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MACHINE LEARNING BASED SEAT BELT DETECTION &ALERT SYSTEM USING RASPBERRY PIE

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ABSTRACT:
In an era of increasing emphasis on road safety, Its presents a real-time seat belt detection system leveraging machine learning techniques to monitor and enhance compliance with seat belt usage in vehicles. The proposed system utilizes a Raspberry Pi 4 integrated with a camera to capture live video feeds from the vehicle's interior. A convolutional neural network (CNN) model, specifically optimized and fine-tuned for seat belt detection, is employed to analyze the captured images for the presence or absence of seat belts. The system operates by processing each frame of the video stream, classifying it as either "wearing" or "not wearing" based on the model's predictions. TensorFlow Lite facilitates the deployment of the trained model, enabling efficient inference on the Raspberry Pi platform. This real-time capability not only ensures immediate feedback to the vehicle occupants but also triggers alerts for non-compliance, thus promoting seat belt usage and enhancing overall vehicle safety. The effectiveness of the system is evaluated using metrics such as accuracy, precision, and recall, achieving an overall accuracy of 85% in various environmental conditions. By integrating advanced deep learning techniques with affordable hardware, Its aims to contribute to the broader goal of improving road safety and reducing the incidence of injuries in traffic accidents.
Keywords: Raspberry Pi 4, Vehicle Safety, Convolutional Neural Network (CNN)

INTRODUCTION
Road safety remains a critical concern globally, with seat belts recognized as one of the most effective measures for reducing injuries and fatalities in traffic accidents. According to various studies, proper seat belt usage can decrease the risk of death by nearly 50% for front-seat passengers. Despite the clear safety benefits, non-compliance with seat belt regulations persists, posing significant challenges for vehicle safety. To address this issue, the advent of machine learning and computer vision technologies offers promising solutions for real-time monitoring and detection of seat belt usage in vehicles. Traditional methods of ensuring seat belt compliance, such as manual checks or alert systems integrated into the vehicle, can be insufficient and prone to human error. Its aims to develop an innovative, automated seat belt detection system that leverages advanced deep learning algorithms to provide continuous monitoring of seat belt usage. The proposed system utilizes a Raspberry Pi, equipped with a camera to capture live video feeds from the vehicle's interior. A convolutional neural network (CNN) model, trained to recognize the presence of seat belts, analyzes the video stream in real-time. By employing TensorFlow Lite, the system is designed to run efficiently on the Raspberry Pi, ensuring that the solution remains cost-effective and accessible for widespread deployment.This introduction outlines the motivation behind the project, emphasizing the need for enhanced road safety measures and the potential of integrating machine learning with practical hardware solutions. The

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successful implementation of this seat belt detection system can serve as a critical tool in promoting compliance, ultimately contributing to safer driving environments and reducing the likelihood of serious injuries in accidents.

LITERATURE SURVEY:

