Iot-Based Highway Potholes and Hump Detection

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Abstract: **-**Continuous monitoring of road conditions is essential for gathering information on roadway conditions, such as potholes, breaks, and other deformities, utilizing the latest technology. This data can enhance driver safety while reducing road repair costs. Traditional methods are time-consuming and expensive, resulting in limited coverage and slow response to road conditions. With the advancements in global networking and widespread use of mobile devices, information can be collected over long distances using built-in sensors in cell phones and in-vehicle video systems. Identifying street potholes using this information is of genuine and significant consequence. Current approaches utilize image recognition techniques based on deep learning or speed-up sequence classification algorithms. These road anomalies can cause vehicle damage and have been involved in several incidents leading to expensive repairs. The cost-effective method proposed in this study provides drivers with immediate warnings about potholes or speed bumps.The proposed system consists of three subunits: the sensor subunit, the server subunit, and the user component. The GPS receiver retrieves the position coordinates of potholes and humps detected by an ultrasonic sensor at the sensing subunit. This information is stored in a separate subunit database. A hardware module installed at the user subunit promptly informs drivers about potholes and speed bumps.This project aims to identify potholes using an ultrasonic sensor and an ESP-32 microcontroller. The system utilizes GPS to relay the location of these potholes to experts, enabling them to take action to maintain the roads and assist drivers in preventing accidents. Alerts are displayed on LCDs to provide drivers with timely information.

Keywords*: IoT-based, Highway, Pothole detection, Hump detection, Ultrasonic sensor, Road safety*

1. Introduction

The identification of street potholes is crucial for enhancing the adaptability of transportation architecture. Besides diminishing driving pleasure, various forms of street surface damage, such as potholes and bumps, also escalate the likelihood of street incidents by causing wear on car components, including tires and suspension systems [1]. According to the 2021 report card on America's infrastructure by the American Society of Structural Engineers (ASCE), 43% of major highways in the US received a low rating. Driving on such roads annually leads to an additional $130 billion in car maintenance expenses. This underlines the need to reduce costs associated with maintaining both cars and roads while simultaneously enhancing fuel efficiency and driving safety by addressing road irregularities over a broad spectrum.

The maintenance of streets, essential for the rapid transformation of our cities into intelligent cities, plays a significant role in promoting human existence. This framework aids people by incorporating innovative ideas for enhancing street development and preventing accidents. Several studies have demonstrated the use of natural vehicles to identify roadway anomalies [2]-[4]. Vaiana et al. analyzed how young individuals drove on level bends at different speeds using data from mobile devices. They combined GPS data with geographical information, creating a comprehensive dataset. A behavior model, considering mental health and real-world security scenarios, explained drivers' reactions to various road conditions. Gillespie et al. [5] were pioneers in developing techniques for the abnormal localization of highway inconsistencies. Botshekan and others [6] suggested three strategies for detecting road anomalies based on acceleration data: edge-based approaches, AI-based strategy, and wavelet transform-based methods.

Eriksson et al. [7] presented a threshold-based pothole watch framework where each trial vehicle was equipped with an extrinsic global positioning system (GPS) and accelerometer. Non-pothole information was filtered using five parameters: speed, high-pass, z-top, xz-proportion, and speed against z-proportion. Mednis et al. [8] found that when a vehicle avoids a pothole, the speed increase in all three axes adds up to zero. They proposed the G-ZERO algorithm based on this finding, achieving an 85% accuracy rate when compared to three other widely used limit-based calculations. However, this accuracy only confirms proper detection, without distinguishing genuine potholes.

In [9], Li et al. determined an intermediate for IRI, assessing the severity of the street section by calculating the root mean square of the z-pivot speed increase for each road segment. Carlos et al. [10] distinguished six well-known limit combinatorial heuristics about datasets of street conditions acquired using the platform. The optimal approach, the STDEV (Z) strategy proposed by Mednis et al. [11], detected potholes by estimating the standard deviation of accelerometer measurements along the z-hub. In that review, they integrated the elements these algorithms employed to extract highlights, supplying fresh component vectors to SVM, and the outcomes surpassed STDEV (Z).

