO pins. In order to incorporate GPS units, it usually makes advantage of UART communication, joining the ESP32's RX pin to a TX pin and the GPS TX pin to an RX pin. The TX and RX pins of LTE modules are connected to the matching pins on the ESP32 via UART, in a similar manner. For smart devices and sensor networks, the ESP32 is a popular alternative due to its low-power modes and wide range of connectivity possibilities.

Three-axis accelerometer and gyroscope data are provided by the MPU6050. The Z-axis acceleration is frequently the most pertinent for road condition monitoring since it records vertical changes that signal potholes or bumps. The accelerometer's sensitivity scale can be changed based on how bad the road conditions are. Common settings, for instance, are ±2g, ±4g, etc. For pothole detection, ±4g is often sufficient.

The sensitivity scale factor for ±4g is typically 8192 LSB/g. Define a sampling rate that's high enough to capture quick changes in acceleration due to potholes. 50-100 Hz is usually adequate for road monitoring. Real world data often contains noise. To improve detection accuracy, apply a low-pass filter to smooth out the high-frequency noise. The simple moving average (SMA) filter is a good start for real-time processing.

The location of the car (latitude and longitude) is obtained using the GY-NEO6MV2 board, which has a u- b ox 6 GPS module. Seamless connections are made possible by this module's UART connection to the microcontroller. Module for cellular internet access enables the IoT node to connect to the distant server. Using a sampling rate of 125 samples per second, the accelerometer in this design gathers acceleration signals, which it then transmits to the microcontroller over the Serial Peripheral link (SPI) link. Together with the vehicle's speed and current position obtained from the GPS module, the microcontroller timestamps these signals and sends them to the monitoring server via the 4G module.

3. IoT Node Design

Ensuring safe and effective transportation requires maintaining acceptable road conditions. Conventional road monitoring techniques are ineffective and time-consuming. This is addressed by a IoT-based real-time road condition monitoring system that uses wireless communication, GPS, and sensors to identify potholes, bumps, and other road irregularities. Utilizing a MPU sensor, Hall Effect sensor, and GPS module, the system gathers data, processes it with ESP32, and sends it to a server and a Android application for monitoring in real time. This increases road safety and maintenance efficiency by empowering authorities and users to act promptly. Fig.2 is the block diagram representing this system and Fig.3 is the detailed circuit diagram showing the connections between the components.

A. Power Supply

For the Node MCU ESP32, sensors, motor driver IC, and peripheral modules to get the required voltage and current, the system needs an external power source of 12 V.

B. Node MCU ESP32

As the central processing unit, the ESP32 is in charge of gathering sensor data, processing it, and sending the pertinent data to the server. To guarantee flawless functioning, it also regulates external parts including the GPS module, LED indicators, and motor driver IC.

C. Sensors for Data Collection

- *Motion Processing Unit (MPU)*: The MPU sensor, most likely an MPU6050, senses the vehicle's tilt, motion, and vibrations. It facilitates the detection of road imperfections like potholes and bumps.
- *Hall Effect Sensor*: By tracking the vehicle's speed and motion, this sensor enables the system to pinpoint the precise location of road irregularities in relation to the motion of the vehicle also the authorities can get the vehicles above a limited speed in the road. FEYING 3144 is used as the hall effect sensor here.

D. Server and Android Application Integration

Real-time data from several devices is processed and stored by a server that is in communication with the ESP32. Users can access real-time road condition updates through the server. (Here android app is used only for controlling of the prototype). Authorities can receive notifications and possibly report the high speed cases for taking actions.

E. Motor Control System

Two DC motors are controlled by the L298N Motor Driver IC. These motors can be used for testing or to mimic the motion of a vehicle. The motor driver receives control signals from the ESP32 and uses them to operate DC Motors 1 and 2.

F. GPS Module

Real-time geographic coordinates are provided by the GPS module to aid in the precise mapping of road conditions. Users and authorities can take action based on precise locations thanks to the data that is supplied to the server.

