

AN INTELLIGENT TRANSPORTATION SAFETY SYSTEM USING REAL-TIME IMAGE ANALYTICS ON EMBEDDED HARDWARE

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Abstract: Road crashes often happen because of visibility fast-moving vehicles and the absence of early alert mechanisms in vital road areas like tight bends and junctions. This project suggests an accident avoidance system utilizing real-time image analysis with a microcontroller development board. A camera module is employed to record live road scenes and track vehicle flow. The gathered information is analysed to identify and categorize vehicle types such, as cars, buses and trucks. The processed data is examined by a microcontroller equipped with edge AI features to enable precise decision-making. Upon detecting a vehicle the system shows the vehicle type, switches on a red traffic light and issues a voice alert to caution drivers and pedestrians, about incoming vehicles. In the absence of a detected vehicle the display and voice alert stay inactive. A green light is turned on to signal a safe situation. This proposed system improves road safety by delivering alerts and visual cues thereby lowering the risk of accidents. Its affordable time functioning and straightforward implementation render it appropriate for use in locations susceptible, to accidents.

Keywords: Image Processing, Vehicle Detection, Embedded System, Microcontroller, Camera Module, Accident Prevention

I. INTRODUCTION

Every year road traffic accidents result in a considerable loss of life and property making them a major global concern. Traffic density has increased, particularly in developing nations, as a result of the growing number of vehicles and the fast urbanization process. Blind bends, small roads, sharp curves, and poorly visible intersections are among the accident prone locations where many accidents happen because drivers are unable to recognize oncoming traffic in time. The effectiveness of traditional safety measures, like mirrors, signboards, and speed breakers, in preventing accidents is limited because they are passive and do not provide real time information. Intelligent accident prevention systems have been made possible by recent developments in embedded systems and image processing. Continuous observation of road conditions and precise detection of approaching vehicles are made possible by camera-based monitoring. Because of their small size, low power consumption, and quick response time, microcontroller development boards offer an effective platform for implementing real-time processing. Edge processing ensures dependable and timely operation by enabling local data analysis independent of internet connectivity. The primary goal of the suggested system is to create an intelligent accident prevention system that detects vehicles and produces visual and audio alerts using real-time image processing. In regions that are prone to accidents, this increases driver awareness, decreases reaction time, and improves overall road safety.

II. METHODOLOGY

The proposed intelligent accident prevention system follows a structured methodology to detect approaching vehicles in the real time and generate timely warning alerts. The system consists of a camera module, a micro controller development board, visual indicators and an audio alert mechanism. The camera module is positioned to continuously capture live images of the road, particularly in accident prone areas such as blind bends and narrow roads. The captured image are processed by the micro controller using image preprocessing techniques such as re sizing, noise reduction and contrast enhancement to improve image clarity and detection accuracy. After preprocessing a lightweight vehicle detection algorithm is applied to identify the presence of vehicles in the captured frames. The algorithm analyzes the image features and classify vehicles based on their shape and movement characteristics. Edge processing is implement to ensure that all

computations are performed on the micro controller, reducing latency and eliminating the need for internet connectivity. When a vehicle is detected, the micro controller activates a red warning indicator and generates a audio alert to notify drivers and pedestrians. If no vehicle is detected then the system maintains a safe state by activating green indicator. This real time detection and alert mechanism ensures that improves the road safety, faster response time and reliable system performance in the critical environments.