The limit-based technique, despite its simplicity, has two disadvantages: difficulty in eliminating noise caused by events such as sharp turns and crisis slowing down, resulting in large fluctuations in speed increase data; and the challenge of reliable parameter selection due to differences in roadway types, hardware sensor execution, and mechanical features of cars. Manageability must be determined based on numerous trials, making its application to a broad scope of street surface identification challenging. AI is another widely used method, in addition to directly identifying edges in the temporal space. To concurrently meet the prerequisites for precision and efficiency, mobile phones with built-in sensors, such as accelerometers and GPS, are frequently used to assess roadway conditions.

Soundararaj et al. [12] retrieved statistical highlights from in-vehicle mobile phone data, including mean, maximum, minimum, etc. AI techniques, including support vector machines (SVM), decision trees, and naïve Bayes, were applied to gather divided speed improvement tests and identify street irregularities. A fixed irregular sign illustrating an increase in vehicle speed is used. Therefore, compared to its time-space highlights, its recurrence space highlights are more consistent. For instance, Perttunen et al. used support vector machines to identify street anomalies after first using rapid Fourier changes to isolate signal elements from the recurrence region. Basavaraju et al. [13] drew the highlights following wavelet transformation. Subsequently, for street strangeness recognition, the extracted grids were separately fed into SVM, a decision tree, and a neural network as computer vision technology advances.

Several specialists have explored techniques using image recognition technology to detect street images taken while operating a vehicle. A method for locating potholes based on dreams was proposed by Akagic et al. [14]. The approach targets only asphalt pavements and concentrates asphalt data by analyzing RGB picture variety space highlights. Picture division, processing, and spectral clustering are performed to find potholes in segmented asphalt pavements. To categorize street surface photos captured by mobile devices, Zhang et al. [15] used a controlled deep convolutional neural network (CNN) to extract distinguishing characteristics directly from their photographs. Furthermore, Fan et al. used CNN to ascertain whether pavement images contained breaks. They employed an adaptive threshold technique to eliminate fissures from asphalt pictures, and the output was further refined by matching filtering for images containing breaks. The YOLOv3-FDL model by Liu et al. [16] has four scale identification layers (FDL) enabling the detection of hidden asphalt splits on ground-penetrating radar pictures using features from the B-output and C-filter views. The model uses the k-means++ grouping computation and the practical crossing point over association misfortune capacity for bounding box regression to construct new anchor sizes assigned to the four scale recognition levels.

The significance of this study lies in its focus on the identification of street potholes and road surface anomalies, which is crucial for enhancing transportation infrastructure. The study addresses the negative impact of road damage on driving experience, vehicle components, and the likelihood of accidents. With a substantial percentage of major highways in the India receiving low ratings, the economic burden on car maintenance and road repairs is significant.

The proposed framework aims to contribute to the development of intelligent cities by leveraging innovations in road improvement and accident prevention. The study reviews various methods, including natural vehicle data, mobile device-based approaches, and artificial intelligence, for detecting road anomalies such as potholes. By exploring these techniques, the research seeks to find efficient and accurate ways to assess road conditions.

Overall, the study's significance lies in its potential to contribute to the creation of smarter, safer, and more efficient transportation systems by addressing the challenges posed by road irregularities and enhancing the adaptability of the transportation architecture.

2. Sensors for Speed Breaker and Pothole Detection

Rapidly detecting speed breakers and potholes is crucial to preventing accidents caused by these road hazards. The following sensors are designed to identify speed breakers and potholes, and their respective advantages are outlined below.

2.1 Ultrasonic Sensor

Ultrasonic sensors rank among the most widely used and cost-effective systems for sound-based distance measurement in automobiles [17]. Commonly installed on the front and rear bumpers, they serve to prevent accidents. These sensors can be positioned beneath the car's body to detect potholes and speed bumps. Figure 1 illustrates a typical method for using an ultrasonic sensor to identify potholes and bumps. The key advantages of this sensor include its low cost, compact size, and easy installation. However, it operates at a slower speed and has a limited detection range of a few meters.