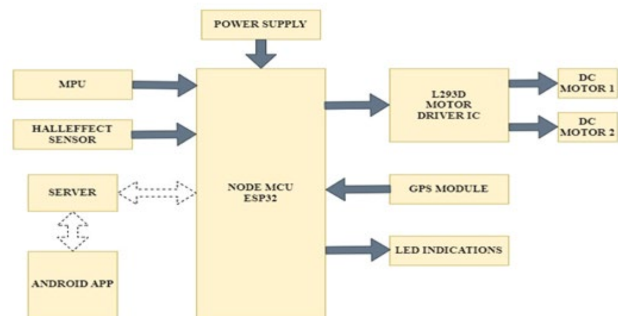


Fig. 2. Block diagram of the system

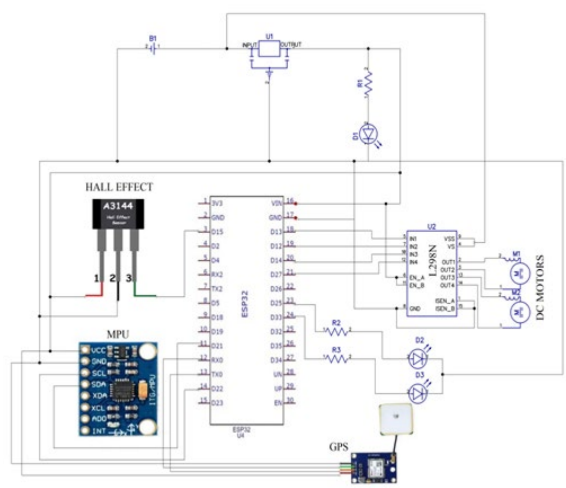


Fig. 3. Circuit diagram of the system

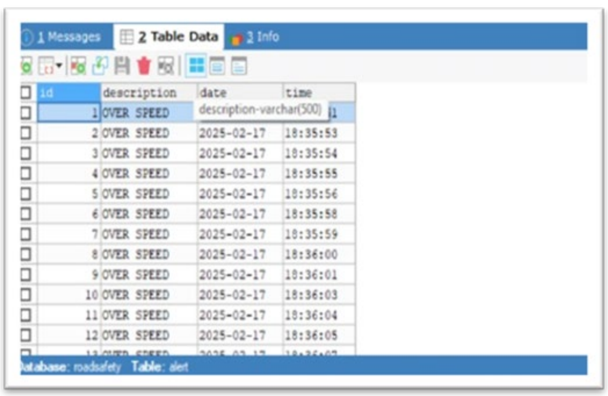
4. Monitoring Server

In order to facilitate smooth data flow, the Arduino IDE and PyCharm interact via a web address or endpoint, usually utilizing HTTP or MQTT protocols. For additional insights and action, this connection makes it easier to detect and log pothole related data in real-time. SQLyog is a graphical tool for MySQL database administration, and shows its data storage interface. Information from the "readings" tab of the "road safety" database is displayed in the Fig.4. Each row of the table contains values corresponding to the columns "id," "depth," "latitude," and "longitude." And also the message of overspeed of vehicles is records in MySQL with vehicle id and time of overspeed as shown in Fig.5. This setup is useful for organizing and assessing location-based data, possibly for environmental monitoring or traffic safety applications. In contrast to Microsoft SQL Server, another well-known relational database management system created by Microsoft, SQLyog is made especially for MySQL databases and offers an easy-to-use interface for effectively managing tables, queries, and data synchronization activities.

1 Messages | 2 Table Data | 3 Info

id	depth	latitude	longitude
6815	-504	10.051788	76.619370
6816	-1708	10.051788	76.619370
6817	-1520	10.051788	76.619370
6818	-1256	10.051788	76.619370
(Auto)	(NULL)	(NULL)	(NULL)

Fig. 4. Data storage in MySQL



1 Messages | 2 Table Data | 3 Info

id	description	date	time
1	OVER SPEED	description-varchar(500)	
2	OVER SPEED	2025-02-17	18:35:53
3	OVER SPEED	2025-02-17	18:35:54
4	OVER SPEED	2025-02-17	18:35:55
5	OVER SPEED	2025-02-17	18:35:56
6	OVER SPEED	2025-02-17	18:35:58
7	OVER SPEED	2025-02-17	18:35:59
8	OVER SPEED	2025-02-17	18:36:00
9	OVER SPEED	2025-02-17	18:36:01
10	OVER SPEED	2025-02-17	18:36:03
11	OVER SPEED	2025-02-17	18:36:04
12	OVER SPEED	2025-02-17	18:36:05

Database: roadsafety Table: alert

Fig. 5. Data storage of overspeed in MySQL

The pothole detection map utilizes a color-coded system green, yellow, and red to represent the severity of road damage based on pothole depth, providing a clear and intuitive way to assess road conditions. Green markings indicate shallow potholes that have minimal impact on vehicles and do not require urgent repair. Yellow represents moderately deep potholes that can cause discomfort and potential damage to vehicles, alerting drivers to be cautious while passing through those areas. Red highlights deep and hazardous potholes that pose a significant risk to both vehicles and pedestrians, requiring immediate.

attention from road maintenance authorities. Figure 6a.,6b. and 6c. are the maps showing the pothole representation according to the depth of it. This system can be implemented using IoT-based sensors and GPS module installed on vehicles or road infrastructure to continuously monitor road surfaces. The collected data is processed and mapped in real time, allowing authorities to prioritize repairs and ensuring safer transportation. Drivers can also access live updates through navigation apps, helping them avoid severely damaged routes. This smart monitoring approach enhances urban road management by enabling proactive maintenance and reducing accidents caused by poor road conditions.Fig.7 shows the complete hardware setup of the speed and road condition monitoring sytem.

