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Smart Traffic Management System Emergency Vehicle

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Abstract: In today's growing urban traffic conditions, emergency vehicles like ambulances often get delayed due to heavy congestion at intersections. Such delays can lead to critical consequences, especially in medical and rescue situations. This project presents a Smart Traffic Management System that automatically detects emergency vehicles and gives them priority by controlling traffic signals in real-time. The system uses an IP camera to continuously monitor traffic at a junction. Real-time video frames are processed using object detection algorithms to accurately identify ambulances. Once an emergency vehicle is detected, the system determines its direction of approach—North, South, East, or West. This direction data is transmitted via the MQTT protocol to the traffic signal controller. The controller then immediately turns the traffic light green in that direction while turning red for all other directions, allowing the ambulance to pass through without delay. After the vehicle clears the junction, the system resets the signals back to normal operation. The entire process is automated and requires no human intervention. This smart solution ensures faster emergency response, improves traffic management efficiency, and reduces risks of accidents at intersections. The use of IoT, image processing, and automation makes the system scalable and suitable for modern smart cities. Ultimately, this system is designed to save lives by minimizing delays for emergency vehicles.

Keywords: *Emergency Vehicle Detection, Smart Traffic Control, Ambulance Priority System, Real-time Object Detection, Image Processing,IoT,MQTT Protocol, Traffic Signal Automation.Computer Vision,Smart City Solutions.*

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I. INTRODUCTION

Traffic congestion is a growing challenge in urban areas, particularly in densely populated countries like India, Thailand, and Japan. Emergency vehicles such as ambulances often struggle to navigate through heavy traffic, leading to delays in reaching hospitals and increasing the risk to patients' lives. Traditional traffic management systems rely on predefined timers or manual interventions, vehicles such as ambulances often struggle to navigate through heavy traffic, leading to delays in reaching hospitals which are often inefficient in handling emergency situations.

This project aims to develop an intelligent ambulance detection system using image processing techniques, specifically YOLO (You Only Look Once) and CNN (Convolutional Neural Networks). The system will process real-time video feeds from often struggle to navigate surveillance cameras installed at traffic intersections to detect ambulances and automatically control traffic signals, prioritizing emergency vehicles. This approach reduces response time, improves traffic flow, and enhances emergency response efficiency by leveraging deep learning algorithms, the system can detect ambulances efficiently without requiring additional hardware installations in vehicles. Once an ambulance is detected, the system will automatically turn the traffic signal green for a specific duration and send a signal to the next traffic intersection to ensure a clear path. This approach reduces response time, improves traffic flow, and enhances emergency response efficiency.

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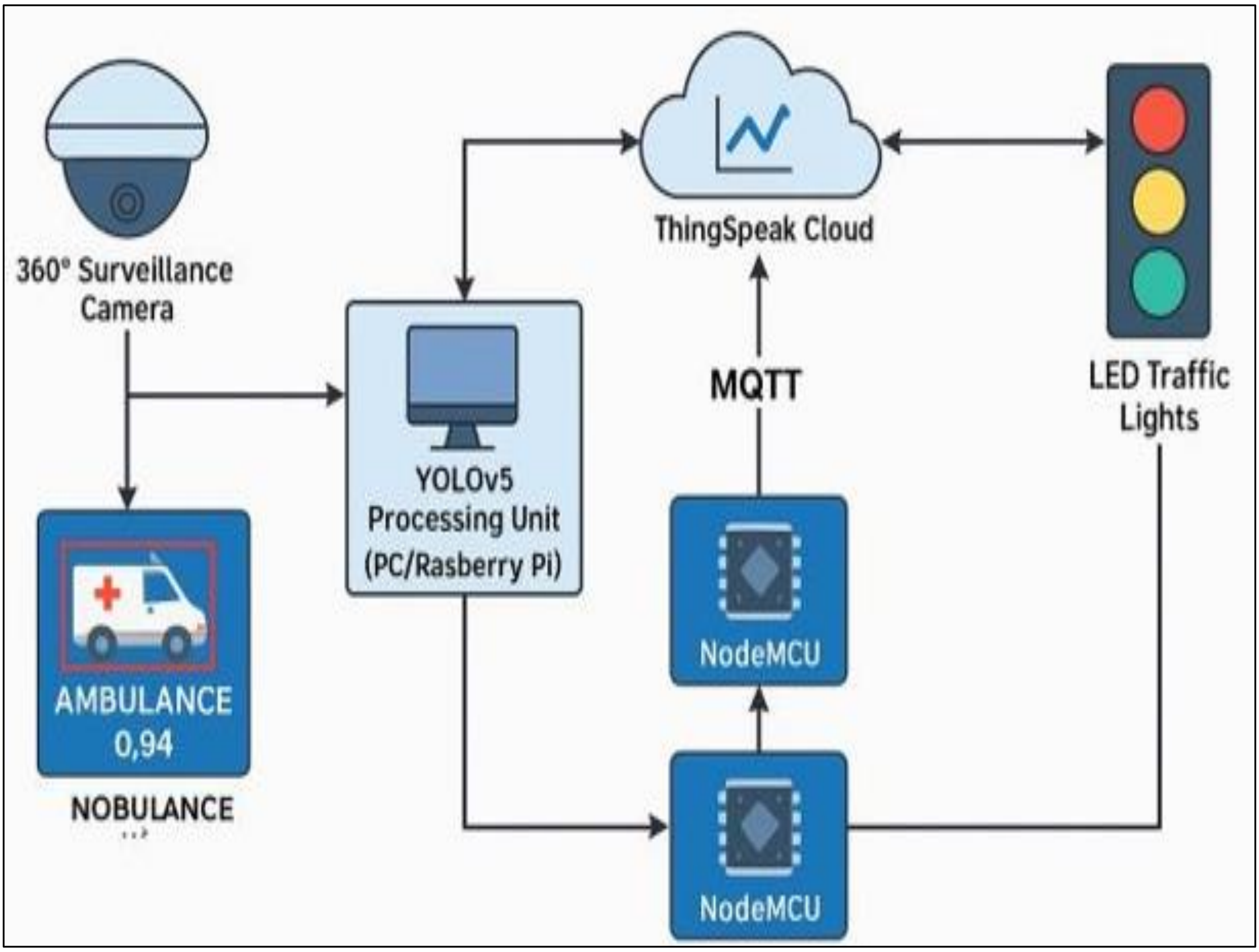