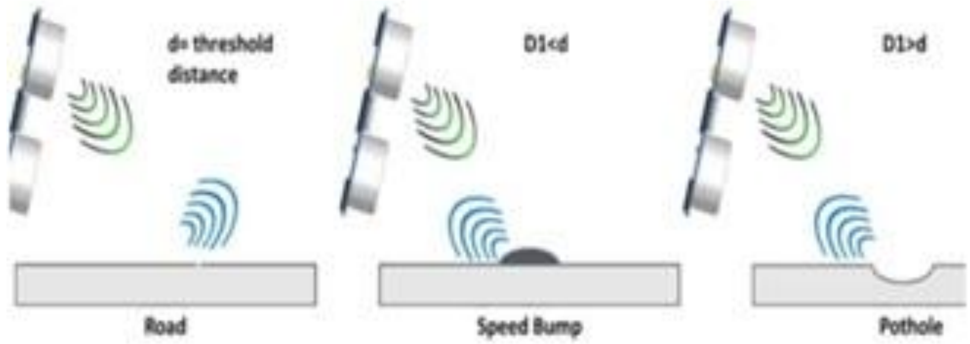

Figure 1.Ultrasonic sensor for detection of speed bumps and potholes [18]

2.2 Accelerometer

In addition to detecting the vehicle's acceleration, deceleration, and direction, accelerometers often incorporate a gyroscope [19]- [21]. Upon impact, they rapidly generate readings, as illustrated in Figure 2. These devices provide precise measurements and can identify anomalies, specifying their intensity in terms of height, breadth, and depth. However, it's important to note that these sensors lack the capability to predict an impending anomaly before its occurrence.

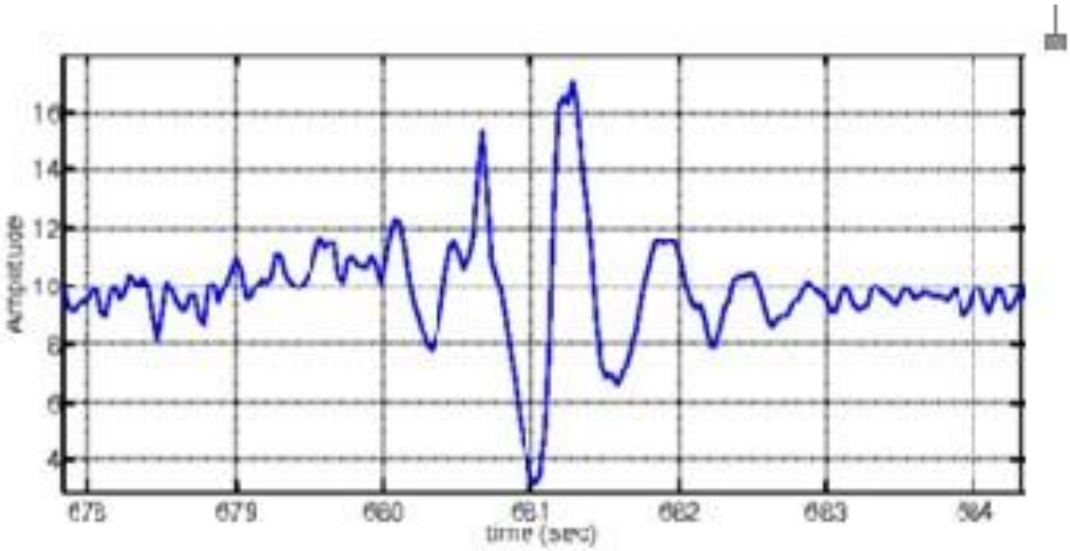

Figure 2.Pothole and speed bump detection with an accelerometer [22]

2.3 Camera

Cameras are widely adopted sensors in automotive applications for monitoring and surveillance [23]-[27]. They offer a comprehensive view of the road and can alert the driver to potential anomalies. Cameras prove to be effective tools for detecting potholes and speed bumps; however, they require image analysis to notify the driver of any abnormalities. These sensors are capable of providing real-time information about irregularities on the road, but the coverage range and accuracy of information may vary among different sensors. Obtaining information well in advance of anomalies remains a challenge. To transmit real-time tracking results for subsequent integration, these sensors need internet connectivity. Therefore, the combination of IoT and machine learning techniques can be employed for enhanced performance and early anomaly detection.