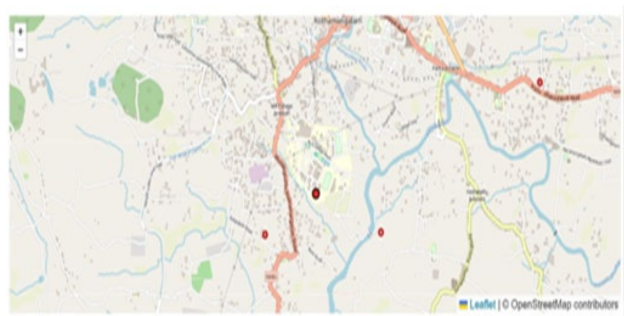


Fig. 6. Representation pothole as red colour in map

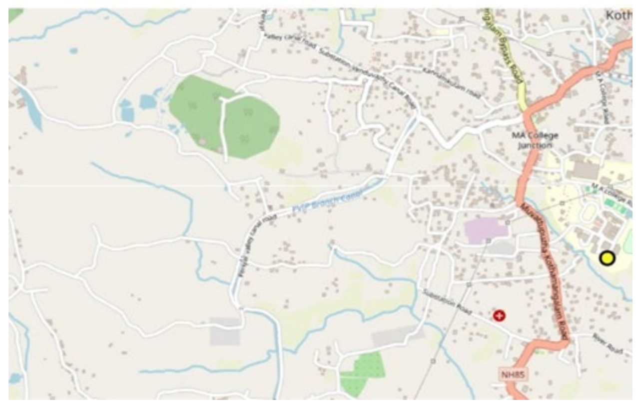


Fig. 7. Representation pothole as yellow colour in map

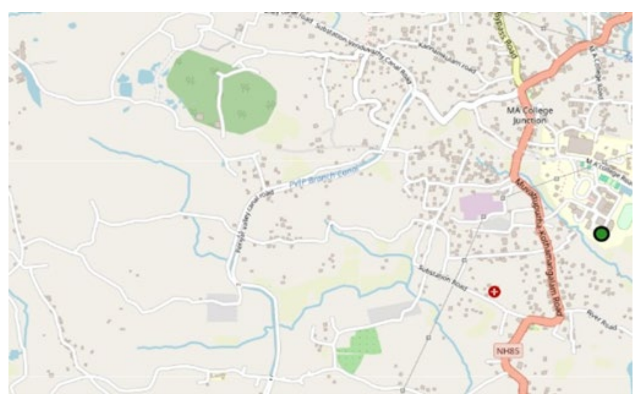


Fig. 8. Representation pothole as green colour in map

5. Conclusion

The hardware implementation of a real-time road condition monitoring system integrates essential components such as the MPU6050 accelerometer sensor, ESP32 microcontroller, and a motor driver IC to effectively detect and analyze road surface conditions. The MPU6050 captures vibrations and irregularities, translating them into measurable data that reflects road quality. The ESP32 processes this data and transmits it wirelessly to a central monitoring system, enabling seamless real-time reporting. The motor driver IC plays a crucial role in regulating motion, ensuring the system's adaptability to different vehicular environments. This combination of hardware components provides an efficient and reliable method for continuously assessing road conditions. By utilizing real-time data transmission and storage, this system enables proactive road maintenance and safety enhancements. Authorities can leverage the collected data to identify deteriorating road sections, prioritize repairs, and optimize maintenance schedules, reducing long-term infrastructure costs. Additionally, integrating vehicle speed data allows for a more comprehensive analysis of road anomalies and their impact on driving behavior. With its IoT-based connectivity and data-driven insights, this system contributes to the development of smart transportation networks, promoting safer and more efficient road management while supporting sustainable urban infrastructure planning.

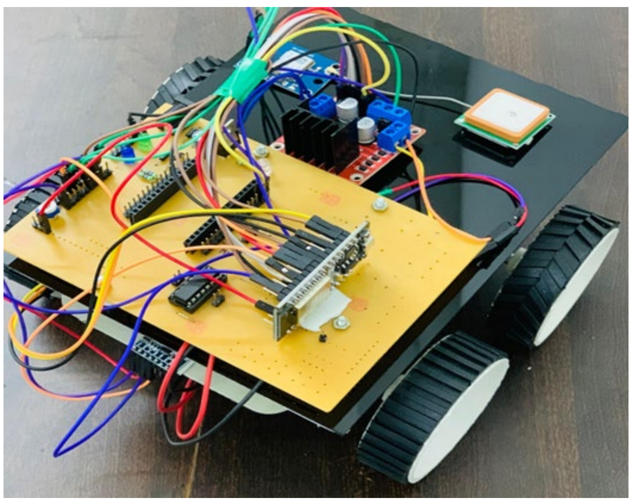


Fig. 8. Prototype of road condition monitoring system

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