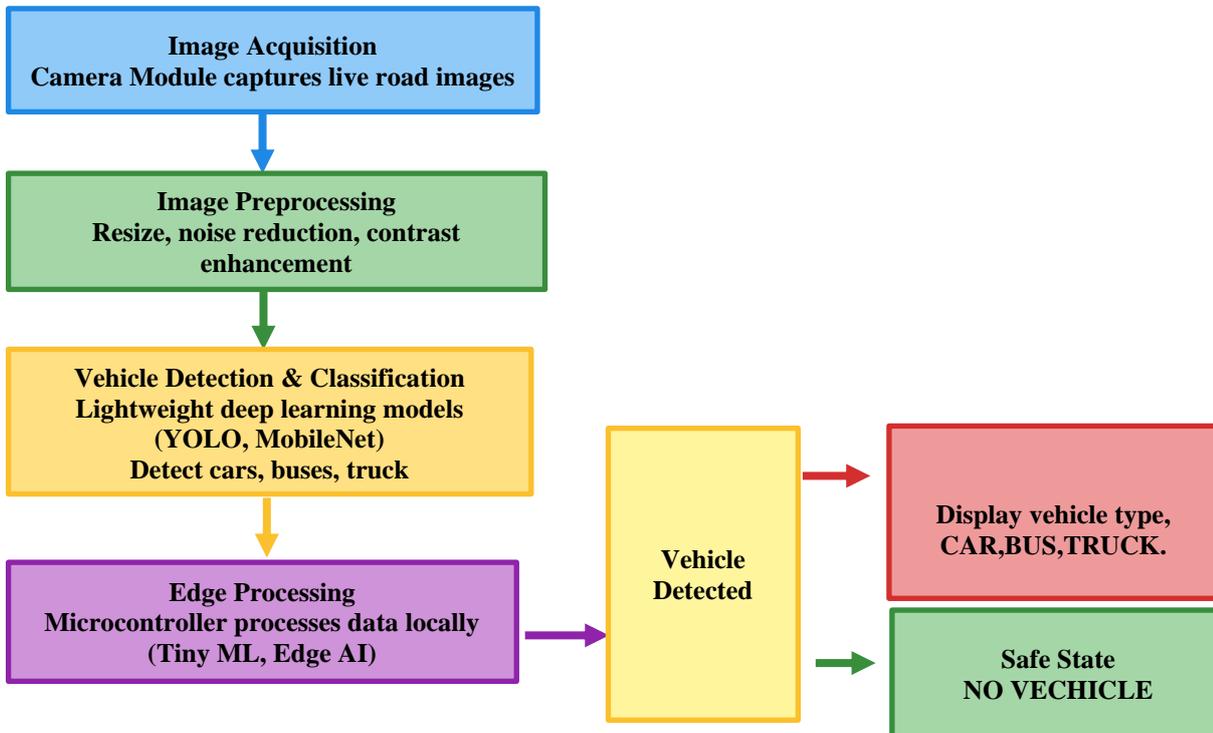


FIGURE 1: BLOCK DAIGRAM

The block diagram represents the overall working process of the vehicle detection and classification system. The first stage is Image Acquisition where the camera module captures live road images in real time. These images are then passed to the Image Preprocessing stage where operations such as resizing noise reduction and contrast enhancement are performed to improve image quality and make the data suitable for model analysis. After preprocessing the images are sent to the Vehicle Detection and Classification stage where lightweight deep learning models such as YOLO or MobileNet are used to detect and classify vehicles into categories like car, bus, or truck. Once a vehicle is identified, the data is forwarded to the Edge Processing stage, where a microcontroller such as Edge AI system processes the results locally without relying on cloud computing. If a vehicle is detected the system displays the vehicle type (Car, Bus, or Truck). If no vehicle is detected the system enters a safe state and indicates “No Vehicle.” This flow ensures real time detection efficient processing and quick decision making at the edge device level.

III. HARDWARE IMPLEMENTATION

After uploading the camera web server code to the ESP32-CAM module using the Arduino IDE and an FTDI programmer Figure 2 shows how the module was able to connect to the configured Wi-Fi network. After connecting it generated a unique IP address which was displayed on the Serial Monitor. This IP address was entered into a web browser such as Google Chrome to access the ESP32-CAM web interface. This interface allowed me to view the camera live video stream and take pictures directly in the browser. The interfaces many adjustable settings which included resolution, brightness, contrast, saturation, sharpness, exposure level, gain control, white balance, and special effects, also allowed me to modify and improve image quality in accordance with lighting conditions.