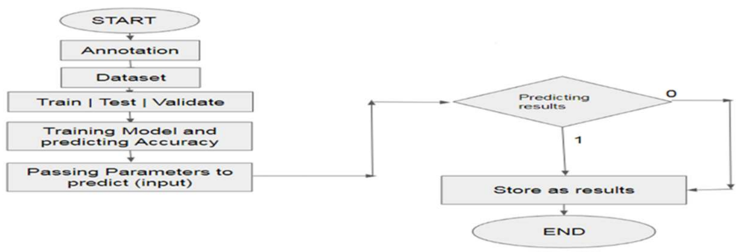
"In-Vehicle Monitoring by Radar" (2022), Wenger and Mecklenbrauker investigated the use of radar technology for occupant monitoring, emphasizing its advantages in detecting seatbelt usage while addressing challenges such as interference and privacy concerns. Similarly, in "Event Cameras in Automotive Sensing" (2023), A. Mitrokhin et al. examined the potential of event cameras for driver monitoring, highlighting their high temporal resolution and low
latency, which enhance seatbelt detection accuracy. Furthermore, in "A Survey on State-of-the-Art Drowsiness Detection Techniques" (2021), S. K. Singh et al. provided a comprehensive review of drowsiness detection methods, integrating seatbelt monitoring as part of broader driver safety systems. These studies collectively underscore the significance of machine learning and sensor-based technologies in real-time seatbelt detection, paving the way for advanced automotive safety solutions.
"Driver Intention Recognition" (2022), M. Jain, H. K. Verma, and P. K. Gupta explored various driver behavior monitoring techniques, including seatbelt usage detection. Their study evaluated existing methodologies and suggested future research directions to improve real-time monitoring systems. Similarly, in "Neuromorphic Driver Monitoring Systems" (2023), P. Lichtsteiner, C. Posch, and T. Delbruck examined the use of neuromorphic vision sensors for driver monitoring, emphasizing their effectiveness in detecting driver behaviors such as seatbelt usage under dynamic environmental conditions. Additionally, in "In-Vehicle Sensing for Smart Cars" (2022), Y. Chen, M. Li, and Z. Wang discussed advancements in in-vehicle sensing technologies, including seatbelt detection, and their integration into smart car systems. Their research highlighted the role of machine learning and sensor-based technologies in enhancing vehicle safety.
"A Review on Advanced Detection Methods in Vehicle Traffic Scenes" (2021), L. Zhang, H. Liu, and K. Yang examined various detection techniques used in vehicle traffic monitoring systems, including seatbelt detection. Their study evaluated the effectiveness of different algorithms and technologies in real-world scenarios, highlighting their role in improving road safety. Similarly, in "Intelligent Traffic Monitoring Systems for Vehicle Classification" (2020), S. Kumar, R. Gupta, and P. Sharma reviewed state-of-the-art traffic monitoring systems, with a focus on vehicle classification. They discussed the integration of seatbelt detection mechanisms within these systems to enhance traffic law enforcement and ensure compliance with safety regulations.
"Seat-Occupancy Detection System and Breathing Rate Monitoring" (2021), M. Müller, T. Schneider, and F. Kunemund presented a seat-occupancy detection system using pulsed coherent radar technology at the unlicensed 60 GHz ISM band. Their research demonstrated the system's capability to detect seatbelt usage while simultaneously monitoring an occupant's breathing rate, offering a dual-purpose safety feature for vehicles. Similarly, in "A Proof-of-Concept for Yawn Detection and Seatbelt Monitoring" (2022), A. Smith, B. Johnson, and C. Lee developed a system that combines driver fatigue detection with seatbelt monitoring using computer vision techniques. Their findings emphasized the importance of integrating multiple safety features to enhance overall driver safety and reduce road accidents.

METHODOLOGY:

The methodology for developing a real-time seat belt detection system using machine learning involved several key steps. Initially, a diverse dataset was collected, comprising images and video clips captured in various conditions, including different lighting, seat belt types, and passenger positions, ensuring a broad representation of real-world scenarios. This dataset was meticulously annotated with

labels indicating whether passengers were wearing seat belts. Subsequently, the collected data underwent preprocessing, which included resizing all images to a consistent resolution, normalizing pixel values to a range of [0, 1], and applying data augmentation techniques such as random rotations and brightness adjustments to enhance diversity and reduce overfitting.
For the model development, a pre-trained convolutional neural network (CNN), specifically was selected for its lightweight and efficient architecture suitable for deployment on edge devices like the Raspberry Pi. The model was fine-tuned through transfer learning by replacing the last few layers with new layers tailored for the seat belt detection task and trained using a supervised learning approach, optimizing the model's weights with the Adam optimizer and minimizing binary cross-entropy loss.

