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Efficient Road Infrastructure Management using IoT Sensor Fusion and V2V Interaction

Akhilesh Kumar Singh[1] **and Damodar Reddy Edla**[2]

[1] Research Scholar, CSE, NIT Goa, Goa, India
[2]Associate Professor, CSE, NIT Goa, Goa, India

E-mail address: akhileshvivek@nitgoa.ac.in, dr.reddy@nitgoa.ac.in
ORCID: 0000-0002-8161-6418, 0000-0002-5040-0745

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Abstract: This paper explores the integration of Internet of Things (IoT) technologies and sensor fusion techniques into modern transportation systems to enhance efficiency, safety, and road quality assessment. The study not only emphasizes the importance of V2V communication using DSRC Dedicated Short Range Communication, Threshold Based Algorithms (TBA) and Dynamic Time Warping (DTW) but also proposes a novel approach of IoT multi-sensor fusion hardware model that is designed to identify clean and rough surface road conditions. By deploying multi sensor module into proposed model, real-time road surface data is collected and processed to classify them into flat clean or bumpy rough categories based on their smoothness index. This not only mitigate the road building infrastructure cost but also reduce the damage occur to vehicle due to poor conditions of road. The proposed study not only detect road anomalies via road surface monitoring but also tries to improvise the next generation future navigation systems for vehicles like autonomous and low ground clearance luxury vehicles. The IoT multi-sensor fusion hardware model presented here identifies road smoothness from obtained pitch orientation and road driving terrain gathered through categorical data from its sensors. The creation and deployment of an IoT road health monitoring system offers up new avenues for research into enhanced, improvised road health focused route guidance systems.

Keywords: IOT, V2V Communication, Autonomous Driving, Sensor Fusion, Edge Computing, Road Quality Index

E-mail: akhileshvivek@nitgoa.ac.in, dr.reddy@nitgoa.ac.in

1. INTRODUCTION

Vehicle production has been marked by rapid advancements, yet a significant gap persists in equipping vehicles to navigate diverse road conditions effectively. Despite the proliferation of modern vehicles, many are ill-suited for the complexities of real-world road environments. This deficiency not only compromises driver and passenger safety but also causes frequent accidents along with substantial vehicle damage repair costs. The absence of such preventive and detectable system that alert drivers with real time awareness of road conditions and potential hazards are modern area of research and exploration in the current era of transportation industry. Several researchers have thrown light to address these challenging issues yet a vast research is still to be explored for innovative and better solutions. However, these efforts have often been limited by scalability and lack of widespread adoption. Additionally, the conventional and traditional approaches that rely on individual vehicles sharing information faces significant barriers that includes the problem of insecure data transmission protocols. Thus, these systems fail to provide the robust and reliable insights necessary for effective vehicle navigation and safety enhancement. As a result, these technologies fall short of offering the solid and trustworthy observations required for efficient vehicle navigation and more secure driving.

In response to the said challenges, the study here aspires to deliver a transformative solution by proposing a sophisticated onboard system that will look for various road irregularity conditions and environmental factors which can influence the vehicle navigation. This system is designed to improvise and integrate the usage of multiple sensors thereby enabling seamless communication and data exchange between them. With the merger of ultrasonic, accelerometer and LiDAR sensors, the system is able to capture precise data about the surrounding road irregularity conditions in real time. Furthermore, to improvise the system's capabilities its impact, this research not only proposes the study of integration of Dedicated Short-Range Communication (DSRC) technology in Vehicle-to-Vehicle (V2V) communication. DSRC technology relays and share critical data from outgoing vehicles to incoming ones there by providing drivers with important information about prevailing road surface conditions and environmental hazards. This V2V communication paradigm improvise traditional navigation paradigms by offering a dynamic and proactive approach to current navigating challenges of road environments.

Moreover, the significance of V2V communication extends the conventional driving scenarios particularly in the field of autonomous driving. By enabling seamless data exchange among vehicles of different lanes, V2V communication facilitates the sharing of gathered road condition information which enhances the precision and safety of autonomous navigation systems. This collaborative approach towards modern navigation system not only empowers road condition awareness to individual drivers but also enhances a collective intelligence about the safety and efficiency of the entire road ecosystem. Thus by integrating sensor fusion techniques a transformative potential of V2V communication can be observed in a new era of road safety and navigation efficiency. Through innovative technology integration and collaborative data sharing, the proposed system promises to reorganize vehicle navigation by mitigating accidents and enhancing overall road safety for drivers and autonomous vehicles. Table 1 presented below shows explored methodologies and algorithms discussed in this study, indicating their roles in improving road infrastructure efficiency and safety through data processing and communication technologies.