Figure 3.Detection of potholes using Camera [28]

3. Modelling/Development of the System

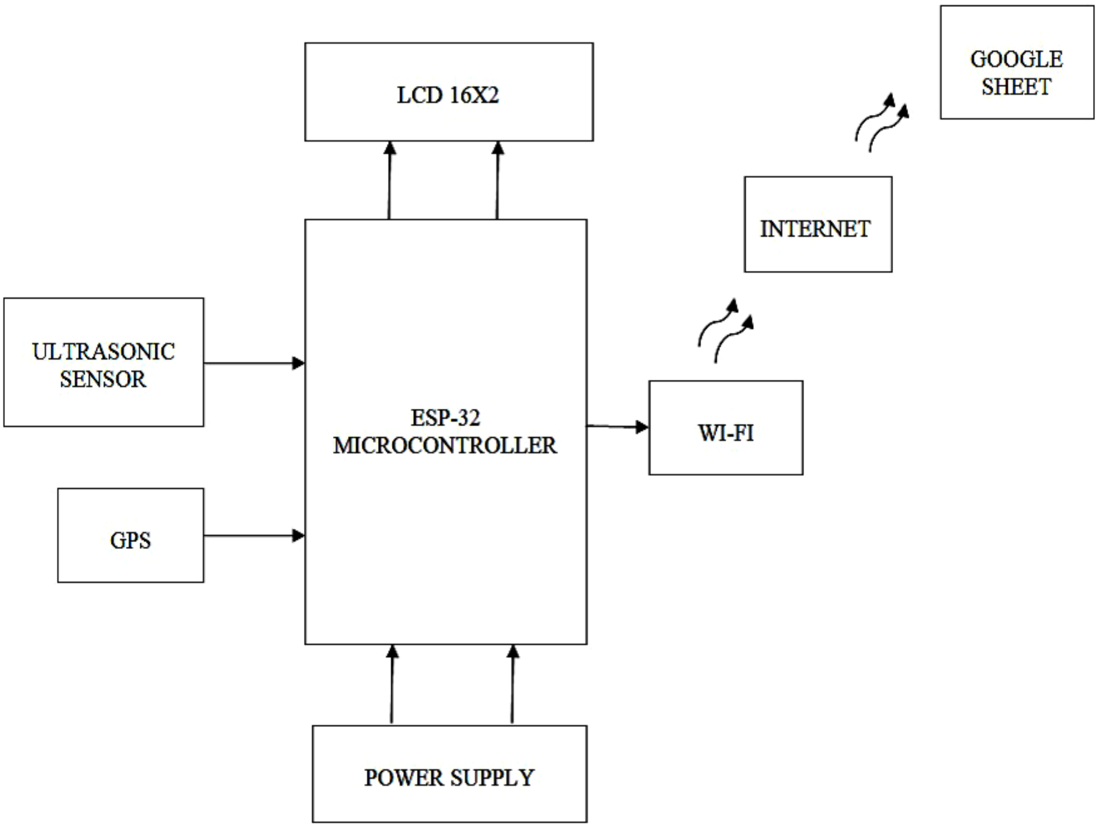

Figure 4.Block Digram of the porposed system

The block diagram of the proposed IoT-based highway pothole and hump detection system is shown in Figure 4. It consists of the following components:

- Sensor subunit: This subunit includes the ultrasonic sensor and the GPS receiver. The ultrasonic sensor detects the presence of potholes and humps on the road, while the GPS receiver records the location of these anomalies.
- Server subunit: This subunit is responsible for storing and processing the data collected by the sensor subunit. It also generates alerts for drivers about potholes and humps in their vicinity.
- User subunit: This subunit includes the LCD and the hardware module. The LCD displays alerts to drivers about potholes and humps, while the hardware module generates audible and/or visual alerts.

