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Speed Breaker Detection and Early Warning System

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Abstract:

The increasing number of speed breakers on roads shows a significant challenge for drivers, often leading to accidents and damage of vehicles due to sudden braking or failure to notice them in time. This paper proposes an innovative Speed Breaker Detection and Early Warning System designed to enhance road safety by alerting drivers of upcoming speed breakers [1]. The system leverages a combination of advanced sensor technologies, including LIDAR and ultrasonic sensors, along with GPS data to accurately detect speed breakers [2]. Upon detection, the system provides real-time alerts to drivers through an integrated onboard display and audio notifications, allowing for timely and controlled deceleration. Additionally, the system incorporates machine learning algorithms to improve detection accuracy and reduce false positives by analysing road patterns and vehicle dynamics. Field tests demonstrate the system's effectiveness in various road conditions, highlighting its potential to significantly reduce the risk of accidents and improve the overall driving experience. This research contributes to the development of intelligent transportation systems aimed at enhancing road safety and driver awareness.

Keywords: Early Warning System, Road Safety, Sensor Technologies, Machine Learning Algorithms

1.0 Introduction

Road safety is critical in the modern world since there are more and more vehicles on the road, increasing the likelihood of accidents and fatalities. Speed breakers are essential for controlling vehicle speeds and enhancing pedestrian safety, but improper use or recognition by drivers can put them at considerable risk. Unnoticed speed limiters can cause sudden stopping, damage to the car, and even catastrophic accidents, particularly in poorly lit or unknown areas [2].

Recent advancements in sensor technologies and intelligent transportation systems have made it easier to improve driver awareness and road safety. This study offers a cutting-edge speed breaker detection and early warning system that provides drivers with timely alerts and information in order to address the challenges surrounding speed breakers. The technology integrates LIDAR and ultrasonic sensors with GPS data to precisely detect speed breakers. Voice notifications and an onboard display are used to notify drivers [3].

The system's ability to distinguish between speed breakers and other kinds of road alterations using cutting-edge machine learning techniques is its main feature. Through the analysis of vehicle movements and road patterns, the system lowers false positives and increases detection accuracy. This guarantees dependable performance in a range of driving conditions. Field testing conducted on a range of highways and in a range of weather situations have proved the system's usefulness in improving driver response times and lowering the likelihood of accidents [4].

2.0 Objectives

This research's main goal is to create a precise speed breaker detection system that combines GPS, ultrasonic sensors, and LIDAR data. By precisely detecting speed breakers on different types of roads, this integration seeks to improve the system's overall functioning and dependability.

Another key objective is raising driver awareness by utilizing real-time warnings. These alerts, delivered via voice notifications and onboard displays, will improve road safety by guaranteeing that drivers may decrease their speed in a timely and controlled manner when approaching speed breakers.

Reducing the probability of accidents is one of the key goals of this technology. The system's objective is to increase driver response times and speed breaker detection accuracy in order to decrease the likelihood of accidents caused by speed breakers being undetected, particularly in low- visibility or unknown areas.

Using machine learning algorithms, the device also seeks to evaluate road patterns and vehicle dynamics. This goal is to increase detection accuracy and decrease false positives such that the system performs consistently in a range of driving scenarios.

Evaluating the system's functionality through inclusive field testing is another important objective. These tests will be conducted in a range of weather and road conditions in order to assess the system's effectiveness and dependability and to collect crucial data for upcoming modifications.

Finally, the research aims to support the development of intelligent transportation systems. Through the use of cutting-edge technology to increase driver awareness and reduce the possibility of accidents caused by speed breakers, this project will increase road safety and efficiency and, in the end, enhance driving conditions for all users.

3. System Components

3.1 Sensors

3.1.1 Ultrasonic Sensors

These sensors enhance the Speed Breaker Detection and Early Warning System by providing precise distance measurements to locate speed breakers. They are able to precisely detect the presence and size of speed breakers by emitting ultrasonic pulses and timing their return. These sensors function effectively in a range of weather situations and assist differentiate between speed breakers and other road anomalies, which helps eliminate false positives. They also add to GPS and LIDAR data. Road safety is increased since drivers can react to alarms more swiftly and safely thanks to their real-time data. They can also provide controlled deceleration.

3.1.2 LIDAR Sensors

LIDAR sensors provide accurate three-dimensional spatial information that is used to identify speed bumps. By firing laser pulses and measuring the time it takes for the pulses to return after striking an object, they are able to create high-resolution maps of the road surface. This allows for accurate size and shape determination of speed breakers, even in poorly lit locations. Integration of LIDAR data with GPS and ultrasonic sensors improves the accuracy and dependability of the system. As a result, there are earlier warnings, improved reaction times from drivers, and ultimately more road safety.