Table 1: Different Methodologies & Algorithms in Road Data Analysis

Method/Algorithm	Description
Sensor Fusion	Integration of ultrasonic, accelerometer, and LiDAR sensors to gather precise data on road surfaces, enhancing situational awareness and enabling real-time analysis of environmental factors.
Edge Computing	Sensor data are processed at the edge to enhance security, prevent data leakage, and enable faster delivery of information for navigation and autonomous driving systems.
Threshold-based Algorithm	Utilizes the Z-DIFF algorithm to detect road anomalies by analyzing consecutive measurements of vertical acceleration data, flagging significant differences as potential irregularities
Dynamic Time Warping (DTW)	Computational technique for detecting road anomalies by comparing accelerometer data with template references, offering improved accuracy over threshold-based methods.
GPS Subsystem	Integrates GPS technology to acquire location data of road surface anomalies, enabling real-time mapping and updating of road condition databases for improved navigation accuracy.
V2V Communication	Facilitates wireless communication between vehicles to exchange crucial data,

	including road conditions and position information, enhancing situational awareness and navigation accuracy.
Dedicated Short-Range Communication (DSRC)	Utilizes DSRC technology to relay data about road surface conditions and environmental factors between vehicles, enabling proactive navigation and timely updates for drivers.

2. RELATED WORKS

Several researchers are continuously exploring new ways and methodology for better and efficient transportation system in contrast with the current modern traffic infrastructure demands. In the research exploration [1], the author throws light on a functional location based subsystem that also act as a vehicle tracking system. The proposed location based subsystem uses integration of three major components namely, a micro-controller, GSM communication module and a GPS receiver to precisely locate the vehicle location. This integration provides invaluable insights for transportation industry. The study outlined in [2] presents a real-time vehicle guidance system that utilizes a dynamic route guidance algorithm to analyses live traffic data for identification of most time efficient routes. To improve the road condition awareness, the paper in [3] introduces a cutting-edge pothole detection system. In this framework, the ultrasonic sensors work in accordance with Wi-Fi Access Points and Mobile Nodes for detection of potholes in real-time. The system further proposes a localization subsystem that enables the precise identification of pothole locations alarming timely alerts and driver warnings.

For a broader pavement analysis and assessment, the integration of Mobile Laser Scanning (MLS) proves essential for transforming 3-Dimensioanl MLS point clouds into a refined 2-Dimensional intensity representation of the road surface after radiometric correction. Subsequently, pavement markings are automatically identified using predefined specific algorithms and the extracted features are further categorized on the basis of their characteristics such as shape, orientation, and size [4]. In [5], the research article explores about the utilization of in-vehicle IOT based sensor technology for the analysis of road conditions in real-time through Live Road Assessment (LiRA). The system enables live road condition evaluation by applying more efficient and data-driven approaches in road infrastructure management. In [6] the author proposes a LiDAR system which is capable of efficiently detecting and measuring objects within its surroundings.

The authors in [7] proposes an integrated system by combining several latest technologies such as SAPS (Smart Accident Precognition System), Google Assistant, Smartphones, RFID tags, Sensors, and Automation platforms like IFTTT. This integration developed a comprehensive system that aims at enhancing safety, user experience, and efficiency of vehicle. Thus they are able to successfully create an IoT-enabled intelligent automobile system that is able to provide advanced safety features, user-friendly interfaces, real-time monitoring capabilities, and efficient resource management. In [12], the researcher’s study discusses about a sophisticated monitoring system that uses photo radar complexes along with a multi-agent strategy for gathering and analyzing sensor data regarding traffic accidents. A unified model that integrates technologies like cloud, fog, and mobile computing is suitable to well organize data processing methodologies. Advanced machine learning techniques such as a hybrid neural network helps in timely analyzing and predicting the road accidents. Their research showcases the system's proficient ability in locating high-risk zones through cluster analysis and highlighting the significant effect of weather conditions on traffic dynamics.