The system works as follows:

1. The ultrasonic sensor detects the presence of a pothole or hump and sends a signal to the ESP-32 microcontroller.
2. The microcontroller uses the GPS receiver to record the location of the pothole or hump.
3. The microcontroller transmits the location data to the server subunit over the internet.
4. The server subunit stores the location data in its database and generates an alert for drivers in the vicinity of the pothole or hump.
5. The alert is sent to the user subunit over the internet.
6. The LCD on the user subunit displays the alert to the driver.
7. The hardware module on the user subunit generates an audible and/or visual alert.

The system can be used in a variety of ways. For example, it can be used to:

- Alert drivers about potholes and humps in their vicinity, so that they can avoid them.
- Provide data to road maintenance authorities about the location and severity of potholes and humps, so that they can be repaired promptly.
- Collect data on the condition of roads over time, so that trends can be identified and addressed.

The system is relatively inexpensive and easy to deploy. It can be installed on vehicles, roadside infrastructure, or even on pedestrians. This makes it a viable solution for a wide range of applications.

Each component in the system is explained in more detail as follows:

- Ultrasonic sensor: An ultrasonic sensor is a device that uses sound waves to measure distance. It emits a pulse of ultrasonic sound and then listens for the echo to return. The time it takes for the echo to return is proportional to the distance to the object that reflected the sound wave. Ultrasonic sensors are commonly used in a variety of applications, such as parking sensors, obstacle avoidance systems, and rangefinders.
- GPS receiver: A GPS receiver is a device that can determine its location by receiving signals from GPS satellites. GPS receivers are commonly used in navigation devices, smartphones, and other mobile devices.
- ESP-32 microcontroller:The ESP-32 microcontroller is a low-cost, low-power microcontroller with built-in Wi-Fi and Bluetooth. It is commonly used in IoT devices, such as smart home devices, wearables, and industrial controllers.
- Server subunit: The server subunit can be implemented on a variety of hardware platforms, such as a Raspberry Pi, a cloud server, or a dedicated server. It is responsible for storing and processing the data collected by the sensor subunit, and generating alerts for drivers about potholes and humps in their vicinity.
- LCD: The LCD is used to display alerts to drivers about potholes and humps. It can be a simple text-based display or a more sophisticated graphical display.
- Hardware module: The hardware module is responsible for generating audible and/or visual alerts to drivers. It can be a simple buzzer or LED, or a more sophisticated device that can generate speech or music.

The flowchart of the proposed IoT-based highway pothole and hump detection system is shown in Figure 5. The flowchart shows the steps involved in the system, from the initialization of the hardware to the sending of alerts to drivers.

Here is a more detailed explanation of each step in the flowchart:

1. START: The system begins by initializing the LCD, sensor, and GPS.
2. CHECK SSID & PASSWORD: The system then checks the SSID and password of the Wi-Fi network that it needs to connect to. If the SSID and password are correct, the system connects to the Wi-Fi network.
3. READ SENSOR'S VALUE: The system then reads the value of the ultrasonic sensor. If the value is greater than a certain threshold, then the system determines that a pothole or hump has been detected.
4. DISPLAY VALUES ON LCD: The system then displays the sensor value on the LCD.
5. IF DISTANCE > 50 cm: If the distance to the pothole or hump is greater than 50 cm, then the system skips the next step and goes to step 6.
6. SEND DISTANCE, LONGITUDE & LATITUDE ON GOOGLE SHEET: The system sends the distance to the pothole or hump, as well as the longitude and latitude of the vehicle, to a Google Sheet. This information can be used by road maintenance authorities to track the location and severity of potholes and humps.
7. STOP: The system then stops.