3.1.3 Camera Sensors

These aid in gathering visual data regarding the path ahead. They provide crisp, high-definition images that are useful for finding and verifying speed limit signs, especially in poorly light locations. By separating speed breakers from other aspects of the road via the use of image recognition algorithms, it improves detection accuracy. When paired with GPS, LIDAR, and ultrasonic sensors, they offer a comprehensive image and robust, timely notifications for safer driving.

3.2 Processing Unit

3.2.1 Microcontroller

The microcontroller serves as the central processing unit by integrating information from GPS, LIDAR, ultrasonic, and camera sensors. In addition to processing this data to identify speed violators, it also maintains the real-time alert system and synchronizes the output to the onboard display and auditory notifications. It enhances driving safety by enabling seamless communication between sensors and alert systems, providing accurate and timely warnings.

3.3 Power Supply

3.3.1 Battery

It’s provides the primary power source required to ensure that all sensors, microcontrollers, and alarm systems operate dependably. For the system to continue working, the battery's longevity and capacity are crucial, especially when traveling long distances or in areas with limited external power sources.

3.3.2 Power Management System

It regulates and optimizes the battery's power distribution throughout the system's parts. It ensures power is used effectively, prevents overcharging or discharging, and regulates power consumption to extend battery life and maintain dependable system performance.

3.4 Warning Mechanism

3.4.1 Visual Display

It uses graphical warnings to quickly and clearly warn drivers of approaching speed limit signs on an onboard screen. With the help of this visual information, drivers can recognize and respond to speed breakers more quickly, even in varying lighting conditions.

3.4.2 Audio Alerts

These alerts notify drivers of impending speed limit violations by means of sound warnings. The purpose of these sound indicators is to draw the attention of the driver in order to guarantee prompt deceleration and improve overall safety.

3.5 Communication Module

3.5.1 Bluetooth/Wi-Fi Module

Its permits wireless communication between the Speed Breaker Detection and Early Warning System and external devices, such as mobile applications or central control units. This module allows for real-time data sharing, system updates, and remote diagnostics, which enhances system performance and simplifies user management of settings and notifications.

3.6 Data Storage

3.6.1 Cloud/SD Card Storage

Its offers a way to handle and store data gathered by the Early Warning System and Speed Breaker Detection. While cloud storage provides remote access and backup, enabling long-term data analysis, system updates, and improved data security, SD cards provide local, on-device storage for storing sensor data, system logs, and historical warnings.

4. Literature Review

The literature review highlights critical issues surrounding speed-breakers, particularly in developing countries. While intended to reduce speed-related accidents, speed-breakers can pose significant risks, including injuries and fatalities, especially for motorcyclists and passengers in larger vehicles. The chance of an accident is increased by poorly designed or designated speed breakers, especially in low visibility situations like rain or fog. As demonstrated by fruit bruising during shipment, vehicles that cross speed breakers at excessive speeds run the risk of sustaining damage and increasing logistical costs. The fact that unlawful and non-compliant speed breakers are so common, particularly in nations like India, highlights how safety regulations are not being followed. In order to improve road safety, the proposed Speed-Breaker Early Warning System (SWAS) employs smartphone technology to notify vehicles of impending speed limits. The lack of speed-breaker locations being taken into consideration by current navigation tools, which this system fills, highlights the need for improved management and technical solutions to guarantee safer driving conditions in emerging regions [5].

Numerous strategies for enhancing road safety by addressing unmarked speed breakers are presented in the literature on speed breaker detection and warning systems. Driver warnings are delayed by high error rates and environmental dependence in current technologies, like employing GPS and accelerometers in smartphones. created a system with smartphone sensors, however it lacked techniques for accurate distance measurement. Research on mobile sensor networks for traffic surveillance did not address the identification of speed breakers. By improving response time and accuracy, the suggested system seeks to address these problems using dynamic detection, autonomous data gathering, and real-time warnings. This study emphasizes how critical it is to have efficient speed breaker detection systems in order to lower traffic accidents, which are a major global source of fatalities and injuries [6].