The integration of V2V communication in transportation network offers an ample of advantages that includes enhanced safety, improvised traffic efficiency, reduced environmental impact, support for advanced driver assistance systems, autonomous self-driven driving, and optimization of infrastructure [13]. By leveraging the collective intelligence and cooperation of vehicles, V2V communication holds great potential to transform the way we experience and interact with transportation systems. The research paper [15] proposed a model aimed at detecting road potholes and speed restricted bumps using a mobile based application. The model utilizes the GPS and accelerometer sensor in a cellular phone to gather data and alert other passing by vehicles and concerned authorities about road conditions. In [20], the paper assembles and analyses accelerometer sensor data for detecting potholes on urban roads. The data was gathered with the help of an updated LynxNet collar based device fitted with a Tmote-Mini sensor node, MSP430F1611 micro-controller, and 3-axial accelerometer ADXL335. Software equipped with MansOS facilitated data acquisition and transmission to a computing peripheral. A prior developed pothole identification methodology called RoadMic was used as a reference for data gathering.

Regarding V2V communication, the paper [21] discusses the challenges and potential solutions in the context of Vehicle Ad-Hoc Networks(VANET), which are a vital component of Intelligent Transportation Systems (ITSs). VANETs involve interconnected vehicles capable of exchanging various types of information such as traffic updates, positioning data, weather conditions, and emergency alerts. The main focus is to ensure the dependable on-time propagation of information among vehicular nodes to enhance the process of decision making and improve road safety, efficiency, and reliability. Despite the usefulness of sensors, their usability is often impaired by weather conditions [8]. Road Weather Models (RWMs) plays a vital role in addressing these challenging issues. Although RADAR and LIDAR sensors perform well in all weather conditions yet the efficiency sometimes lack during lightning or low visibility.

Gathering data information about the health status and condition of roads along with its sharing with other vehicles is very crucial [9]. The research based on crowd sensing and V2X technologies proposes a wide area road surface state information collection and sharing platform. Several sensors are merged to precisely detect various road surface states and to determine hazardous anomaly locations using Geographic Information System (GIS). Additionally, the research in [10] explores the impact of growing automobile industry along with huge surge of personal vehicle overuse on road safety issues. It also throws light on emergence of Cooperative Intelligent Transport Systems (C-ITS) in integration with Internet of Things (IoT) solutions to mitigate the above said challenges. It also proposes a sensory data collection system that utilizes vehicle CAN bus, OBD-II port, smartphone, and additional sensors along with the communication technologies like BLE, Wi-Fi, and ITS-G5, to enhance real-time analysis.

3. DISCUSSION

Sensors are essential components of modern IOT based road infrastructure management systems that includes automatic traffic management, automatic street light management, advanced driver assistance system and many more. The trend towards using multi sensor fusion based approach are gaining popularity for improved efficiency and improvised navigation solution. One significant advantage of this approach is the system's ability to collect data on specific factors that individual sensors operating independently may find hard to detect. The merger of IoT technology into our current transportation system enhances the awareness of road health conditions and other factors that affect these condition and causes road anomalies to occur [11]. One of such approach that incorporates IoT into current modern transportation system involves fusing multiple sensors to collect road surface data. These data serve as a feeder of processing device can then be processed using several modern technologies like edge computing which can further be transmitted and propagated to drivers via any communication networks such as Bluetooth or Wi-Fi. Processing these data on the edge devices not only enhances security but also prevents the leakage of data along with drivers' locations.

The foundation of these system for more improvised efficiency lies in on-board fitted sensors that are essential for data collection during traffic navigation. These sensors serves as eyes and ears of the vehicle that continuously monitores road conditions and surroundings and generate alerts as and when required. Efficient communication between sensors enables real-time data sharing and analysis, enhancing situational awareness. Vehicle-to-vehicle (V2V) communication further augments sensor capabilities by enabling information exchange among nearby vehicles, improving navigation and safety. Integration of Dedicated Short-Range Communication (DSRC) technology facilitates efficient data exchange over short distances, aiding in timely dissemination of critical information. Figure 1 presented below illustrates the integration of sensors and raspberry pi module to concurrently capture data, aiming to detect road conditions while navigating.

a) Sensor Fusion

Constant measurement of the road surface is facilitated by ultrasonic sensors. If the ultrasonic sensor's measurement exceeds a predefined threshold distance, indicating a significant deviation, it identifies the area as a pothole; otherwise, it registers it as a smooth surface [14]. Relying solely on ultrasonic sensors for road surface measurement lacks precision. Incorporating accelerometer data enhances accuracy, as accelerometers can detect potholes and bumps through their readings, which exhibit notable changes upon encountering such road imperfections [16]. To further improve the system, a 2D LiDAR sensor is integrated into the current setup. LiDAR sensors offer high-resolution data, enabling more precise assessment of the road surface. Unlike ultrasonic sensors, which may have limited resolution and accuracy, LiDAR can discern smaller features like cracks or minor surface irregularities.