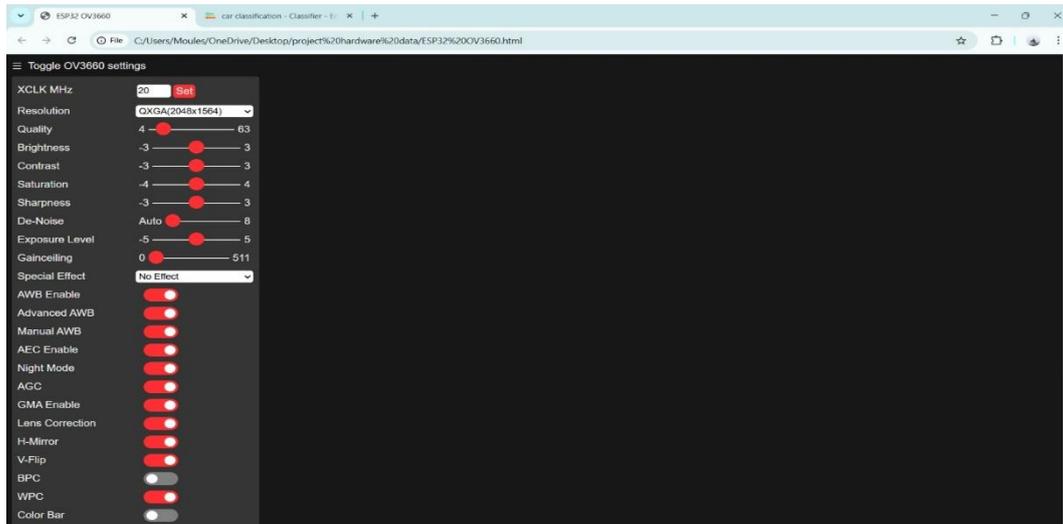


FIGURE 2: ESP32-CAM Web Server Interface displaying camera configuration settings and image control options accessed through the generated IP address in a web browser.

After experimenting with different settings and taking multiple photo I confirmed that the ESP32-CAM was functioning correctly hosting a web server streaming video and taking pictures over the Wi-Fi network.

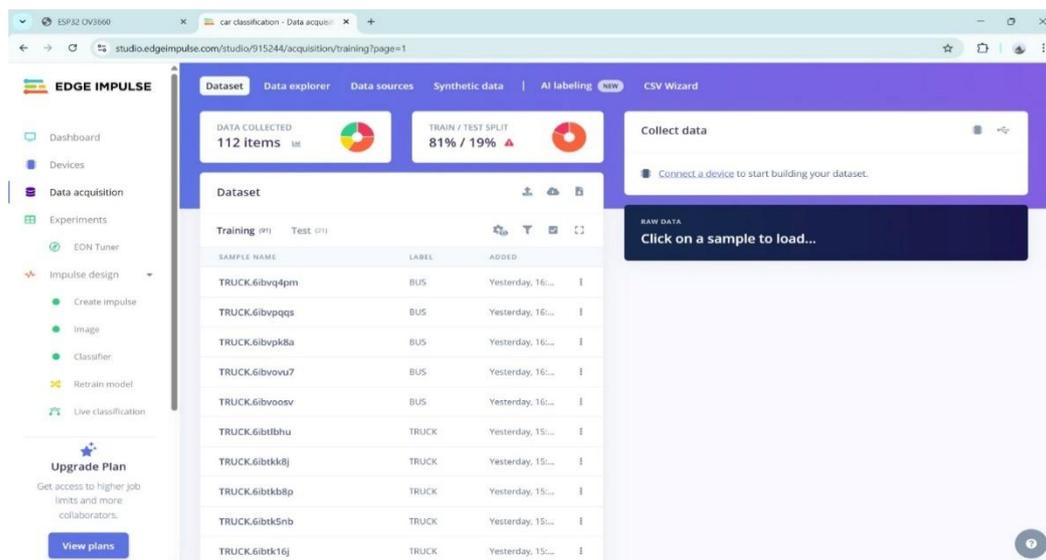


Figure 3: Data Acquisition- Edge Impulse Dataset Interface displaying uploaded ESP32-CAM images categorized and prepared for vehicle classification training (Bus, Car, Truck, etc.).

This picture displays the Edge Impulse platforms dataset page where photos taken with the ESP32-CAM are uploaded, saved and arranged in order to train the machine learning model as seen in figure 3. Following the camera module image capture Edge Impulse receives the data and classifies it into various labels such as "bus," "truck," "car," or "no vehicles." The train/test split percentage displayed on the screen indicates that the dataset is separated into training and testing sets. The dataset list includes each captured image along with its sample name label and upload date. Before training the model, this platform enables appropriate data management labeling, and preparation. I was able to confirm that the gathered photos were appropriately labeled and stored by using this interface, which is a crucial step in creating a precise vehicle classification system.

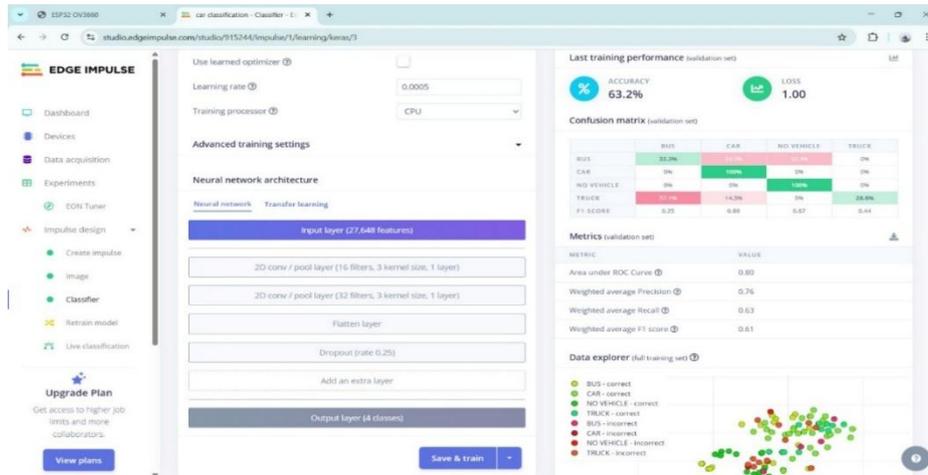


Figure 4: Classifier-Edge Impulse Model Training Interface showing neural network architecture, validation accuracy, loss, and confusion matrix for vehicle classification.