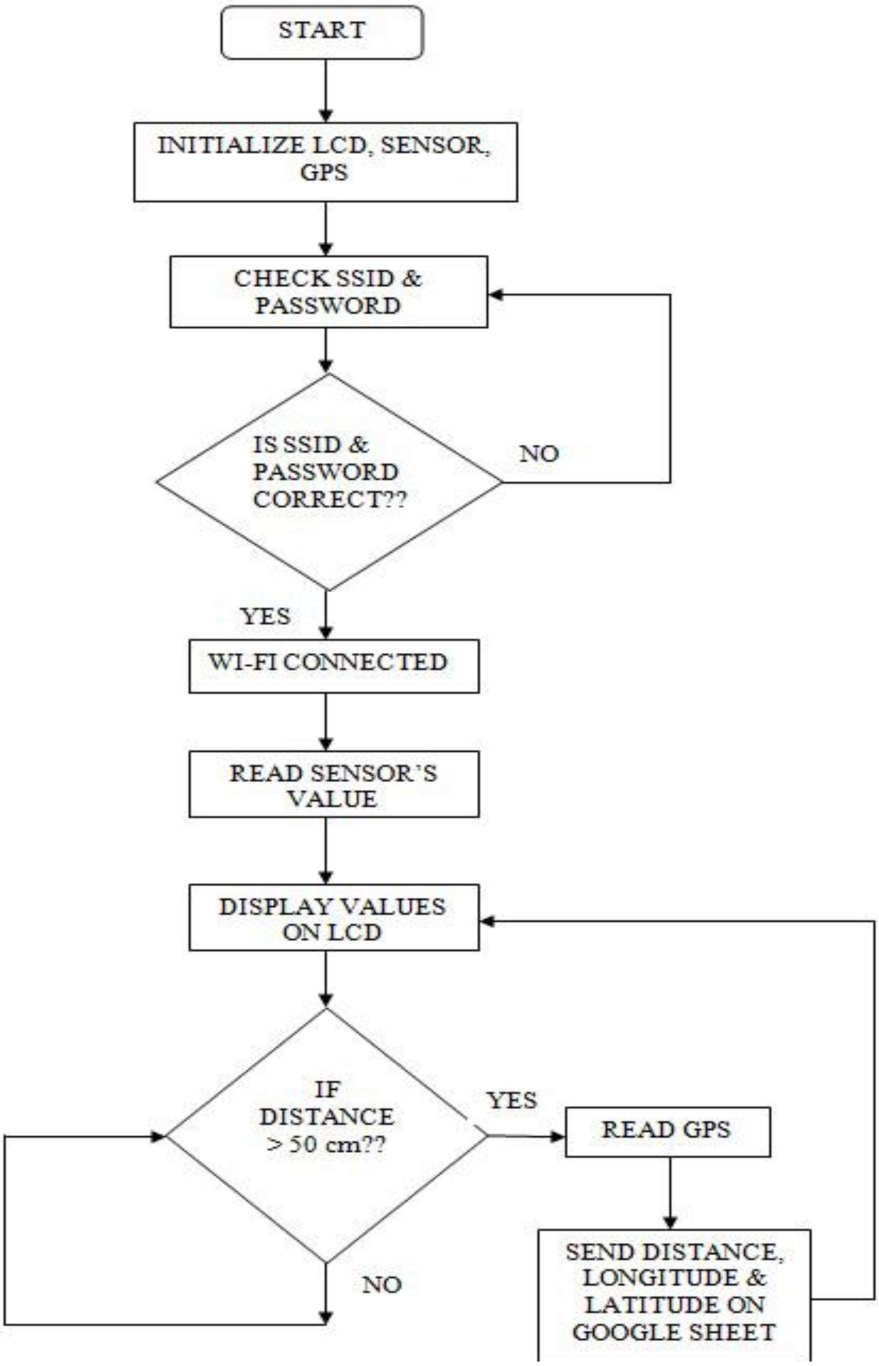

Figure 5. Flowchart of the proposed system

The system repeats steps 3-7 continuously, so that it can continuously monitor the road for potholes and humps.

Here is an example of how the system would work:

1. The system is initialized and connected to the Wi-Fi network.
2. The system reads the value of the ultrasonic sensor.
3. The system determines that a pothole or hump has been detected because the sensor value is greater than a certain threshold.
4. The system displays the sensor value on the LCD.
5. The system checks the distance to the pothole or hump.

6. Since the distance to the pothole or hump is less than 50 cm, the system sends the distance to the pothole or hump, as well as the longitude and latitude of the vehicle, to a Google Sheet.
7. The system stops.