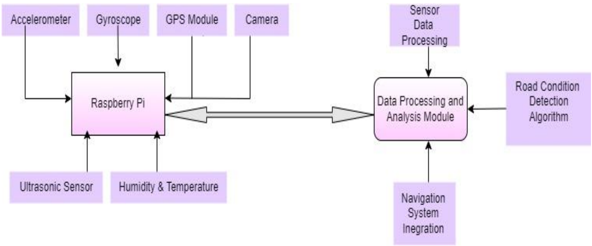


Figure 1: Illustrates the integration of Sensors and IOT Micro-controller

Utilizing the LiDAR system involves several key processes:

- Clustering: Point cloud data received from the LiDAR sensor is organized into clusters by measuring the distance between adjacent points and identifying breakpoints using the Adaptive Breakpoint Detector (ABD) method. This method establishes clusters by determining a threshold value, Dmax, and identifying breakpoints based on this threshold. Points beyond the threshold distance form breakpoints, and under certain conditions, they are grouped into clusters.
- Line Segment Extraction (Iterative End Point Fit Algorithm): Each and every cluster passes through the Iterative End Point Fit (IEPF) algorithm for the fetching of individual line segments.
- Data Function Generation: For every fetched line segment a polynomial function f(a,b) is created.
- Data Function Gradient: The gradient of the generated polynomial function is computed to detect potholes. The first order based derivative of f(x,y) is calculated, and if a pothole is present, there will be a sudden change in the differential waveform of f(x,y). The first and last abrupt change points indicate the width of the pothole.

Generally, the LiDAR system is composed of a single camera for pothole and speed bump detection that assist autonomous vehicles in path planning [18]. The estimation of fixed vertical angles are required for the identification of road anomalies such as speed bumps. As the vehicle approaches towards the speed bump, The Z-axis from 3-axial measurement initially increases rapidly then decreases immediately. This change in vertical angle causes it to detect for speed bumps. This process is accomplished in three primary stages: Data Acquisition, Data Filtering, and Data Processing.

For an efficient and effective pothole detection, image segmentation is an important ingredient of latest technology. By applying intensity-based thresholding techniques such as Global and Otsu's thresholding, the image is partitioned into two regions: foreground and background. The process of better pothole detection is further enhanced by spectral clustering that group the image pixels based on their connectivity and similarity by overlapping with the segmentation results. To accurately locate pothole locations, vertical and horizontal extraction methods are used [3].

The GPS modules plays a very crucial role in acquiring location data for detected road surface anomalies. Whenever the algorithm detects a road anomaly such as pothole, it triggers the GPS module to immediately retrieve and access the location latitude and longitude coordinates. These coordinates are then merged with the pothole data and transmitted to a cloud database. The GPS module generally gathers data using a Neo-6M GPS Sensor connected to a Raspberry Pi micro controller. This latitude and longitude coordinate information can also be extracted from the GPRMC sentence in the NMEA data output by the GPS receiver [13,18,20].

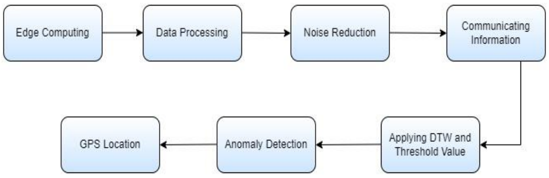


Figure 2: Sensor Data Computation Process

Figure 2 depicts the sensor data computation process for determining whether an anomaly has been detected. This process involves noise reduction to prevent misinterpretation of data. Upon detection of any obstacles, road bumps, or potholes, the system records the GPS location of the detected area. The results are then communicated to the driver and temporarily stored for transmission to incoming cars via V2V communication.

b) Processing sensor data

This paper is based on edge computing; this means raspberry pie is used to process data in place. This makes it faster to deliver information while navigating and autonomous driving. Computing these data from the sensors is done in two ways; Threshold and DTW (Dynamic Time Wrapping).

- Threshold: By using the Z-DIFF algorithm[20], road anomalies are detected by analyzing consecutive measurements of vertical acceleration data. The algorithm searches for differences between these measurements that exceed a specific threshold level.

