

AI-Based Intelligent Traffic Management System

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Abstract - Rapid increases in the number of vehicles in urban traffic require intelligent traffic management methods more than the fixed time method. The following work represents the design of real-time traffic management based on artificial intelligence technology with the use of computer vision, embedded systems control and wireless communication. Video input from a USB camera is processed by a graphical user interface (GUI), using the YOLOv8 model trained specifically for traffic vehicle detection and detection of emergency vehicles. ArUco markers are used to estimate lane localization and vehicle density. Control information received from the GUI is sent via serial communication to an ESP32 sender, then is relayed wirelessly to an ESP32 receiver using ESP-NOW and transferred via UART to an Arduino Mega for control of the traffic light. Experimental results prove high accuracy of the proposed algorithm and fast performance with mAP50 equal to 0.835 and inference speed of 3.9 ms per frame.

Key Words: *Intelligent Traffic Management; YOLOv8; Computer Vision; ESP32; Arduino Mega; ESP NOW; ArUco Markers; Real-Time Detection; Smart Cities*

1. INTRODUCTION

Congestion remains one of the most challenging issues within the cities as a result of rising vehicle density in the urban environment. Traditional traffic signals follow predetermined time schedules and cannot respond appropriately to changing traffic conditions, causing ineffective traffic flow, wastage of time, fuel consumption, and accidents. Intelligent traffic management system, therefore, presents itself as the solution to these problems. With recent developments in AI, computer vision, and the IoT technology, it is possible to design a system capable of providing a real-time view of the traffic and traffic management capabilities.

An intelligent traffic management system using AI, embedded systems, and wireless technology to manage traffic in real time through adjusting traffic signal lights based on the analysis of live traffic video is proposed in this paper. YOLOv8 based object detection framework will be used to detect objects and estimate the density of vehicles within each lane. Based on the obtained information from the algorithm, traffic signal lights are dynamically controlled, giving priority to emergency vehicles for faster reaction time.

The designed system features an effective communication strategy utilizing ESP32 units and ESP-NOW technology to facilitate timely wireless information transfer among different parts of the system. Data generated by the graphical user interface after processing traffic information are wirelessly transferred to the central controller, where an embedded system based on an Arduino unit is used to perform the signal control operations. The inclusion of lane detection based on ArUco markers contributes to precise determination of the position and density of vehicles. Experimental testing proves that the proposed design can attain reliable performance in real-time operation with high precision and response speed.

2. LITERATURE SURVEY

Modern traffic studies are inclined towards moving away from conventional static timing techniques and implementing intelligent adaptive mechanisms for traffic management. Previous implementations were based on IR sensors and basic controller mechanisms to detect vehicles' densities and manage the signal. However, the systems lacked scalability and accuracy. Thanks to the development in embedded platforms like Raspberry Pi, vehicle detection is currently implemented with the help of computer vision, as well as convolutional neural networks (CNNs).

YOLO detection systems have received much attention due to their speed and efficiency in classifying numerous vehicles that contribute to adaptive signal control. Moreover, communication through IoT platforms and protocols such as MQTT and ESP-NOW ensures efficient data sharing. Emergency vehicles can be managed to provide an efficient response, yet the problems of illumination effects, small datasets, and delays in communications still exist. The present implementation resolves these concerns with the use of YOLOv8 detection, ESP32 communication, and embedded management systems.

3. METHODOLOGY

3.1 System Overview

The system consists of a USB webcam, GUI, YOLOv8 model, ESP32 modules, and Arduino Mega 2560. Live traffic video is captured and processed in the GUI for vehicle detection and density estimation.

3.2 System Block Diagram

An illustration of the proposed intelligent traffic management system's architecture is shown in Fig.1 below. This system comprises the following units: vision, processing, wireless communication, and traffic control unit. In the first instance, a camera attached to the intersection captures video footage, which is transmitted in real-time to a computer where it will be processed using the GUI. Vehicle detection, lane-wise density estimation, and emergency vehicles detection will be carried out in the process, utilizing YOLOv8-based deep learning approach. Traffic data and control decision-making will then be transmitted to the sender ESP32 module via a serial communication link.

This data will then be communicated wirelessly via the ESP-NOW protocol from the ESP32 sender to the ESP32 receiver with minimal delay and loss. Finally, the receiver's processed data will be communicated further to the central control unit through UART communication channel. The main controlling unit in this case will be Arduino Mega microcontroller board, which will be used in managing signal timings to control traffic flow dynamically depending on the vehicle density. In addition, an RFID reader and ultrasonic sensors can be considered as back-ups for detecting emergency vehicles and other vehicles, respectively.

