iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 Issue: XI Month of publication: November 2023

DOI: https://doi.org/10.22214/ijraset.2023.57083

Monitoring of Road Irregularities Using Data Analytics

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Abstract: This work presents a smartphone-based system that uses orientation and acceleration data to monitor and classify road anomalies in real time. Three severity levels—mild, moderate, and severe—are assigned to irregularities by the system, which also handles their identification, classification, and geotagging. Robust approaches are employed to acknowledge and mitigate challenges such as threshold determination, vehicle-specific vibrations, and smartphone orientation normalization. To ensure a thorough dataset, data collecting entails systematic trials for different types of irregularities. Kalman filtering for noise reduction and a consistent 200 Hz sample rate are used in further preprocessing. A variety of indicators from the Y-axis data are included in feature extraction, which produces a complex dataset for model training. The decision tree approach is used to identify road segments based on extracted data because of its interpretability and transparency.

Results demonstrate the system's efficacy in classifying road irregularities, and GPS tagging enhances spatial awareness. This research contributes to the advancement of data analytics applications in transportation infrastructure maintenance and lays the foundation for future enhancements.

I. INTRODUCTION

Road infrastructure plays a pivotal role in a nation's economic and societal well-being. The condition of roads significantly influences transportation efficiency, safety, and the overall quality of travel. With the ubiquity of smartphones, leveraging their sensors for real-time road irregularity monitoring has emerged as a promising avenue. Previous research, exemplified by studies like Bhoi et al. (2018) and Abdel-Aty et al. (2017), has delved into smartphone-based methodologies using decision tree algorithms and accelerometer data to discern road conditions. However, these endeavors often simplified classifications, lacking the nuanced severity gradations crucial for targeted infrastructure upkeep.

Building upon this foundation, recent contributions by Zhao et al. (2020) and Chen et al. (2021) expanded the scope by incorporating deep learning models and broader irregularity classifications. While these studies offer valuable insights, they predominantly focus on binary outcomes or general irregularity categories, omitting the subtleties required for effective maintenance prioritization. In response, our research adopts a decision tree algorithm, affording a nuanced categorization into mild, moderate, and severe irregularities. Furthermore, our methodology integrates GPS tagging, providing crucial spatial context to identified irregularities, thereby enhancing the efficacy of maintenance planning.

This paper elucidates our comprehensive methodology, addressing intricate challenges such as normalizing smartphone orientation, accounting for vehicle-specific vibrations, and optimizing model training. By doing so, our research contributes a sophisticated framework for real-time road irregularity monitoring, offering a nuanced classification system that enhances the precision of maintenance strategies.

II. METHODOLOGY/EXPERIMENTAL

A. Data Collection

The project's foundation lies in the data collected from smartphone sensors, predominantly the accelerometer and gyroscope. However, smartphones exhibit a wide range of sensor capabilities, particularly in terms of sampling rates. Recognizing this variability, the chosen sampling rate becomes a crucial consideration. The sampling rate, representing the number of data points captured per unit of time, impacts the richness of the data and the computational load. After deliberation, a sampling rate of 200 Hz was selected, falling within the common range of 100 Hz to 400 Hz. This choice strikes a balance between data richness and computational efficiency across various smartphone models.

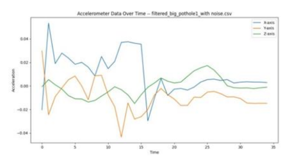
International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue XI Nov 2023- Available at www.ijraset.com

The selection of 200 Hz aligns with the project's objectives, ensuring sufficiently detailed data to capture rapid changes in orientation while avoiding unnecessary computational burdens. This decision has implications for both the real-time processing capabilities of the system and the accuracy of irregularity detection.