Figure 4 depicts the vehicle classification models training and performance evaluation phases on the Edge Impulse platform. A neural network model was set up and trained using the gathered dataset after the photos were uploaded and labeled. A flatten layer a dropout layer to lessen overfitting an input layer with multiple 2D convolution and pooling layers for feature extraction and an output layer with four classes (Bus, Car, No Vehicle, and Truck) are all part of the architecture. The training results which have a loss value of 1.00 and a validation accuracy of 63.2%, are shown on the right side. The confusion matrix highlights misclassifications between vehicle categories and shows how well the model predicts each class. To gauge overall performance additional evaluation metrics are also offered including precision, recall, F1-score and area under the ROC curve. This step verifies that the model has been successfully trained and assessed and gives information about how well the system can categorize various car types.

IV. RESULTS

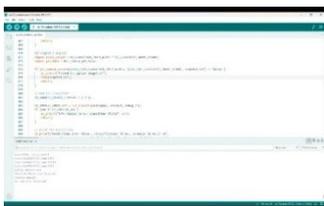


FIGURE.5: detect a no vehicle



FIGURE.6: detect a vehicle (car)



FIGURE.7: detect a Vehicle (bus)



FIGURE.8: detect a Vehicle (truck)



The proposed Intelligent Accident Prevention System based on ESP32-CAM and Edge AI was successfully implemented and tested for real time vehicle detection and classification. The system was evaluated using different input images including road scenes with no vehicles and images containing different types of vehicles such as cars buses and trucks. During testing, when no vehicle was present in the camera frame (Figure 5 the system correctly identified the scene as “No Vehicle,” indicating that the model can distinguish between empty road conditions and vehicle presence. When a car image was provided (Figure 6), the system successfully classified it under the “Car” category. Similarly, for bus images (Figure 7), the model accurately detected and classified the vehicle as “Bus.” For truck images (Figure 8), the system correctly identified the vehicle as “Truck.” The classification results demonstrate that the trained deep learning model deployed on the edge device is capable of performing real time vehicle detection with satisfactory accuracy. The

system successfully processes captured images performs preprocessing applies the trained model and displays the detected vehicle type. These results confirm the proper functioning of the hardware setup image acquisition process model training, and edge deployment. Overall the experimental results validate that the proposed system can effectively detect and classify vehicles which can be further utilized in intelligent accident prevention and road safety applications.

V. CONCLUSION

Road accidents are common in areas with poor visibility such as blind curves and narrow roads where traditional warning systems are often ineffective. This project proposed an intelligent accident prevention system using image processing and a microcontroller based edge computing approach. The camera module continuously monitors the road and detects vehicles such as cars buses and trucks using deep learning techniques. Since all processing is performed locally on the microcontroller the system ensures low delay reliable operation and independence from internet connectivity. When a vehicle is detected, alerts are provided through visual displays and voice notifications to improve driver awareness and reduce accident risks. In the absence of vehicles, the system remains in a low-power safe state. The proposed system is cost effective, energy efficient, and suitable for deployment in high risk areas such as highways school zones and industrial regions. Future enhancements may include advanced machine learning models, infrared cameras, and IoT integration for smart city applications.

VI. FUTURE SCOPE

The proposed intelligent accident prevention system can be further enhanced in several ways to improve its performance and real world applicability. Advanced deep learning models with higher accuracy can be implemented to improve vehicle detection under challenging conditions such as low light, rain, or fog. Integration of infrared or thermal cameras can enable night time and poor visibility detection. The system can also be connected to the Internet of Things (IoT) for remote monitoring real time data sharing and smart traffic management in smart city environments. Future improvements may include number plate recognition speed estimation and automatic alert transmission to nearby vehicles or traffic control centers. The addition of sensors such as ultrasonic or radar modules can further enhance detection reliability. Optimization of the hardware design for lower power consumption and solar powered operation can make the system more sustainable for remote or highway installations. With these advancements the system can evolve into a comprehensive intelligent traffic safety solution.

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