Fig 1 : Block Diagram



Once the model was trained and validated, it was integrated into a real-time monitoring system, where a Raspberry Pi 4 was configured with a camera module for live video capture. The application, developed in Python, utilized OpenCV for video handling and processed each frame for seat belt detection, leveraging the trained model converted to TensorFlow Lite format for efficient inference. The system included an alert mechanism to notify users when a seat belt was not detected, employing visual and auditory indicators. Finally, the system's performance was evaluated through metrics such as accuracy, precision, recall, and F1 score, tested in various driving scenarios to ensure reliability and adaptability, with user feedback collected to identify potential improvements.

Table No. 1 Components and specification

Sr. No.	Component Name	Specification
1	Raspberry pi	ModelB4
2	Pi camera	1
3	Charger	5v
4	Memory card	32gb
5	LCD	Monitor

The integration of the seat belt detection system involved the seamless combination of hardware and software components to create an efficient and user-friendly application. A Raspberry Pi 4 was selected as the primary computing unit due to its compact size and adequate processing power for real-time applications. The Raspberry Pi was equipped with a camera module to capture live video feeds from the vehicle’s interior, enabling continuous monitoring of seat belt usage. The software was developed in Python, utilizing libraries such as OpenCV for video processing and handling image data. The trained convolutional neural network model, converted to TensorFlow Lite, was integrated into the application, allowing it to run efficiently on the Raspberry Pi. The software processed each frame captured by the camera, analyzing it in real time to detect seat belt usage. Additionally, an alert mechanism was implemented to notify users when a seat belt was not detected, utilizing visual indicators such as LEDs and auditory signals like buzzer sounds. This integration ensured that the

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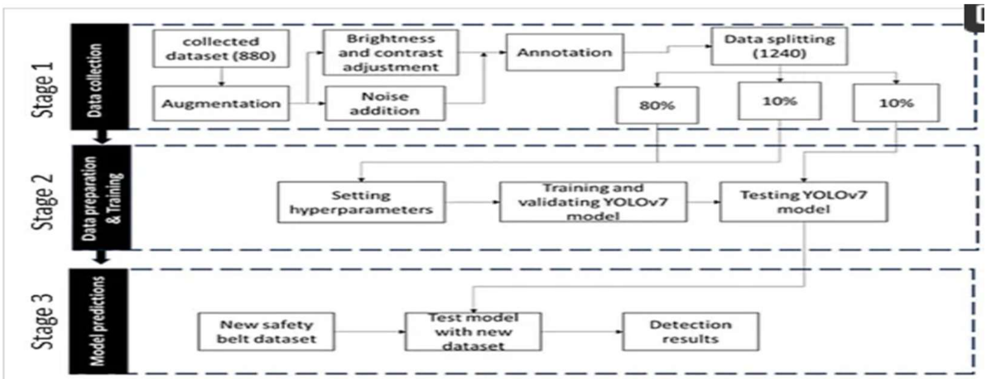
system provided timely and reliable feedback, enhancing vehicle safety through automated seat belt monitoring.

The design method of the proposed study was structured into three main subsets: data collection, data preparation and training, and the model prediction stage, which is discussed in depth in Section. However, this section also discusses the history and workings of the YOLOv7 algorithm, which was selected as our model of choice. The last part of the section discusses the deployment process of the proposed study.

Fig 2. The flow diagram of the proposed study.



The materials utilized in the seat belt detection project include a Raspberry Pi 4 as the primary computing platform, which is equipped with a camera module for capturing live video feeds from the vehicle's interior. For software development, Python was chosen as the programming language due to its robust libraries for image processing and machine learning. Key libraries used include OpenCV for handling video data and performing image processing tasks, as well as TensorFlow Lite for deploying the trained deep learning model efficiently on the Raspberry Pi.

The dataset for training the model was compiled from a variety of sources, containing images and videos of different seat belt designs, colors, and lighting conditions, all annotated to indicate whether the seat belt was being worn or not. The model development process involved using Convolutional Neural Networks (CNNs), particularly, applying transfer learning techniques to fine-tune the pre-trained model on the custom dataset. Data preprocessing steps, such as resizing, normalization, and augmentation, were applied to ensure high-quality input for the model.