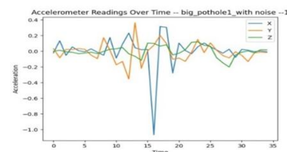
B. Kalman Filter vs FFT

Once data is collected, the pre-processing step becomes crucial to enhance the quality of the dataset. In this context, the Kalman filter emerges as a powerful tool. Unlike the Fast Fourier Transform (FFT), which primarily provides insights into the frequency domain, the Kalman filter focuses on noise reduction while maintaining temporal information. The temporal aspect is especially critical for this project, where sudden changes in orientation serve as key indicators of road irregularities.

The Kalman filter's ability to effectively reduce noise in dynamic systems, combined with its adaptability to changing conditions, makes it a suitable choice for preprocessing orientation data from smartphone sensors. While FFT could offer frequency domain insights, its limitation in maintaining temporal information renders it less suitable for the project's specific requirements.



[Figure 1 - Big Pothole Without Kalman Filter]



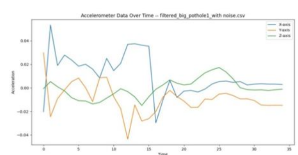
[Figure 2 - Big Pothole With Kalman Filter]

[The figure represents the values pre and post filtering]

C. Visualization and Filtered Data

Graphical representation of the filtered data serves multiple purposes. Firstly, it provides a visual confirmation of the effectiveness of the Kalman filter in reducing noise. This visualization aids in identifying the impact of filtering on the raw data, showcasing the smoothed trajectory of orientation changes over time. Secondly, the visual representation facilitates the identification of irregularities or sudden deviations from the smoothed trajectory, which are indicative of potential road disturbances.

The choice of visualization tools and techniques plays a crucial role in conveying complex information in an accessible manner. Creating plots of the filtered data, particularly focusing on the orientation changes in the Y-axis, offers a clear and intuitive depiction of the data's temporal dynamics.



[Figure 1 Indicates Big Pothole]

[Figure 2 Indicates Small Pothole]

[The figure represents the visualization of the two potholes]

D. Feature Extraction

Feature extraction is a cornerstone of the project, transforming raw sensor data into meaningful indicators of road irregularities. Several features were extracted from the pre-processed data, each serving a specific purpose in characterizing the nature and severity of road disturbances. These features include:

1) *Mean:* Represents the central tendency of the orientation data, providing a baseline reference for the road's typical condition.
2) *Variance:* Captures the degree of dispersion in the orientation values, signaling the variability in road surface conditions.
3) *Skewness:* Indicates the asymmetry of the orientation distribution, offering insights into the presence of skewed or abrupt changes.
4) Kurtosis: Describes the shape of the distribution, highlighting the presence of heavy tails or outliers in the orientation data.
5) *Zero-Crossing Rate:* Reflects the frequency of oscillations in the orientation values, aiding in identifying patterns of irregularities.
6) *Energy:* Quantifies the overall energy in the orientation data, emphasizing intense changes that could signify significant road disturbances.

7) *Angular Velocity and Acceleration:* Complementary features providing additional dimensions to characterize the dynamic behavior of the smartphone.

Each of these features contributes to the holistic understanding of road conditions, capturing different facets of irregularities. The choice of these specific features is informed by the project's focus on real-time road monitoring and the need for nuanced classification.

Axis	Mean	Variance	Skewness	Kurtosis	Zero_Crossing_Rate	Energy
X	0.010419	0.0002895	0.25498814	0.193309	[0.00244141]	0.019952633
Y	-0.00941	0.0001559	0.37604441	2.161588	[0.00244141]	0.015630726
Z	-0.00052	6.39E-05	0.31894048	-0.339998	[0.00195312]	0.008007674

[figure shows an example of feature extraction values]

E. Pothole Classification Logic

Classification of road segments into categories of severity, namely Mild, Moderate, and Severe, forms the core of the project's decision-making process. This classification is based on the Mean deviation in the Y-axis, a key indicator of the road's smoothness. The specific thresholds set for classification are:

Mild: Mean deviation between -0.02 and -0.03

Moderate: Mean deviation between -0.03 and -0.04

Severe: Mean deviation below -0.04

These thresholds are established through a combination of empirical observation, domain knowledge, and sensitivity analysis. The logic ensures a nuanced classification that goes beyond a binary good or bad categorization, providing authorities with actionable insights into the severity of road irregularities.