Fig 1 System Architecture of Smart Traffic Management

The proposed system offers a cost-effective, scalable, and automated solution for managing traffic congestion and ensuring faster medical assistance, ultimately saving lives.

II. METHODOLOGY

In the proposed project, we implement a smart traffic control system using image processing techniques powered by deep learning models such as CNN and YOLOv5. The objective is to detect ambulances in traffic and automatically control traffic signals to prioritize their movement, thereby reducing emergency response time. The system functions by capturing real-time traffic images through strategically placed surveillance cameras. These images are processed by machine learning models to identify ambulances, following which the system issues commands to traffic signals to allow a clear path for the emergency vehicle.

The key components of the system include a surveillance camera for real-time traffic image acquisition, a CNN and YOLOv5-based detection model for ambulance identification, and a microcontroller such as NodeMCU (ESP8266/ESP32) or Raspberry Pi to process and forward control signals. The traffic signal controller receives these instructions, altering the light sequence accordingly. A Wi-Fi module enables seamless communication between the image processing unit and the traffic management system. On initialization, the system loads trained deep learning models, sets up the camera interface, and configures the communication protocols between the microcontroller and the traffic control unit.

The system continuously captures live traffic images, which undergo several stages of processing: image acquisition, pre-processing, feature extraction, object detection, decision-making, and finally, traffic signal control. Pre-processing steps

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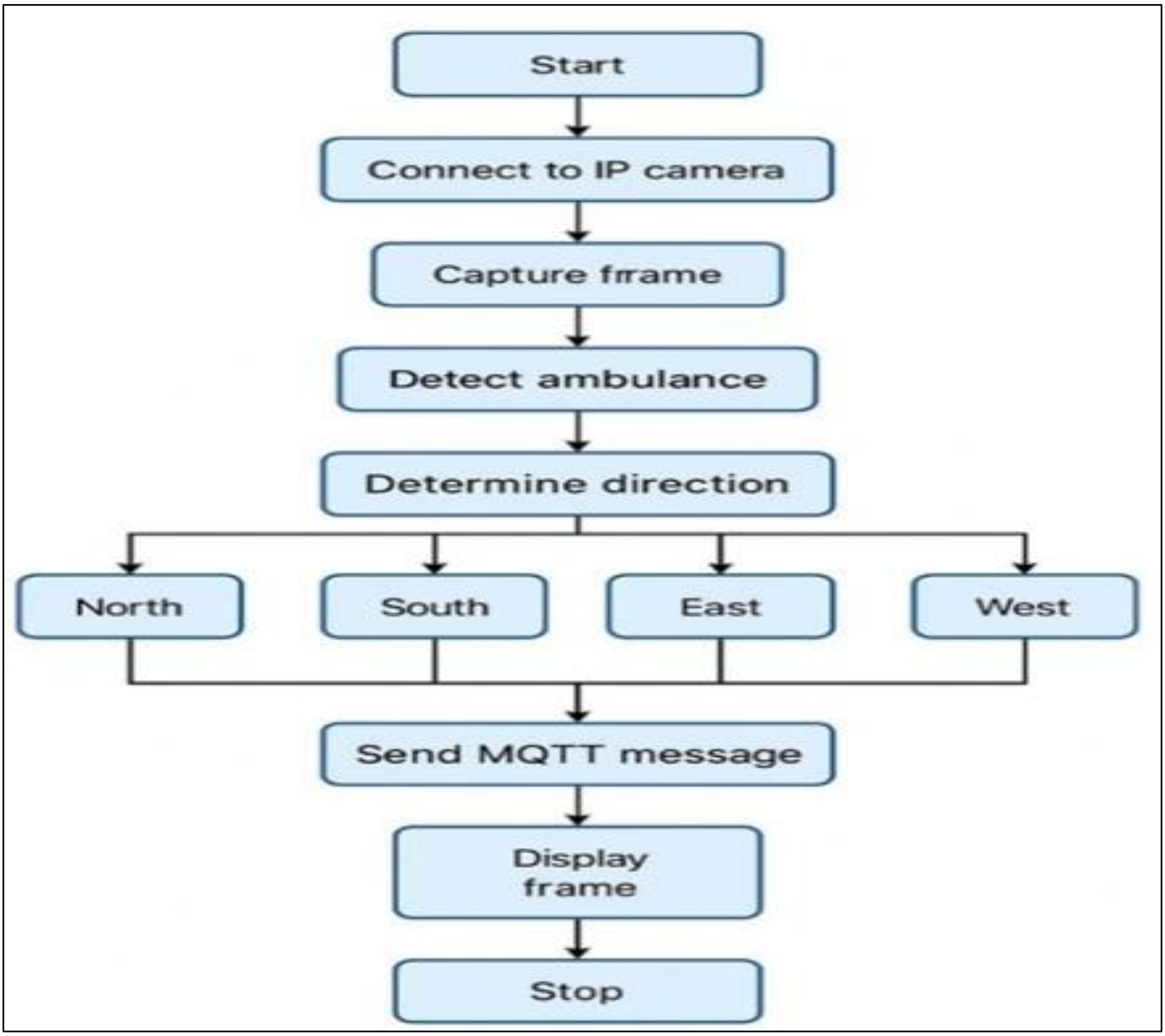