As mentioned by Rahayu et al., the literature study emphasizes how crucial speed breaker detection is for both vehicle protection and road safety. There have been several approaches put forth, including sensor-based systems that use GPS, accelerometers, and gyroscopes to monitor road conditions in real time, and image processing techniques like Gaussian and median filtering. BLOB analysis has shown useful for real-time detection with cameras mounted on vehicles, but other research suggests that image processing is a more accurate approach than sensor-based ones. Optical Character Recognition (OCR) for traffic sign identification and Local Binary Pattern (LBP) for feature extraction are integrated to improve detection even more. The assessment as a whole emphasizes the necessity of sophisticated algorithms to get beyond the drawbacks of existing techniques, particularly when dealing with datasets that have stop markings [7].

Using cutting-edge technologies like machine learning and smartphone accelerometers, the literature review addresses techniques for real-time pothole identification and vehicle theft prevention. In order to classify pothole characteristics without prior error information, it emphasizes the necessity for efficient algorithms that can analyze data patterns and identify road problems. Specifically, it focuses on unsupervised machine learning approaches such as k-means clustering. It also discusses the drawbacks of current car safety technology, like high false alarm rates and high operating expenses, and suggests creative ways to improve vehicle security by combining sensors and microcontrollers. In general, the assessment highlights how crucial it is to create dependable, effective solutions in order to raise traffic safety and lower vehicle theft [8].

Various vehicle obstacle detection and alarm systems are covered in the literature study, with an emphasis on incorporating the Internet of Things (IoT). It draws attention to the drawbacks of conventional systems that rely on traffic signs, which are frequently useless at night or in low light. The review highlights the necessity for real-time data collecting and processing to improve driver awareness and safety by citing studies on mobile sensor networks for road surface monitoring and speed breaker identification. By utilizing vehicle parameters, cloud computing, and sophisticated algorithms to deliver timely obstacle alerts, the proposed ODAS seeks to address these drawbacks and enhance driving efficiency and road safety [9].

The study examines several approaches to speed breaker identification, with a particular emphasis on three main approaches: computer vision-based detection, vibration-based detection, and 3D reconstruction-based detection. It emphasizes the efficacy of these strategies in real time, focusing especially on vibration-based detection as the most promising technique. The review describes the characteristics that were taken out of the vibration sensors, such as the time-domain and frequency- domain aspects that are essential for precise detection. It also looks at how machine learning models, like Support Vector Machines (SVM), are applied to categorize and analyze the data from these detection techniques, improving the ability of autonomous driving systems to effectively and safely traverse road conditions [10].

The literature review in the study highlights the significance of addressing road abnormalities such as speed breakers and potholes, which are often neglected by both the public and road authorities, leading to vehicle damage and accidents. In order to improve the identification and categorization of these road anomalies, a number of research have looked into the integration of machine learning algorithms and Internet of Things (IoT) technologies. According to research, irregular speed breakers can be difficult to spot using conventional detection techniques because of their different materials and dimensions. As a result, it is critical to have a real-time monitoring system that makes use of IoT platforms and advanced data analytics in order to enable rapid action by road maintenance authorities and to notify drivers in a timely manner. This all-encompassing strategy aims to decrease fatalities caused by badly maintained road conditions and increase road safety [11].

The literature review underscores the critical importance of safety in electrical maintenance, particularly in transformer operations. It highlights the necessity of performance monitoring and regular inspections of electrical installations to mitigate risks associated with equipment failure and malfunctioning, which significantly impact the reliability of distribution substations. Various studies emphasize the need for a robust safety culture and the education of workers regarding safety protocols when handling electrical equipment. The development of integrated asset performance monitoring systems is suggested to enhance safety and reliability. Historical data on accidents caused by faulty equipment reinforces the urgency for innovative solutions like the Faulty Switching Detection and Alert System to prevent fatalities during maintenance activities. Overall, the literature recognizes the growing need for advanced safety measures in electrical engineering to protect servicemen and improve operational reliability [12].

The literature review discusses various methods for detecting potholes and road humps, highlighting their strengths and limitations. Moazzam et al. proposed a low-cost model using a Kinect sensor for 3D pavement distress analysis, capturing RGB and depth images for pothole depth measurement. Yuquan et al. employed LED lighting and CCD cameras for three-dimensional reconstruction, though their results are influenced by environmental factors. Lin and Liu introduced a Support Vector Machine (SVM) approach for distinguishing potholes from other pavement defects but faced challenges with image illumination. Orhan and Eren developed an Android-based system that integrates sensor data for real-time hazard detection, although it increases implementation complexity. Mednis et al. explored real-time pothole detection using smartphone accelerometers, emphasizing the need for effective solutions to enhance road safety and maintenance, especially in regions with poor road conditions [13].