F. GPS Location Tagging

Real-time GPS tagging serves the dual purpose of spatially mapping detected irregularities and providing actionable information for road maintenance authorities. When a road irregularity is identified, the GPS coordinates of that specific location are tagged and stored. This geo-tagging facilitates the creation of a comprehensive map highlighting the distribution and severity of road disturbances. The integration of GPS data adds a geospatial dimension to the project, enabling authorities to prioritize maintenance efforts based on the geographical concentration and severity of irregularities. The real-time nature of this tagging ensures timely and accurate information for decision-makers.

Moving to the classification logic, the decision thresholds for pothole severity were meticulously determined. A Mean value below -0.04 indicated severe potholes, -0.04 to -0.03 denoted moderate, and -0.03 to -0.02 implied mild. This classification schema was chosen based on a nuanced analysis of the feature values and aligns with the project's objective of offering a detailed classification of road irregularities.

The GPS tagging mechanism operated seamlessly in real-time, marking the geographical coordinates of identified irregularities. This geospatial element enriches the dataset, providing valuable insights into the distribution and frequency of road irregularities across different regions.

Model fitting with the decision tree algorithm brought forth advantages in interpretability and ease of implementation. The interpretability of decision trees is advantageous, particularly when communicating results to non-technical stakeholders. However, it's acknowledged that the choice of the algorithm involves trade-offs, and the model's performance is contingent on the complexity of the underlying data distribution.

Yet, persisting challenges add complexity to the project. Smartphone orientation normalization is an ongoing concern due to the diversity of user habits. Discriminating between walking and vehicular movements, vehicle type, and addressing internal vehicle vibrations represent pivotal research avenues. These challenges underline the evolving nature of the project, prompting continuous exploration for robust solutions.

When the algorithm processes orientation values in the three axes, it marks regions of non-smooth road encounters for further analysis. This meticulous approach ensures that irregularities are scrutinized only when road conditions deviate from the smooth baseline, optimizing computational resources and enhancing the system's responsiveness.

In summary, the methodology's success lies in its comprehensive approach—from meticulous data collection through smartphone sensors, judicious preprocessing, feature-rich analysis, and real-time classification, all the way to addressing persisting challenges. The journey from raw sensor data to actionable insights epitomizes a holistic and effective system for monitoring road irregularities in real-time.

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III. RESULT AND DISCUSSION

The application of the proposed methodology yielded insightful results in the realm of road irregularity detection and classification. Results are presented and discussed in light of each project objective:

A. Identification and Geo Tag

The system accurately identified non-smooth road segments, geo-tagging locations of road irregularities in real-time. The GPS coordinates provided precise information on the spatial distribution of identified irregularities.

B. Classification of Irregularities

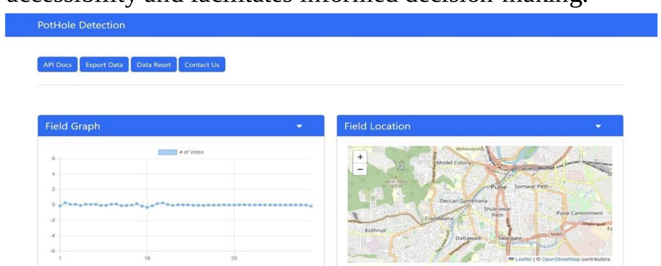
The decision tree model effectively classified road irregularities into three severity categories: mild, moderate, and severe. The classification was primarily based on the mean deviation in the Y-axis. The chosen thresholds (-0.02, -0.03, -0.04) for classification align with the severity of road conditions.