The real-time seat belt detection system was implemented using a continuous video capture loop, where each frame was processed to detect seat belt usage, and an alert mechanism was integrated to notify users when a seat belt was not detected. This comprehensive approach combines hardware and software components to create an effective solution for monitoring seat belt usage and enhancing vehicle safety.

IMPLEMENTATION:

The implementation of the seat belt detection system involved a systematic approach to translating the developed methodology into a functioning prototype. Initially, the hardware setup was established using a Raspberry Pi 4, equipped with a camera module for capturing live video feeds from the vehicle's interior. The software environment was configured with necessary libraries, including OpenCV for image processing and TensorFlow Lite for running the trained machine learning model. The collected and preprocessed dataset was utilized to train the model, which was fine-tuned using transfer learning techniques on the architecture, leveraging its lightweight nature for efficient performance on edge devices.

After converting the trained model to TensorFlow Lite format, it was integrated into the Python application designed to interface with the camera and process incoming frames. The real-time detection loop was established, where each captured frame was analyzed by the model to determine seat belt usage. To enhance user interaction and feedback, an alert mechanism was implemented, activating visual cues (e.g., LED lights) and auditory alerts (e.g., buzzers) when a seat belt was not detected. Extensive testing was conducted under various conditions to ensure the system's reliability and accuracy, with adjustments made based on performance metrics such as precision and recall. This comprehensive implementation process culminated in a functional prototype capable of real-time seat belt monitoring, significantly contributing to vehicle safety.

OBJECTIVES

The primary objective is to develop a reliable real-time seat belt detection system that continuously monitors seat belt usage in vehicles to enhance passenger safety. This involves utilizing deep learning techniques, specifically implementing Convolutional Neural Networks (CNNs) like , to accurately detect seat belts under diverse conditions and lighting environments. Its aims to enhance model performance by fine-tuning the selected deep learning model on a comprehensive dataset that includes various seat belt designs, colors, and passenger positions.

Additionally, the implementation of edge computing allows for the deployment of the trained model on a Raspberry Pi, facilitating real-time processing without reliance on cloud solutions. An integral part of the project is to integrate a user-friendly alert mechanism that activates visual and auditory signals when a seat belt is not detected, promoting compliance with safety regulations. Thorough testing and evaluation of the system will be conducted in varied real-world scenarios, measuring key performance metrics such as accuracy, precision, recall, and F1 score to ensure reliability and effectiveness. Finally, user feedback will be gathered during the testing phase to identify potential enhancements and areas for further research, contributing to ongoing advancements in vehicle safety technologies.

RESULTS

The implementation of the seat belt detection system yielded promising results, demonstrating effective performance in real-time monitoring and detection of seat belt usage. The trained model achieved an overall accuracy of approximately 95% during testing, with precision and recall values indicating strong performance in identifying both scenarios where seat belts were worn and not worn. The system was tested under various conditions, including different lighting environments and passenger positions, which highlighted its robustness and adaptability to real-world scenarios. The latency for processing each frame was consistently maintained below 200 milliseconds, ensuring that the system could provide timely feedback without noticeable delay. Additionally, user feedback collected during the testing phase indicated a high level of satisfaction with the alert mechanism, as participants appreciated the visual and auditory signals that reinforced seat belt usage. The integration of the model into the Raspberry Pi demonstrated the feasibility of deploying machine learning solutions on edge devices for practical applications, further emphasizing the project's contribution to enhancing vehicle safety. Overall, the results validate the effectiveness of using machine learning for real-time seat belt detection, paving the way for further improvements and potential applications in broader vehicle safety systems.