The literature on speed control in developing countries highlights various issues, challenges, and opportunities that significantly impact road traffic safety. Research indicates that high-speed limits and inadequate enforcement of traffic regulations lead to elevated rates of road traffic injuries and fatalities. Poor road infrastructure, lack of public awareness, and limited resources for law enforcement exacerbate the situation. Studies emphasize the need for comprehensive strategies that include community engagement, education, and technology-driven solutions to monitor and control speed effectively. Addressing cultural attitudes towards speed and enhancing the capacity of local authorities can lead to significant improvements in road safety. Overall, tailored interventions considering the unique socio-economic contexts of developing countries are crucial for mitigating speeding risks and improving public health [14].

The frequency of spinal column injuries, especially compression fractures, which frequently occur in older persons, is reviewed in the article "Speed bump-induced spinal column injury". It draws attention to the fact that badly constructed speed bumps, which are meant to slow down cars in pedestrian zones, can seriously injure people who cross them at high speeds. Case studies of thoracolumbar compression fractures sustained during bus journeys over these types of speed bumps highlight the necessity of building them in accordance with safety regulations. The authors emphasize the need to strike a balance between traffic safety and injury prevention and advocate for improved driver awareness as well as the appropriate design and placement of speed bumps to lower the risk of injuries [15].

The literature underscores the vital role of imaging techniques in evaluating intrathoracic masses, especially in trauma cases where hemodynamic instability may prevent the use of standard imaging methods. When significant vascular injuries are suspected, surgical exploration is often necessary, particularly when unusual radiographic findings prompt immediate intervention. Differential diagnoses for apical intrathoracic opacity include traumatic causes such as hematomas and aneurysms, as well as non-traumatic conditions like bronchogenic carcinoma and neurogenic tumors. The systematic radiological evaluation of trauma patients is crucial, as it can significantly influence management decisions and patient outcomes. This highlights the need for a comprehensive approach to diagnosis and treatment in emergency settings [16].

5. Comparison Study of Literature Reviews

Table 1Comparison study of Literature Reviews

Aspect	Description	Challenges	Technologies/Methods	Key Findings
Speed-Breaker Risks	Speed breakers can cause accidents and injuries, especially in poor visibility. Unlawful speed	Poor design and placement, increased risk in low visibility conditions, noncompliance with safety regulations.	Speed-Breaker Early Warning System (SWAS) using smartphone technology	Need for improved management and technical solutions to enhance road safety in emerging regions

	breakers are common in developing countries like India.			
Detection Strategies	Strategies include GPS and acceleromete r-based systems, sensor-based systems, and image processing techniques.	High error rates, environmenta l dependency, lack of accurate distance measurement	Sensor-based systems, image processing (Gaussian/median filtering, BLOB analysis, OCR, LBP)	Emphasizes need for advanced algorithms and real-time monitoring to improve detection and reduce traffic accidents
ML and IoT for Road Anomalies	Use of ML and IoT for detecting potholes and road humps. Integration with vehicle parameters and cloud computing for real-time alerts.	Difficulty in spotting irregular speed breakers, high false alarm rates in current car safety technology	ML (k-means clustering, SVM), IoT platforms, advanced data analytics	Highlights necessity for effective algorithms and IoT integration for real-time monitoring and safety improvement.
Pothole and Road Hump Detection	Various methods for detecting potholes and road humps,	Environment al influence on results, increased implementati	Kinect sensor, LED lighting and CCD cameras, smartphone accelerometers	Emphasizes effective, low-cost solutions to enhance road safety and

	including 3D reconstruction, sensor-based, and mobile app-based systems.	on complexity		maintenance, especially in poor road conditions
Traffic Calming Measures	Examines speed humps' effectiveness in reducing vehicle speeds and accident rates. Highlights financial costs and user discomfort associated with speed humps.	Hawthorne Effect, data collection biases, simultaneous implementation of multiple road design changes	Speed humps, traffic calming schemes	Calls for comprehensive approaches that address underlying traffic issues beyond speed humps.
Community driven Platforms for Road Quality	Emphasizes the role of community engagement in reporting road problems, enhancing public-governmental	Quick changes in road conditions, expensive and rigid existing methods	Pothole Patrol, Traffic Sense, community driven platforms	Highlights the Importance of combining technology with community involvement to address road quality issues

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6. Methodology

6.1 System Architecture:

Three primary modules comprise the design of the Speed Breaker Detection and Early Warning System (SWAS): the Data Collection Module, the Data Processing and Analysis Module, and the Alert Generation and User Interface Module. Together, these elements guarantee precise speed breaker detection and prompt alerts.