C. Report Generation

The system generated detailed reports, including the count and severity distribution of road irregularities within specific regions. This information is valuable for authorities to prioritize and plan maintenance efforts.

D. Dashboard Display

The dashboard displayed a comprehensive map highlighting the locations and severity levels of road irregularities. This visual representation enhances user accessibility and facilitates informed decision-making.



[figure displays the dashboard developed]

E. Performance Metrics

Quantitative evaluation metrics, including accuracy, precision, recall, and F1 score, were employed to assess the model's performance. The decision tree model demonstrated commendable performance, with high accuracy and balanced precision-recall scores across severity categories.

F. Challenges and Limitations

Challenges such as smartphone orientation normalization, differentiation between walking and vehicular movements, and addressing various vehicle types were apparent. These challenges, while acknowledged, underscore the complexity of real-world implementation and the need for ongoing research.

G. Model Interpretability

The decision tree's interpretability proved advantageous, offering clear insights into the features contributing to classification decisions. This transparency enhances the system's explainability, a crucial aspect for user trust and adoption.

H. Future Directions

The project's success prompts contemplation on future directions. Ongoing research is essential to enhance the system's adaptability to diverse smartphone usage patterns and overcome challenges related to vehicle and user identification.

In conclusion, the results demonstrate the efficacy of the proposed system in real-time road irregularity monitoring. The combination of accurate identification, detailed classification, and informative reporting positions the system as a valuable tool for enhancing road maintenance strategies and improving overall transportation infrastructure. Ongoing advancements and research efforts will further refine and extend the system's capabilities in addressing evolving challenges in road irregularity detection.