The system would then repeat steps 3-7 continuously, so that it can continuously monitor the road for potholes and humps.

4. Methodology and discussion on Results

Potholes, characterized as deteriorated or openings in the street's surface, pose significant challenges to smooth and safe driving, potentially leading to accidents. These accidents can result from various factors such as drunk driving, excessive speeds, disregarding signals, road protrusions, speed breakers, and, notably, potholes. Effectively addressing this issue involves the thoughtful design of Indian highways to ensure deliberate and secure traffic flow.

To mitigate the impact of potholes on road safety, a proactive solution is proposed: the implementation of a Pothole Identification and Awareness Device based on Arduino. This device plays a crucial role in the ongoing efforts to tackle pothole-related challenges on streets. By promptly detecting potholes and issuing warnings to drivers, this technology aims to enhance the driving experience, promote smooth traffic flow, and, most importantly, prevent accidents caused by the presence of potholes.

In summary, the deployment of innovative technologies, such as the Arduino-based Pothole Identification and Awareness Device, represents a pioneering approach to address the pervasive issue of potholes on Indian roadways. This solution aligns with the broader goal of creating roads that prioritize safety, efficiency, and a seamless driving experience for all motorists.

4.1 Methodology

AThe ultrasonic sensor employed in this study is the JSN-SR04T, featuring two transducers. It converts an electrical signal into an ultrasonic sound pulse, with the recipient capturing the transmitted pulses. This lightweight sensor is easily integrated into mechanical innovation projects, offering non-contact range recognition between 20 mm and 4 m with an accuracy of 3 mm. Operating on 5 volts, it can be seamlessly connected to Arduino or other 5-volt microcontrollers.

The sensor works by receiving reflected pulses, causing a variable-width pulse from 150 microseconds to 25 milliseconds. The JSN-SR04T has a range between two centimeters and two thousand centimeters, requires a 5-volt input voltage, draws 20 milliamperes of current, has a 30-degree sensing angle, and a 15-degree angle of impact. If pulses are not reflected, the echo signals end after 38 milliseconds.

The system is divided into three subsystems: detection, communication, and notification. These subsystems share a common data point, emphasizing data generation, collection, coordination, and dissemination.

1. Detection Subsystem:
This component focuses on detecting records, specifically the longitude and range of potholes. An accelerometer detects potholes based on the intense external pressure applied to the sensor, representing the pothole through the accelerometer's diverted perspective. Additionally, an ultrasonic sensor is employed to protect drivers from collisions and prevent accidents by measuring the distance between objects using sound waves.
2. Communication Subsystem:
The core of the apparatus is the communication subsystem. It uses a GPS beacon to locate the pothole's position, sending this information to a computer or database for real-time mapping. The GPS data aids in displaying the object's location on a map backdrop.
3. Localization Subsystem:
This subsystem utilizes the information provided by the access point to determine the pothole's location, alerting the driver through an Android app. The GPS is crucial for determining the pothole's current location, while accelerometers contribute to pothole detection. Sensor data is collected, analyzed, sent to the cloud, and retrieved to design the region on an Android app.

The JSN-SR04T ULTRASONIC SENSOR features a 5V input voltage, 20mA current draw, a 30-degree sensor angle, 40 KHz ultrasonic frequency, a 15-degree angle of impact, and a range of 2 to 400 cm.

The Arduino, an open hardware development board, facilitates easy usage through USB connection, providing power and serving as a serial connection for programming Node MCU microcontrollers. The Arduino IDE is used for programming, compatible with various operating systems.

The system modules, when processed, activate the OLED panel, displaying data provided by the microcontroller. The GSM SIM 900 is employed for communication across the network, facilitating text messages and voice calls, enhancing the system's capability for sending updates and receiving information from drivers. GSM utilizes TDMA technology for signal transmission.