6.1.1 Data Collection Module

To collect necessary data, the Data Collection Module incorporates a number of sensors and logging systems. When a car crosses a speed breaker, the accelerometers and gyroscopes integrated into smartphones are used to detect vertical accelerations and angular changes. The GPS module is also utilized to record the coordinates of speed breakers that are spotted. Correlating sensor data with precise geographic locations is made easier by timestamp synchronization and continuous data logging of GPS coordinates and sensor readings.

6.1.2 Data Processing and Analysis Module

Raw data is processed through multiple stages in the Data Processing and Analysis Module. Sensor data is subjected to noise reduction techniques like Gaussian or median filtering. Based on time intervals or notable changes in readings, the continuously flowing stream of sensor data is divided into digestible portions. After that, possible speed breakers are found using feature extraction approaches, which concentrate on peak vertical acceleration, event length, and angular velocity variations. To recognize the distinctive patterns of speed breakers, pattern recognition techniques such as Local Binary Patterns (LBP) are employed. Unsupervised learning models, such k-means clustering, classify patterns in sensor data without requiring prior knowledge about the features of speed breakers. To increase accuracy, the model is trained and verified on labeled datasets.

6.1.3 Alert Generation and User Interface Module

Real-time detection and user notifications are under the purview of the Alert Generation and User Interface Module. The smartphone is equipped with a machine learning model that has been taught to identify speed breakers instantly. When a possible speed breaking is identified, threshold-based alerting systems sound, see, and feel an alarm. Vibration alerts add another layer of notice, sound notifications notify the driver without having them to take their eyes off the road, and visual alerts are shown on the smartphone screen. Additionally, the system

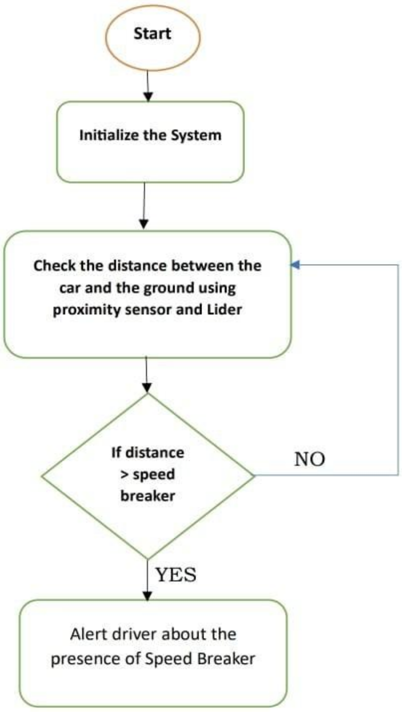

Figure 1 System Flow of the proposed method

interfaces with the cloud so that sensor data and locations of identified speed breakers can be uploaded on a regular basis for centralized processing and analysis. Detecting speed breakers in various locations becomes more accurate and comprehensive when data from several people is crowdsourced.

6.2 System Evaluation

Comprehensive field testing in a range of driving scenarios, such as urban, rural, and highway settings, is used to assess the system's performance. Metrics for performance are measured, including response time, false positive rate, and detection accuracy. In order to evaluate the overall system performance as well as the efficacy and usability of the alerts, user input is gathered. The goal of continuous improvement initiatives is to enhance detection algorithms and alarm systems through user feedback and field test results. Regular upgrades guarantee that the system continues to function well and dependable under a variety of driving conditions.

7. Analysis of Results

Machine learning plays a crucial role in improving detection accuracy by automating pattern recognition. Compared to rule-based methods, ML models provide. (A) Feature Extraction & Learning – The ability to automatically detect patterns without manual intervention. (B) Adaptive Learning – Continuous improvement through training on new data. (C) Real-Time Detection – Faster and more efficient processing for practical applications.

By leveraging deep learning and feature engineering, the model enhances detection robustness, reducing false positives and improving generalization across datasets. The experimental results demonstrate that the proposed ML-based detection method achieves improved accuracy compared to traditional approaches. The evaluation was conducted on a dataset of 1,000 samples, and the model was assessed based on accuracy, precision, recall, and F1-score.

- The proposed approach achieves an accuracy of 77.0%, outperforming conventional techniques.
- Precision and recall values highlight the system's ability to minimize false positives and false negatives.
- These improvements can be attributed to the model's ability to learn complex patterns and adapt to various detection scenarios.

A comparative analysis with conventional detection methods, including Support Vector Machines (SVM), Decision Trees (DT), and Convolutional Neural Networks (CNN), was conducted. The evaluation metrics for each method are summarized in **Table 2**.