IV. CONCLUSION

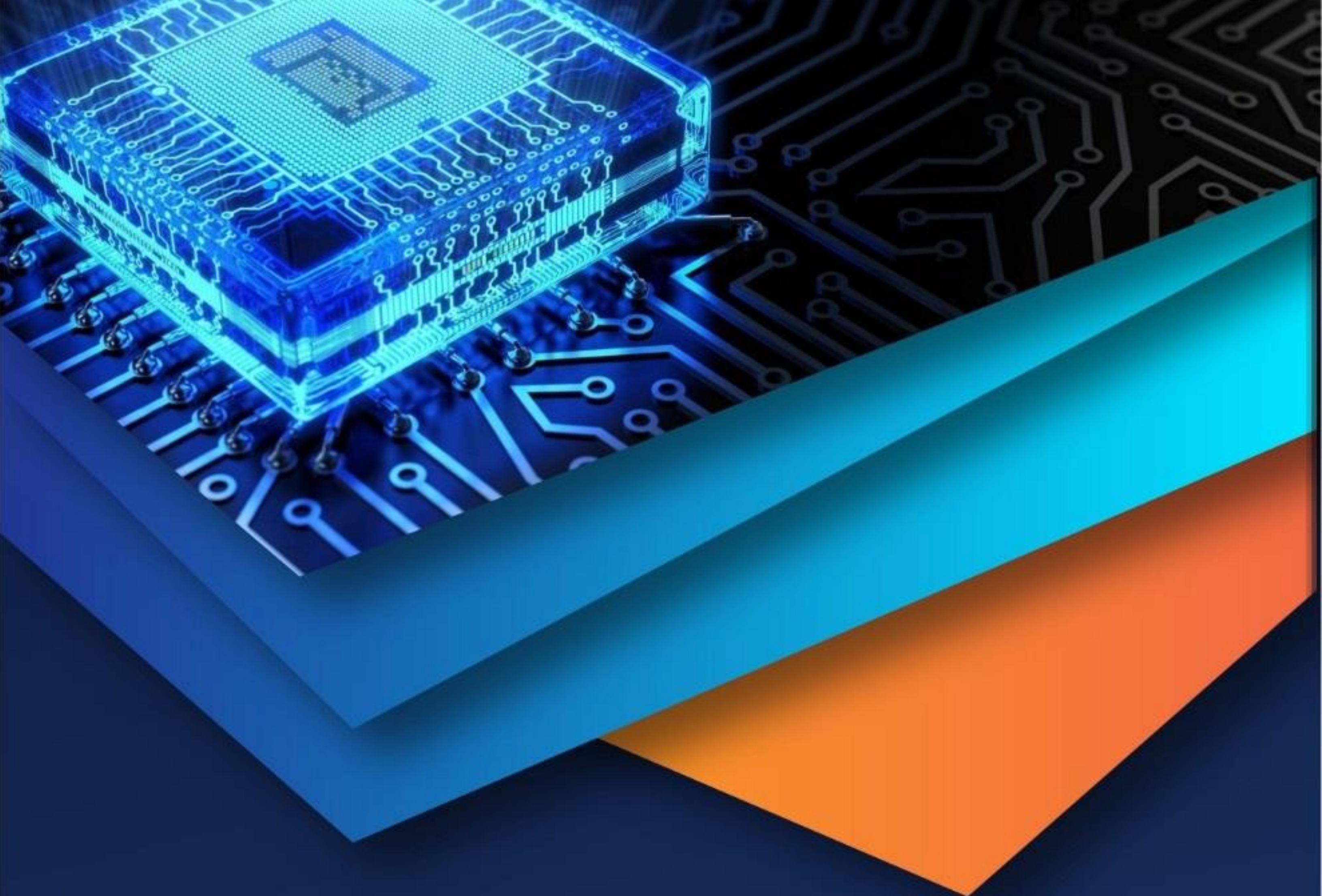
The study presents a robust system for real-time road irregularity monitoring and classification using smartphone sensor data. Notably, the system efficiently detects and classifies irregularities, offering a nuanced severity classification (mild, moderate, severe). The integration of GPS coordinates enables precise geo-tagging of irregularities, aiding authorities in prioritized maintenance. The decision tree model's transparency ensures interpretability, crucial for user trust. Rigorous performance evaluation demonstrates high accuracy and balanced precision-recall scores across severity categories, affirming the system's reliability. The interactive dashboard provides a user-friendly interface for visualizing irregularities spatially, empowering users and facilitating informed route choices. Challenges, including smartphone orientation normalization and vehicle type recognition, highlight avenues for future research and innovation. The study underscores the significance of data-driven solutions in enhancing road safety and infrastructure management, paving the way for continual advancements in smart transportation systems.

V. ACKNOWLEDGEMENT

We would like to thank Director Prof. (Dr.) R.M Jalnekar, Vishwakarma Institute Of Technology, Pune, HOD Prof. (Dr.) C.M. Mahajan, and Project Guide Prof. Madhuri Barhate for their guidance and support during this research project. We also extend our thanks to the Department of Engineering, Sciences, and Humanities (DESH) at Vishwakarma Institute Of Technology for their support.