4.2 Results and Discussions

Table1.Identification of Potholes using the proposed system on Nashik-Pune Highway

Date and Time	Project Name	Location Area	Distance in Cm	inches
March 21, 2022 at 04:16PM	Pothole		20.3	
March 21, 2022 at 04:16PM	Pothole			7.99
March 21, 2022 at 04:18PM	Pothole	NASHIK_PUNE		
March 21, 2022 at 04:18PM	Pothole		49.1	
March 21, 2022 at 04:18PM	Pothole			19.33
March 21, 2022 at 04:18PM	Pothole	NASHIK_PUNE		
March 21, 2022 at 04:18PM	Pothole		20.3	
March 21, 2022 at 04:18PM	Pothole			7.99
March 21, 2022 at 04:18PM	Pothole	NASHIK_PUNE		
March 21, 2022 at 04:18PM	Pothole		39.85	
March 21, 2022 at 04:18PM	Pothole			15.69
March 21, 2022 at 04:19PM	Pothole	NASHIK_PUNE		
March 21, 2022 at 04:19PM	Pothole		44.66	
March 21, 2022 at 04:19PM	Pothole			17.58
March 21, 2022 at 04:19PM	Pothole	NASHIK_PUNE		
March 21, 2022 at 04:19PM	Pothole		46.34	
March 21, 2022 at 04:19PM	Pothole			18.24
March 21, 2022 at 04:19PM	Pothole	NASHIK_PUNE		
March 21, 2022 at 04:19PM	Pothole		45.54	
March 21, 2022 at 04:19PM	Pothole			17.93
March 21, 2022 at 04:19PM	Pothole	NASHIK_PUNE		

The table of data showing the dates, times, project names, location areas, distances in centimeters, and distances in inches for several potholes on Nashik-Pune highway is tabulated in Table 1. The data is sorted by date and time.

The first column in the table shows the date and time of the pothole detection. The second column shows the name of the project that the pothole is associated with. The third column shows the location area of the pothole. The fourth column shows the distance to the pothole in centimeters. The fifth column shows the distance to the pothole in inches.

The table shows that there were 10 potholes detected on March 21, 2022. The first pothole was detected at 4:16 PM and was located in NASHIK PUNE. The distance to the pothole was 20.3 cm (7.99 inches). The last pothole was detected at 4:19 PM and was also located in NASHIK PUNE. The distance to the pothole was 45.54 cm (17.93 inches).

The table also shows that the average distance to the potholes was 39.5 cm (15.55 inches). The smallest pothole was 20.3 cm (7.99 inches) in diameter and the largest pothole was 49.1 cm (19.33 inches) in diameter.

The data in the table can be used to identify areas where potholes are more likely to occur and to track the condition of roads over time. The data can also be used to prioritize pothole repairs and to allocate resources to road maintenance.This tabulated data serves as a valuable tool for strategic decision-making in road maintenance and contributes to the overall improvement of road safety and infrastructure quality.

5. Conclusion and Future Scope

In conclusion, our study has not only enhanced the output capabilities of the system but has also addressed its limitations. Our microcontroller-based solution for identifying and addressing potholes and speed bumps on roads involves recording information on a server and implementing speed reduction measures when necessary. Potholes, often caused by factors like rain and oil spills, can lead to accidents, emphasizing the importance of our proposed solution.

We utilize ultrasonic sensors to detect potholes, capturing their height, depth, and size. For real-time and accurate pothole location, GPS technology is employed. All collected data is securely stored in a cloud-based database, enabling timely interventions to improve road conditions. This approach contributes to swift and effective road maintenance, preventing potential accidents.

Future Work:

As part of ongoing research, there are several avenues for improvement and expansion:

- **Data Diversity:** Collecting data from various types of roads and vehicles is essential for creating models that function effectively across different scenarios.
- **Model Enhancement:** Developing models that classify potholes in greater detail will require additional annotation and refinement, allowing road maintenance organizations to prioritize repairs based on severity.
- **System Optimization:** Continuously improving the system's ability to provide accurate and timely output, considering advancements in technology and sensor capabilities.
- **Extended Functionality:** Exploring additional features such as integrating the system with autonomous vehicles or developing predictive maintenance models for proactive road repair strategies.

By addressing these areas in future work, our system can further contribute to the enhancement of road safety and infrastructure maintenance.

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