When the vehicle encounters a road anomaly, such as a pothole or an uneven surface, rapid changes in vertical acceleration occur. These changes causes a significant level of acceleration differences between consecutive measurement values, which the algorithm recognizes as a possible detection of road anomalies. As the vehicle move along the road, the accelerometer continuously records acceleration data at a high sampling rate. The recorded data is then processed with Z-DIFF algorithm in real-time and compared with its immediate predecessor. If the difference between consecutive measurements exceeds a predefined threshold level, the algorithm alert it as a potential road anomaly.

Suppose Ai represents the ith measurement of vertical acceleration and n represents the total number of measurements then the application of Z-DIFF algorithm compares the difference between consecutive measurements of vertical acceleration denoted by ‘ΔAi’’ with a predefined threshold value ‘T’. If ΔAi exceeds this threshold value T, it is reported as a potential road anomaly detection.

$$\Delta A_i = |A_i - A_{i-1}|$$

If $\Delta A_i > T$, then a road anomaly event is detected, for $i=1$ to n

This approach allows timely detection of road anomalies along the vehicle movment. The Z-DIFF algorithm can identify the vibration and disturbance caused in normal fluctuations than by the disturbance caused due to potholesh or other road irregularities by focusing on rapid change of vertical acceleration.

- DTW: It is applied for the identification of road anomalies such as rough patches, potholes and speed bumps through an iterative computation. Initially, accelerometer readings collected during vehicular travel over potholes and bumps are processed, smoothed, and normalized to form Template References (TRs) denoted as TRi . These TRs serve as a baseline for comparison. The accelerometer data collected from smartphones mounted on vehicles undergo various filtering processes, including Speed Filter SF, Virtual Re-orientation VR, Filtering Z-axis FZ, Simple Moving Average (SMA) SMASMA, and Band-Pass filter BPFBPF, to remove noise and gravity components. The filtered data Fi is then compared with the TRs using DTW, which calculates the similarity between two time series sequences. If the distance calculated by DTW Dij falls below a predefined upper bound UB, it indicates the presence of a potential anomaly.

$$D_{ij} < UB \Rightarrow \text{Potential Anomaly Detected}$$

DTW is used only with data from accelerometer as is computationaly intensive but also adequately better than threshold based approach in detecting any anomalies

- V2V: This communication assist in the exchange of wireless messages between vehicles, enhancing safety and efficiency on the road. Equipped with wireless transceivers operating in designated frequency bands such as 5.9 GHz for DSRC or cellular frequencies for C-V2X, vehicles broadcast messages containing crucial data like position, speed, and heading. Nearby vehicles receive and process these messages, integrating them with sensor data to develop a comprehensive situational awareness. Through data fusion algorithms, V2V-enabled vehicles can make informed decisions to avoid collisions, enhance intersection safety, and issue warnings about emergency vehicles. V2V communication is pivotal for advancing vehicle safety and enabling future navigation solutions, including connected and autonomous vehicles.

Figure 3 shows vehicle A is considered the incoming vehicle, while vehicle B is classified as incoming vehicle of opposite direction. Using Dedicated Short-Range Communication (DSRC) in V2V communication, information regarding road conditions and external factors is broadcasted from Vehicle B to anticipate any upcoming road bumps or obstacles. DSRC has a very short range of 300 meter to 1Kilo-meter. Information from incoming vehicles in the other lane of the road are packaged into DSRC messages which contains details about road surface conditions like potholes or speed bumps, vehicle position, speed, and heading. Following this, the outgoing vehicle broadcasts these messages using its DSRC transceiver, operating in the 5.9 GHz frequency band since it uses overpopulated band used by many other wireless based devices[22]. Meanwhile, the incoming vehicle receives these DSRC messages via its own DSRC transceiver, continually scanning for transmissions within its communication range. Upon reception, the incoming vehicle processes this data, integrating it with its sensor and navigational data to enhance situational awareness. Depending on the detected conditions, the vehicle notify the driver or autonomously adjust its speed or trajectory to mitigate potential risks.

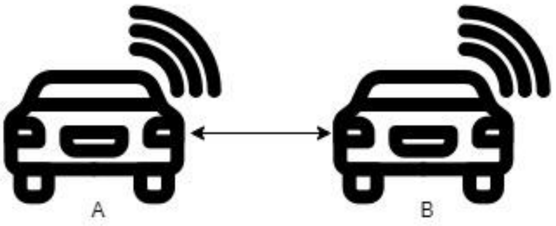


Figure 3: V2V Communication using DSRC.