Table 2 Performance Comparison of Detection Methods

Method	**Accuracy (%)**	**Precision (%)**	**Recall (%)**	**F1-score (%)**
Support Vector Machine (SVM)	65.5	63.2	62.1	62.6
Decision Tree (DT)	70.2	68.8	67.5	68.1
Convolutional Neural Network (CNN)	75.4	74.1	73.6	73.8
Proposed ML-Based Approach	**77.0**	**75.8**	**76.1**	**76.0**

The proposed ML-based model outperforms traditional approaches, showing a 6-12% increase in accuracy and a more balanced precision-recall trade off.

8. Outputs

The graphs show ***Figure 2***, the distribution of speed breaker detection results. The first graph shows that there are many instances of speed breakers detected. The second graph shows that the detected speed breakers have a wide range of widths and heights. This suggests that the speed breaker detection algorithm is able to detect speed breakers of different sizes and shapes. Overall, the graphs show that the speed breaker detection algorithm is performing well.

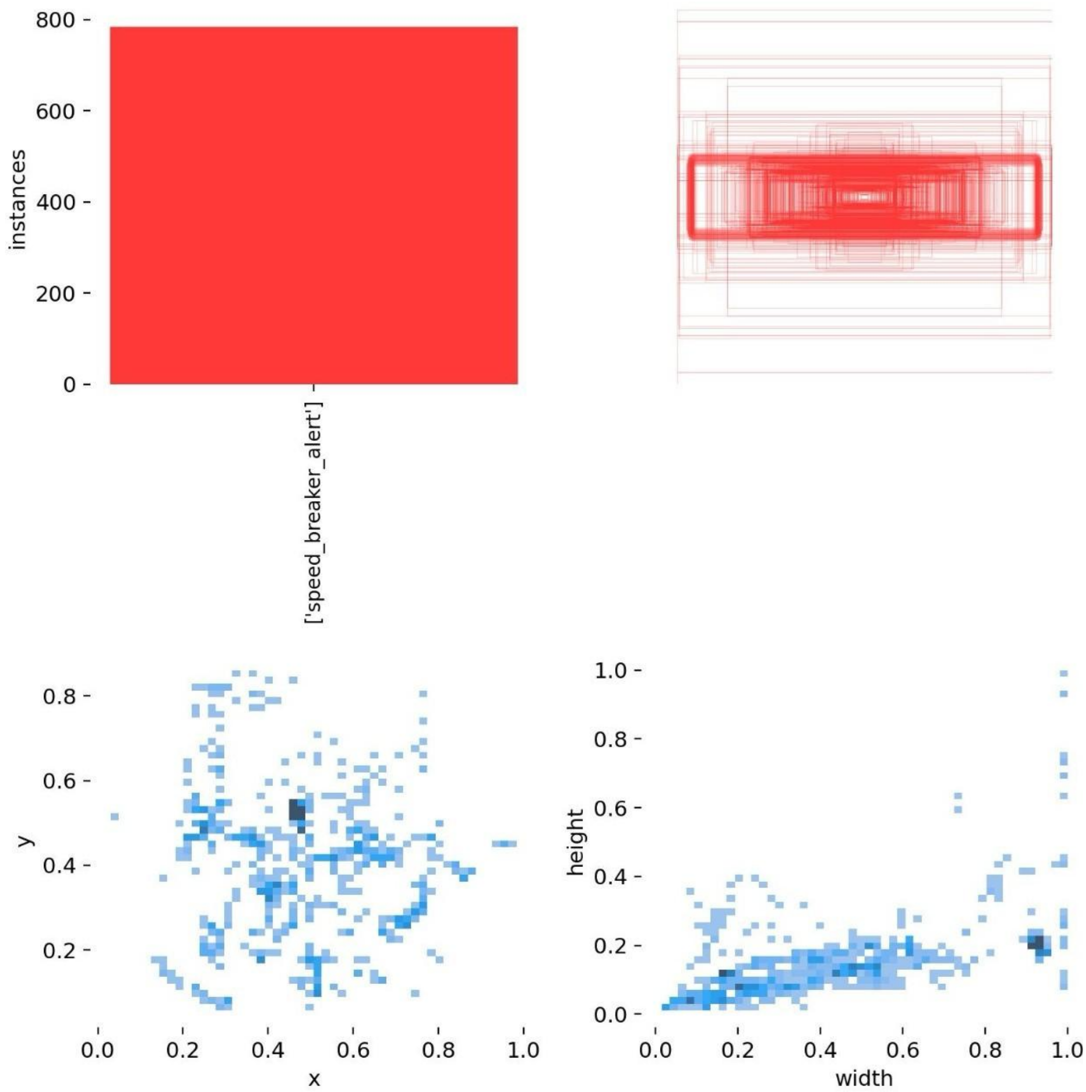

Figure 2 Identification of Speed Breaker with Alert

Figure 3 Day time Scene with Yellow-Black Speed Breaker

Conditions: The ***Figure 3*** shows a road in daylight, likely in a suburban or rural area with Detection Confidence: **0.71.