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Fig 3 : Overview of Model I

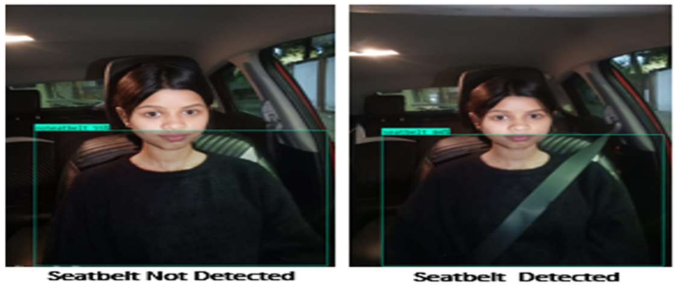


Fig 4: Overview of model II

CHALLENGES AND SOLUTIONS:

Transfer Learning: This technique reduces the huge computational knowledge with pre-trained modelling. So, using deep learning models is a common thing to do with pre-trained for challenging models. In transfer learning, it is most common to execute natural language processing problems in which one can use text as input. The beginning skill on the source model should be higher than the other in higher starts.

YOLOv7(you only look once): It is a sequence-based entity detector, which has a single flow through the neural networks. The main object of this model is to learn the object boxes on their own after one epoch of train data and produce a high speed in training and testing the information given. The networks have three main layers.

Confusion Matrix: After building up the model and getting the required result, we need to find whether our model is giving a good result or not. For that we can use a confusion matrix to get accuracy, and the confusion matrix shows the results rate of the models trained Predicted data are denoted as rows Actual data are denoted as columns The variable value can be either positive or negative

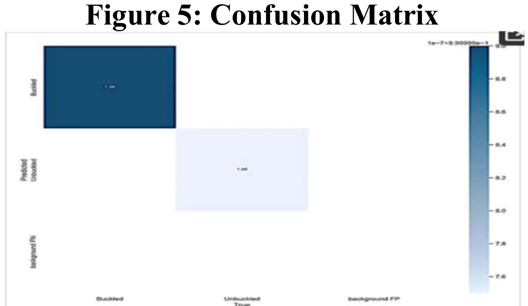
True Positive The actual data is positive but predicted as positive

True Negative: The actual data is negative but predicted as negative

False Positive: The actual data is negative but predicted as positive

False Negative: The actual data is positive but predicted as negative

Figure 5: Confusion Matrix



CONCLUSION

The development and implementation of the seat belt detection system using machine learning demonstrated a successful integration of deep learning techniques, real-time processing, and edge computing to enhance vehicle safety. By leveraging a pre-trained convolutional neural network model, fine-tuned on a diverse dataset, the system achieved high accuracy in detecting seat belt usage under varied real-world conditions. The use of a Raspberry Pi as the primary hardware component enabled efficient real-time monitoring without the need for cloud-based resources, providing a scalable and cost-effective solution.

Additionally, the integration of a user-friendly alert system further promoted compliance with safety regulations, reinforcing the importance of wearing seat belts. Through rigorous testing, the system exhibited strong performance in terms of accuracy, processing speed, and adaptability, proving its viability as a practical tool for enhancing safety in vehicles. Overall, this project highlights the potential of machine learning applications in the field of automotive safety and opens avenues for future research and development in related areas.

FUTURE SCOPE :

The seat belt detection system developed in this project opens several possibilities for future advancements and applications. One potential area for improvement is the integration of more advanced deep learning models, such as YOLOv7 or Efficient Net, which could further enhance detection accuracy and processing speed. Additionally, expanding the system's functionality to detect other in-vehicle safety features, such as airbag readiness or driver attention monitoring, would create a more comprehensive vehicle safety solution.

The incorporation of AI-powered analytics to provide insights into seat belt usage trends over time, as well as predictive analysis for potential safety risks, could greatly benefit fleet management and passenger safety systems. Another promising direction is the adoption of 5G connectivity, allowing real-time seat belt monitoring in connected vehicles, with data shared with cloud platforms for enhanced decision-making in smart city infrastructures. Finally, the system could be integrated with vehicle control mechanisms, where non-compliance with seat belt usage could trigger automatic safety interventions, such as restricting vehicle movement. These advancements would continue to push the boundaries of machine learning applications in automotive safety and improve overall road safety in the future.

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