4. PROPOSED MODEL

The proposed novel approach of identification of clean and rough surface road is based on IOT multi sensor fusion approach. The proposed methodology involves building of IOT hardware to gather input level data, classifying and processing of gathered data, obtaining outcome from the processed data and finally deciding about the condition of road as clean or rough road surface. We have designed a simulation scenario on which the proposed IOT hardware model is simulated and the required 3-axial data is gathered. This 3-axial data will lead to classification of roads on two categories clean & rough road surface by processing the smoothness index of road which further stands as a milestone in futuristic navigation system as better mobility navigation application for next generation vehicles such as autonomous, self-driven or low ground clearance luxurious vehicles. Figure 4 shows different surface of road patch- clean vs rough patch.

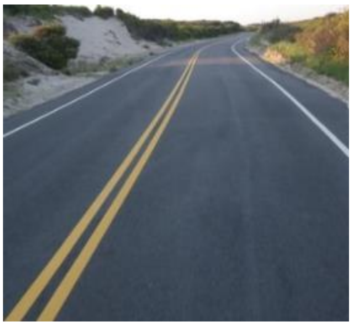


Figure 4: Clean Road Surface vs Rough Road Surface

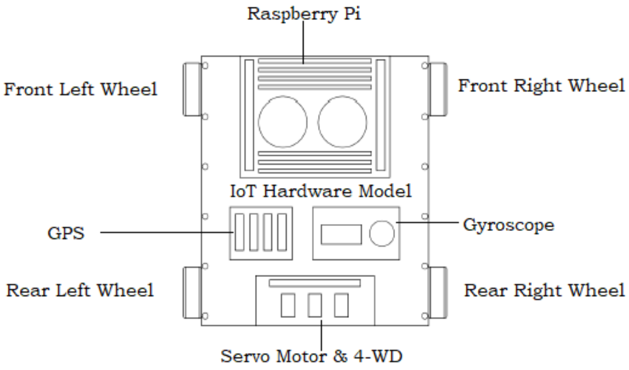


Figure 5: Proposed IOT multi sensor fusion hardware model

Figure 5 shows a schematic view of the proposed IOT multi sensor fusion hardware model equipped with raspberry pi microcontroller, gyroscope to collect yaw, pitch and roll value, Accelerometer to sense the wheel vibration and a GPS module to locate the location of identified patch. The model gathers input data by the movement of its independent wheel through 4-wheel drive simulator framework. The gyroscope attached with the independent wheels captures the 3-axial orientation of the model. The accelerometer attached is activated when the gyroscope detects the change in pitch orientation of the model which further captures the retardness and the vibrations occurs in the wheels. On acquiring sufficient data, if the rough patch of road is detected then GPS module is activated to capture the location of identified rough road patch.

The pseudo algorithm for the proposed IOT multi sensor fusion hardware model is summarized and proposed as follows:

Initialization: Initialize the Raspberry Pi microcontroller to manage data collection and processing.

Sensor Data Representation:

Gyroscope Data:

Yaw (ψ), Pitch (θ), Roll (φ) readings can be represented as:
Yaw: ψ(x)
Pitch: θ(x)
Roll: ϕ(x)

Accelerometer Data:

Acceleration along x (ax), y (ay), z (az) axes can be represented as: Acceleration along x: ax(t)
Acceleration along y: ay(t)
Acceleration along z: az(t)

Detection of Rough Patch:

Define a threshold for significant change in Pitch (θ): θ threshold

Pitch change(θ):|θ(t) - θ(t0) | > θthreshold

Where:
θ(t) is the current pitch angle.
θ(t0) is the initial pitch angle.
t0 is the initial time.

GPS Activation:

Activate GPS module upon detecting a rough patch:
GPS Activation: activateGPS ()
This function captures the location (latitude, longitude) of the identified rough patch.

Algorithm Representation:

Define a function to detect rough patches:
Function: detectRoughPatch(θthreshold)
Algorithm:

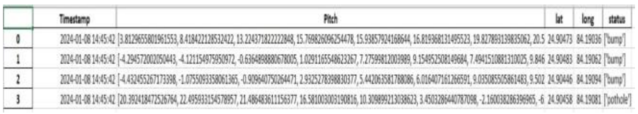
```
while True:
    Read gyroscope data: ψ(t), θ(t), ϕ(t)
    If |θ(t) - θ(t0) | > θthreshold
        Activate GPS module to record location: activateGPS ()
```