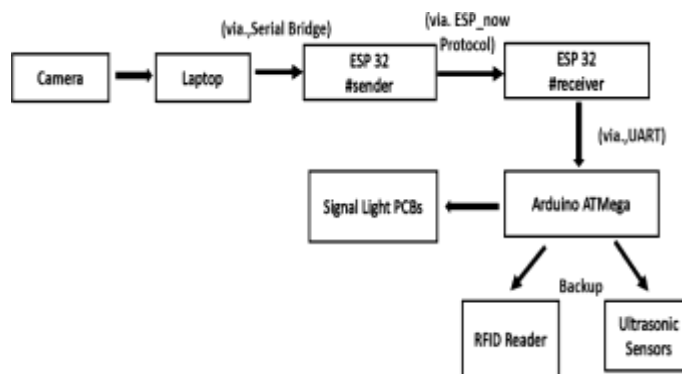


Fig.1: Block diagram of the intelligent traffic management system

3.3 System Flow Diagram

The working of intelligent traffic management system can be understood with the help of Fig.2 below. The process starts with initializing the system, after which the real-time video captures takes place using a camera that is installed at the traffic intersection. The acquired video is sent to a laptop through which the processing of images takes place through GUI using a detection model based on YOLOv8. The system retrieves lane wise vehicle density values and detects the presence of any emergency vehicles from the frames obtained. After this, decision making takes place where the detection of an

emergency vehicle like an ambulance is determined. In case of detecting an emergency vehicle, the lane is instantly prioritized by granting it a green signal for a certain period.

If there is no emergency vehicle detected in the frame, then the lane with the maximum number of vehicles is prioritized in the density-based approach. Then the calculated control data is sent to ESP32 sender module. From there, the ESP-NOW protocol is used to transmit the data to the receiver ESP32. After this the information is transferred to the Arduino ATmega controller using UART communication. The Arduino executes the traffic control logic and toggles the traffic signals accordingly. This process is continuously repeated in a loop to ensure real-time adaptive traffic management. The flowchart highlights the integration of computer vision, decision-making algorithms, and embedded communication for efficient traffic signal control.

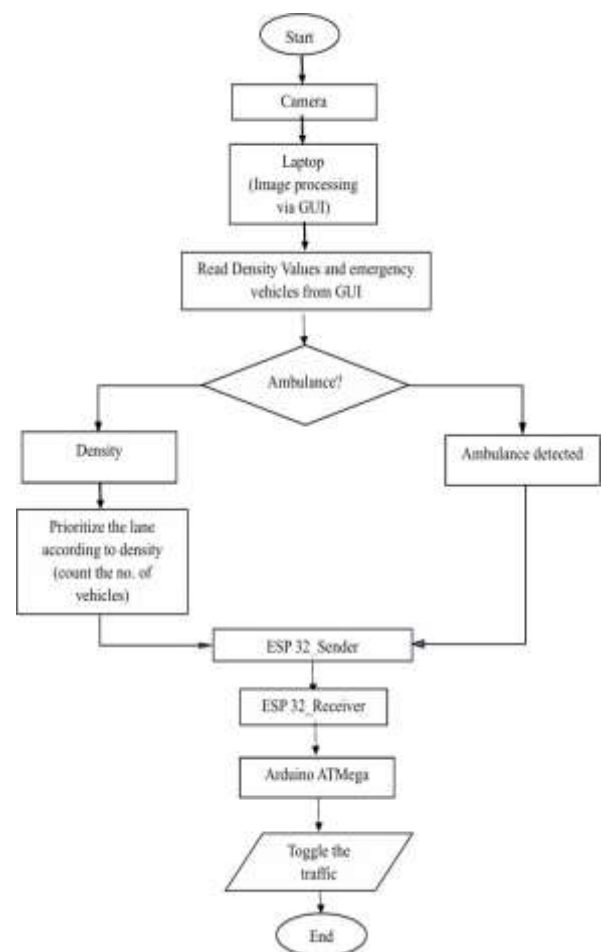


Fig.2: Flowchart representing system operation.

3.4 Vehicle Detection Using YOLOv8

YOLOv8 is used to find objects in real time. It can quickly and accurately find cars, emergency vehicles, traffic lights, and lane markings. The model processes each frame quickly, which makes it possible to keep an eye on things all the time.

3.5 Dataset Preparation

A custom dataset of about 230 images was made from the traffic prototype. Each image was manually labelled and put into one of nine object classes. This made it easier to find objects and recognize multiple objects at once.

3.6 Lane Detection Using ArUco Markers

ArUco markers define lane boundaries and improve vehicle counting accuracy by enabling precise localization of detected objects within each lane.