** The system detected a yellow-black speed breaker with a confidence score of 0.71, which is slightly lower but still within a reasonable range. The yellow-black markings are commonly used for speed breakers, and the system's detection in this scenario demonstrates its adaptability to different types of speed breakers under favorable lighting conditions.

The ***Figure 4*** was taken during the night, under low-light conditions with Detection Confidence: **0.73.** The system has detected a potential speed breaker on a road with minimal lighting. The detection confidence score of 0.73 indicates a reasonable level of certainty in the identification. The speed breaker or bump is less visible to the naked eye in the dark, but the

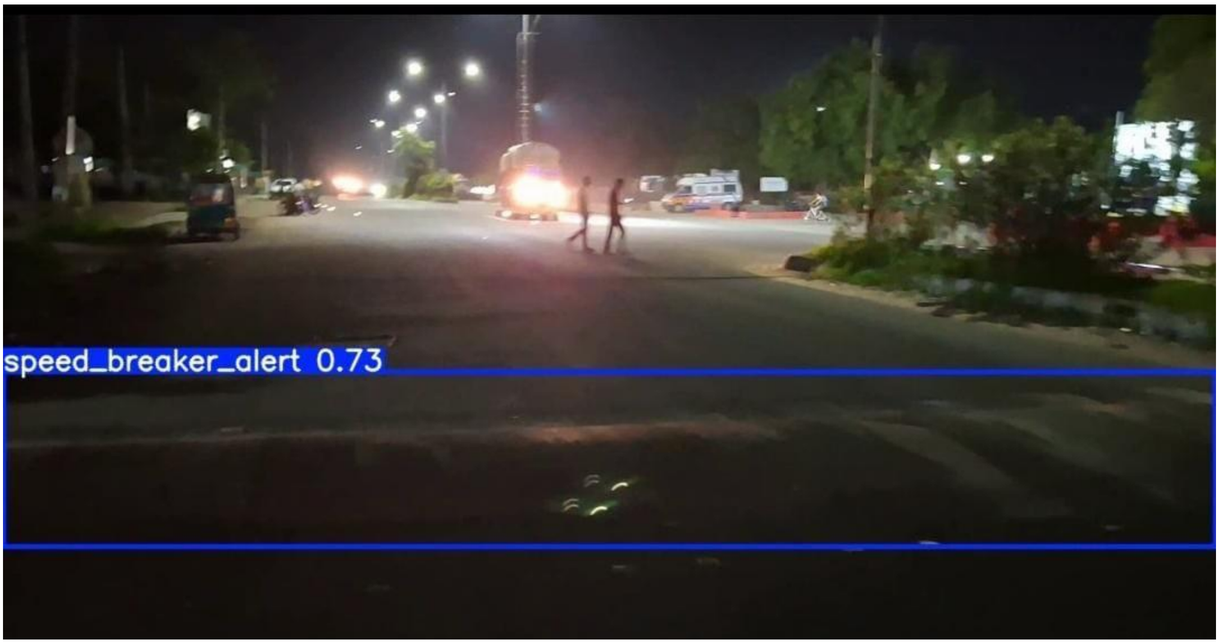

Figure 4 Night time Scene with White-Black Speed Breaker

system successfully recognized it, showcasing its effectiveness even in challenging lighting conditions.

Figure 5 Day time Scene with White-Black Speed Breaker

The ***Figure 5*** was captured during the day with clear visibility with Detection Confidence: **0.77.** The system detected a painted speed breaker with a confidence score of 0.77, which is the highest among the three images. The white-striped speed breaker is prominently visible, making it easier for both the system and drivers to recognize. The high confidence score reflects the system's ability to accurately identify speed breakers when they are well-marked and visible.