Integration and Processing

Outcome and Decision

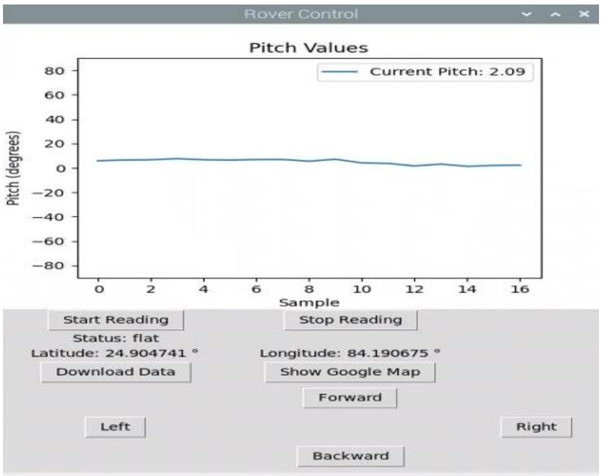
Figure 6 shows the sample of collected data from the proposed IOT multi sensor fusion hardware model. The model's gyroscopic 3-axial sensor records the value of roll, pitch and yaw. The focus of the model here is to mainly observe and record the pitch orientation value recorded in a regular frequency of every 5 milliseconds on the volume of 50 records per simulation.

The integration of the collected pitch orientation data is classified into 2 categories: flat or clean road surface and bumpy or rough patch road surface. The obtained pitch orientation data value is analyzed to form a curvature using the Matplotlib function in the proposed IOT multi sensor fusion hardware model.



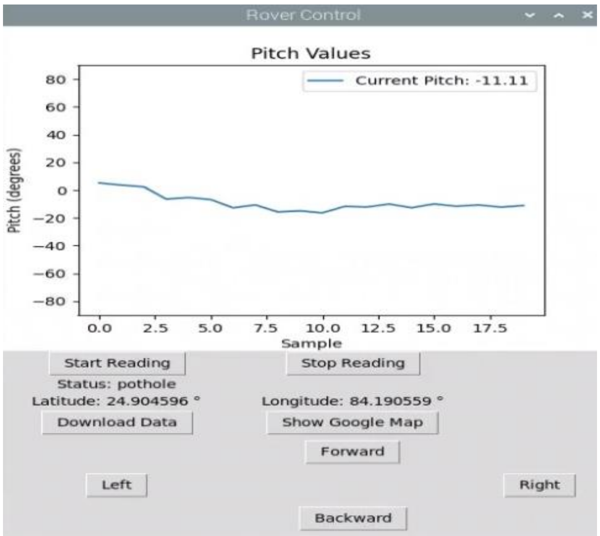
	Timestamp	Pitch	lat	long	status
0	2024-01-08 14:45:42	[3.812965580196l553, 8.418422128532422, 13.224371822222848, 15.769826096254478, 15.938579241668644, 16.819368131495523, 19.827893139835062, 20.5	24.90473	84.19036	['bump']
1	2024-01-08 14:45:42	[-4.294572002050443, -4.121154975950972, -0.636489888067805, 1.0291165548623267, 7.27599812003989, 9.154952508149684, 7.494151088131002 5, 9.846	24.90483	84.19062	['bump']
2	2024-01-08 14:45:42	[-4.432455267173398, -1.0755093358061365, -0.909640750264471, 2.9325278398830377, 5.442063581788086, 6.016407161266591, 9.035085505861483, 9.502	24.90446	84.19094	['bump']
3	2024-01-08 14:45:42	[20.392418472526764, 22.495933154578957, 21.486483611156377, 16.581003003190816, 10.309899213038623, 3.4503286440787098, -2.160038286396965, -6	24.90458	84.19081	['pothole']