3.7 Communication System

Through serial communication, the GUI sends processed traffic density data to the ESP32 sender. Using the ESP-NOW protocol, the sender sends the data wirelessly to the receiver ESP32. The receiver sends the data to the Arduino Mega through UART communication so that it can control the signal.

3.8 Traffic Signal Control

The Arduino Mega changes traffic lights based on how many cars are on the road. Longer green lights (20 seconds) are given to lanes with more cars, while emergency vehicles get priority green signals for 30 seconds and take over normal operation.

4. RESULTS AND DISCUSSION

The YOLOv8 model was trained on 231 images over 100 epochs using GPU acceleration. The model demonstrated strong detection performance and real time processing capability.

Table 1: Model Performance Metrics

Metric	Value
mAP50	0.835
mAP50-95	0.551
Precision	0.809
Recall	0.784
Inference Time	3.9 ms/image

The results indicate that the model achieves a good balance between accuracy and speed, making it suitable for real-time traffic applications.

4.1 Detection and GUI Results

Sample outputs are shown in Fig. 3 and Fig. 4.

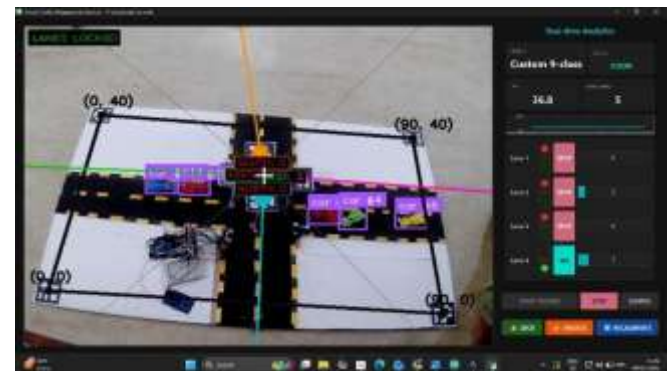


Fig.3: Real-time vehicle density detection.



Fig.4: Emergency vehicle prioritization.

The system successfully detects multiple vehicles in real time and displays bounding boxes with class labels in the GUI. ArUco markers enable accurate lane identification and improve vehicle counting reliability. The GUI provides real-time visualization of traffic density, system status, and detection outputs.

4.2 System Performance

The system demonstrated efficient real-time operation with low-latency communication between modules. Based on the detected traffic conditions, the Arduino Mega dynamically controls the traffic signals. When an emergency vehicle is detected, the system immediately overrides the normal signal sequence and assigns a green signal for 30 seconds to the corresponding lane, ensuring fast and uninterrupted movement. In normal operation, when vehicle density is detected, the system prioritizes the lane with the highest vehicle count and assigns a green signal duration of 20 seconds to that lane. This adaptive timing mechanism helps reduce congestion and improves overall traffic flow. The results confirm that the system responds quickly to real-time traffic conditions and effectively balances normal traffic control with emergency prioritization. The developed GUI is shown in Fig. 5.

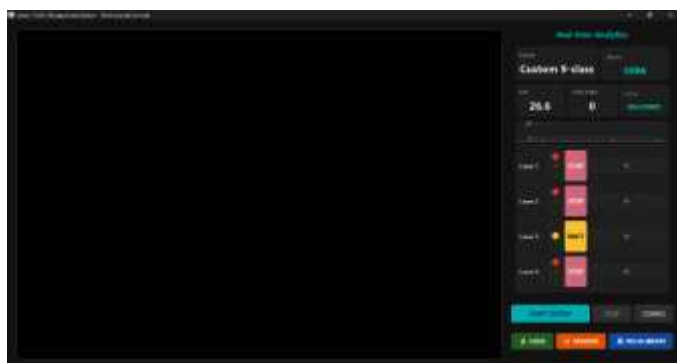


Fig.5: GUI for real-time detection and monitoring.

5. CONCLUSION

The designed system is capable of incorporating AI, IoT, and embedded system technology in order to deliver effective and adaptive traffic control. The system carries out real-time vehicle detection, determines the traffic density accurately, and adapts to change the signal timing depending on the actual situation. High accuracy was attained during real-time processing with an mAP50 of 0.835, while low latency is demonstrated by the system with an average inference time of 3.9 ms per image frame.

In addition, the inclusion of the priority feature of emergency vehicles makes the proposed system more road-friendly, as it reduces the response time and minimizes any risk to road users. This was possible with the help of efficient wireless transmission carried out using the ESP32 module, together with robust control from the Arduino platform.

Overall, this technique offers an efficient and cost-effective way of traffic management that can be deployed successfully in future.

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