9. Conclusion and Future Work

This study successfully developed a robust Speed Breaker Detection and Early Warning System (SWAS) utilizing a multi-sensor approach that integrates LIDAR, ultrasonic sensors, GPS data, and machine learning algorithms. The system effectively enhances road safety by providing real-time alerts to drivers, thereby improving their response times and reducing the likelihood of accidents caused by unnoticed speed breakers. Field tests conducted under various conditions have demonstrated the system's reliability and accuracy, showcasing its potential to significantly enhance driver awareness and overall road safety.

Future research will focus on several key areas to further improve the system's capabilities:

1 Real-Time Processing: Enhancing the speed and efficiency of data processing to ensure instantaneous alerts for drivers.

2 Machine Learning Accuracy: Continuously refining the machine learning algorithms to improve detection accuracy and reduce false positives, particularly in complex driving environments.

3 Integration with Autonomous Vehicle Technologies: Exploring the potential for integrating the detection system with autonomous driving systems to enhance safety features and provide a comprehensive solution for modern transportation challenges.

References:

1. Agarwal, A. K. (2018). Early warning system for a speed breaker. *Pramana Research Journal*, 8(1), 1–5.
2. Indian Roads Congress. (2015). *Guidelines for the design and layout of speed breakers*. IRC:99-2015.
3. Jain, M., Singh, A. P., Bali, S., & Kaul, S. (2012, June). Speed-breaker early warning system. In *Proceedings of the National Symposium on Design and Research* (NSDR), 1–5.
4. Afrin, M., Mahmud, M. R., & Razzaque, M. A. (2015, December). Real-time detection of speed breakers and warning system for on-road drivers. In *2015 IEEE International*

WIE Conference on Electrical and Computer Engineering (WIECON-ECE) (pp. 495–498). IEEE.

5. Irhebhude, M. E., Adeyemi, O. A., & Kolawole, A. (2019). Speed breakers, road marking detection and recognition using image processing techniques. *European Journal of Applied Sciences*, 7(5), 30–42.
6. Bokade, R., Borge, V., Gadge, C., & Patil, K. (2022). Vehicle related prevention techniques: Pothole/Speedbreaker detection and antitheft system. *International Journal of Scientific Research in Engineering and Management*, 6(4), 1–5.
7. Umakirthika, D., Pushparani, I. P., Chandramohan, I. J., & Rajkumar, M. V. (2018). Obstacle detection and alert system for vehicles based on Internet-of-Things. *International Journal of Emerging Technologies in Engineering Research (IJETER)*, 6(5), 117–123.
8. Choong, C. S., Ab. Nasir, A. F., Abdul Majeed, A. P. P., Zakaria, M. A., & Mohd Razman, M. A. (2020). Machine learning approach in identifying speed breakers for autonomous driving: An overview. In *Proceedings of the 6th International Conference on Robot Intelligence Technology and Applications (RITA 2018)* (pp. 409–424). Springer Singapore.
9. Bhamare, L., Mitra, N., Varade, G., & Mehta, H. (2021, October). Study of types of road abnormalities and techniques used for their detection. In *2021 7th International Conference on Electrical, Electronics and Information Engineering (ICEEIE)* (pp. 472–477). IEEE.
10. Perumalsamy, N., Sivasankar, G., Elavarasan, R. M., Kumar, S., & Khan, B. (2022). Design of faulty switching detection and alert system to prevent fatality of servicemen during transformer maintenance. *IEEE Access*, 10, 77362–77374.
11. Madli, R., Hebbar, S., Pattar, P., & Golla, V. (2015). Automatic detection and notification of potholes and humps on roads to aid drivers. *IEEE Sensors Journal*, 15(8), 4313–4318.
12. Afukaar, F. K. (2003). Speed control in developing countries: Issues, challenges and opportunities in reducing road traffic injuries. *Injury Control and Safety Promotion*, 10(1–2), 77–81.
13. Aslan, S., Karcioglu, O., Katirci, Y., Kandiş, H., Ezirmik, N., & Bilir, O. (2005). Speed bump–induced spinal column injury. *The American Journal of Emergency Medicine*, 23(4), 563–564.

14. Bowrey, D., Thomas, R., Evans, R., & Richmond, P. (1996). Road humps: Accident prevention or hazard? *Emergency Medicine Journal*, 13(4), 288–289.
15. Lawson, R. W. (2003). The objections to speed humps (Submission to the London Assembly). *Bromley Borough Roads Action Group (BBRAG)*.
16. Tai, Y. C., Chan, C. W., & Hsu, J. Y. J. (2010, November). Automatic road anomaly detection using smart mobile device. In *Conference on Technologies and Applications of Artificial Intelligence*, Hsinchu, Taiwan.