Figure 6: Proposed model gathered sample data

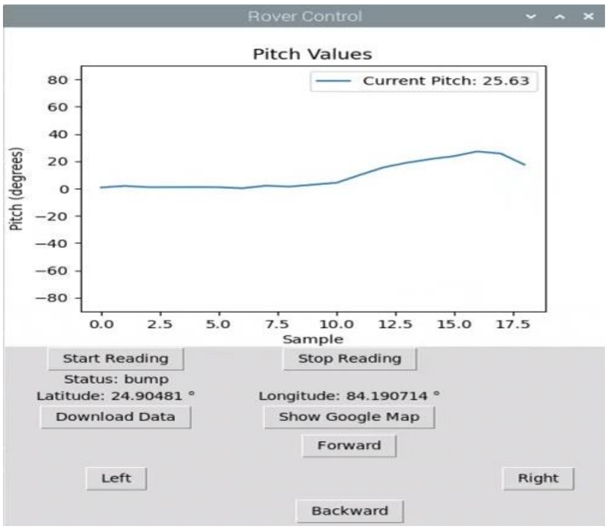


Status: flat
Latitude: 24.904741 °
Longitude: 84.190675 °

Figure 7: Flat or Clean Road Surface detection from the proposed model



Status: pothole
Latitude: 24.904596 °
Longitude: 84.190559 °



Status: bump
Latitude: 24.90481 °
Longitude: 84.190714 °

Figure 8: Bumpy or Rough Road Surface detection from the proposed model

Figure 7 and 8 clearly identifies the pitch orientation curves for signifying the quality of road smoothness. The vibration curves obtained from gyroscopic 3-axial sensor can be classified as flat pitch curve and inverted or non-inverted U shape curve. The analysis for the obtained curve in figure 7 and 8 can be summarized as follows:

Smoother Road Surface (Flat or Clean Road Surface): Pitch Orientation Deviation: There is minimal deviation from the neutral axis.

- Curve Shape Obtained: Results in a relatively straight-line curve.
- Road Smoothness: Represents a smooth and even road surface, typically free from bumps or potholes.
- Non-Smoother Road Surface(Bumpy or Rough Road Surface):
- Pitch Orientation Deviation: Exhibits noticeable deviations from the neutral axis.
- Bump: Deviates from the neutral axis to a positive axis orientation and then returns to the neutral axis orientation.
- Pothole: Deviates from the neutral axis to a negative axis orientation and then returns to the neutral axis orientation.
- Curve Shape Obtained: Forms irregular curves:
- Bump: Creates an inverted U-shape curve.
- Pothole: Forms a U-shape curve.
- Road Smoothness: Indicates an uneven or disrupted road surface, characterized by bumps, potholes, or other irregularities that can affect vehicle stability and comfort.

The basic distinction observed between clean smooth road surfaces and rough road surfaces as seen in figure 7 and 8 is significant for understanding the quality of road and its impact on driving conditions. Clean road surfaces are classified by minimal pitch orientation deviation that results in almost a straight-line curve, thereby offering a smoother and almost uniform driving experience. In contrast, the rough road surface shows a pitch orientation deviation, forming the irregular curves such as inverted U-shapes (for bumps) or U-shapes (for potholes). These surfaces are classified to be non uniform and more shaking roads that affects the vehicle stability and passenger comfort. The presence of such road surface imperfection not only highlight the necessity and immediate requirement of road maintenance but also lacks in passenger safety that can lead to a major cause of road accidents.

5. CONCLUSION

The integration of Internet of Things (IoT) technologies into smart transportation systems new era of revolutionizing efficiency and safety on our roads. Through sensor fusion techniques and vehicle-to-vehicle (V2V) communication, this research highlights transformative approaches for transportation infrastructure. By deploying multi sensor fusion approach that involves ultrasonic, accelerometer, and LiDAR sensors along with edge computing, the real time road surface condition data is collected and analyzed with precision. By gathering precise data through the proposed 4-wheel drive simulator framework, the model is able to capture 3-axial orientation that not only detects pitch orientation changes for the identification of road anomalies but also analyses it to indicate the smoothness quality of the road surface.

Furthermore, the incorporation of V2V communication, particularly leveraging DSRC technology, amplifies the benefits of IoT integration This integration of IoT technologies, sensor fusion techniques, and V2V communication holds significant promise for improving efficiency, safety, and overall road infrastructure management, particularly in the context of autonomous driving scenarios.

Author Contributions

Akhilesh Kumar Singh has carried out research exploration, review, implementation and

documentation. Dr. Damodar Reddy is supervisor and has reviewed the work of the research article.

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability

The data underlying this article cannot be shared publicly due to research work is part of undergoing doctoral thesis. The data will be shared on reasonable request to the corresponding author after completion of thesis work

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Akhilesh Kumar Singh currently pursuing Ph.D. in CSE department from National Institute of Technology, Goa. He has completed his M. Tech from IIT in Computer Science domain. His area of interest lies in IOT, Smart Transportation, Networks and Operating System

Dr. Damodar Reddy Edla currently working as an Associate Professor in the Department of CSE at National Institute of Technology, Goa. He has published more than 150 reputed SCI and SCOPUS journal articles. His area of interest lies in Machine Learning, Deep Learning, Artificial Intelligence, Data Mining and IOT

E-mail: akhileshvivek@nitgoa.ac.in, dr.reddy@nitgoa.ac.in