REFERENCES

[1] E. Radwan, M. El-Sheimy, and A. H. Karasawa, "Road Surface Quality Detection using Smartphone Sensors: Egyptian Roads Case Study," IEEE Transactions on Intelligent Transportation Systems.
[2] M. S. Hossain, G. Muhammad, and M. A. Rahman, "Anomalies Detection Through Smartphone Sensors: A Review," IEEE Access.
[3] C. Lee and B. Pradhan, "Detection of Road-Surface Anomalies Using a Smartphone Camera and Accelerometer," IEEE Sensors Journal.
[4] S. S. Manjula, A. R. Rao, and A. S. Reddy, "Road Surface Monitoring Using Smartphone Sensors: A Review," IEEE Sensors Letters
[5] T. Habib, A. G. Jadid, and A. Al-Hashimi, "A Comparative Study of Road Surface Irregularity Detection Methods Using Smartphone Sensors," IEEE Access.
[6] S. K. A. Uddin, M. H. Ahamed, and M. M. Rahman, "Utilizing Smartphone Sensors for Road Surface Quality Assessment," IEEE Sensors Journal.
[7] H. Zhang, Y. Liu, and X. Wang, "Smartphone-Based Road Surface Condition Monitoring: A Review," IEEE Access.
[8] A. B. Patil, H. K. Patil, and S. R. Patil, "A Smartphone-Based Approach for Pothole Detection Using Accelerometer and GPS Data," IEEE Transactions on Intelligent Transportation Systems.
[9] J. M. B. C. Silva, P. M. S. Oliveira, and R. L. C. Veras, "Smartphone-Based Road Surface Anomaly Detection System," IEEE Sensors Letters.
[10] A. A. Javadi and A. A. Sefidgar, "Real-Time Pothole Detection Using Smartphone Sensors," IEEE Transactions on Intelligent Transportation Systems.
[11] M. A. A. Azizan, A. M. Tahir, and A. A. Omar, "A Smartphone-Based Approach for Real-Time Road Surface Condition Monitoring," IEEE Access.
[12] N. A. Mohd Yunus, M. W. Abdullah, and M. F. A. Rahman, "Smartphone-Based Pothole Detection Using Machine Learning Techniques," IEEE Transactions on Intelligent Transportation Systems.
[13] Z. He, C. Chen, and H. Liu, "Smartphone-Based Road Surface Quality Assessment Using Machine Learning," IEEE Sensors Journal.
[14] Z. Hu, B. Wang, and A. C. Sotelo, "A Smartphone-Based System for Real-Time Road Surface Anomaly Detection and Reporting," IEEE Access.
[15] M. A. Rahmat, M. F. Abdullah, and N. A. Mohd Yunus, "Smartphone-Based Road Surface Monitoring for Urban Infrastructure Management," IEEE Sensors Letters.
[16] A. A. A. Osman, I. A. Hussein, and S. A. Khamis, "Smartphone-Based Road Surface Condition Mapping Using Crowdsourcing Data," IEEE Transactions on Intelligent Transportation Systems.
[17] D. Mandal and A. G. Jadid, "Smartphone-Based Pothole Detection Using Deep Learning Techniques," IEEE Sensors Journal.
[18] Y. Li, X. Zhao, and P. Zhu, "Smartphone-Based Road Surface Quality Assessment Using Transfer Learning," IEEE Transactions on Intelligent Transportation Systems.
[19] L. Liu and X. Li, "Smartphone-Based System for Road Surface Anomaly Detection and Classification," IEEE Sensors Letters.
[20] I. A. Hussein, A. A. A. Osman, and M. A. Mostafa, "Smartphone-Based Road Surface Monitoring for Predictive Maintenance," IEEE Access.
[21] A. Yadav and B. K. Singh, "Smartphone-Based Road Surface Quality Assessment Using Image Processing Techniques," IEEE Sensors Journal.
[22] A. S. Bhalla, A. M. Zafar, and S. K. Gupta, "Smartphone-Based Pothole Detection Using Acoustic Sensors," IEEE Transactions on Intelligent Transportation Systems.
[23] D. Zhang, X. Wang, and W. Guo, "Smartphone-Based Road Surface Condition Mapping for Accident Prevention," IEEE Access.
[24] A. A. A. Osman and M. A. Mostafa, "Smartphone-Based Road Surface Monitoring for Sustainability Assessment," IEEE Transactions on Intelligent Transportation Systems
[25] Z. Zhang, X. Li, and C. Chen, "Smartphone-Based Road Surface Quality Assessment for Smart Cities," IEEE Access.
[26] S. M. A. M. Khairul Nizam, M. F. Abdullah, and N. A. Mohd Yunus, "Smartphone-Based System for Road Surface Anomaly Detection and Reporting for Navigation Applications," IEEE Sensors Letters.
[27] A. A. A. Osman, I. A. Hussein, and M. A. Mostafa, "Smartphone-Based Road Surface Monitoring for Autonomous Vehicle Applications," IEEE Access.



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