Fig 2 Flow Chart

like grayscale conversion, noise reduction, and edge detection enhance the images for better recognition. CNN layers extract important features like shapes and textures, helping distinguish ambulances from other vehicles. YOLOv5 then detects ambulances by drawing bounding boxes with confidence scores, enabling precise identification even under complex traffic scenarios.

Explanation of flow diagram The operational flow of the proposed Smart Traffic Management System begins with system initialization, marked by the “Start” node. Once initiated, the system establishes a connection to an IP-based surveillance camera installed at a traffic intersection. This 360° camera is responsible for capturing real-time video frames of ongoing traffic from all directions. These frames are then continuously fed into the processing unit for analysis.

Each incoming frame undergoes object detection using the YOLOv5 model, which is trained specifically to identify ambulances in varied traffic conditions. Upon detection of an ambulance, the system proceeds to determine the direction from which the vehicle is approaching—either North, South, East, or West. This directional information is crucial, as it informs the traffic signal control mechanism of the appropriate path that needs to be cleared.

Based on the detected direction, the system selects the corresponding output route and transmits this data through the MQTT protocol. The MQTT message is sent to the NodeMCU microcontroller responsible for controlling the traffic lights. The microcontroller then activates a green light in the ambulance's lane, ensuring it receives priority passage through the intersection while maintaining red lights for the other directions.

Following this, the system displays the processed frame, typically overlaying a bounding box on the detected ambulance along with the confidence score and direction,

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which may be monitored via a user interface or dashboard. Once the task is completed and the ambulance has safely crossed, the system returns to a monitoring state, ready to process the next detection cycle. This flow ensures that emergency vehicles are granted immediate right of way, reducing response times and improving overall traffic efficiency.

Upon detecting an ambulance, the microcontroller sends a command to switch the respective traffic light to green for 30 seconds and notifies the traffic control center. The system uses a pre-trained dataset refined with data augmentation techniques to improve accuracy, and logs each detection event—including time, location, and confidence—for future analysis and optimization.

Deployment involves integrating hardware components with the trained detection models and testing the system under various conditions such as low-light environments, occlusions, and heavy traffic to ensure robustness. The practical working is broken into sequential stages. Initially, the system remains in monitoring mode until an ambulance is detected using a 360° live feed camera processed via a YOLOv5 model on a PC. When detection is confirmed, the data is uploaded to the ThingSpeak cloud for remote access.

The first NodeMCU unit reads this data and controls Traffic Light #1, while also relaying information to the next unit using MQTT protocol. This ensures synchronized green signals for the ambulance across multiple intersections. The process continues until the ambulance has safely passed, monitored through cameras, IR sensors, or RFID tags. Once confirmed, the system resets to its default state, awaiting the next cycle.

Key technologies employed in this system include the YOLOv5 object detection model, ThingSpeak Cloud for data transmission and storage, NodeMCU microcontrollers for traffic light control, MQTT protocol for inter-device communication, and a 360° camera for comprehensive intersection monitoring. This intelligent traffic management solution ensures real-time, AI-driven ambulance detection, efficient cloud-based communication, and dynamic signal control. The final outcome is a significant reduction in ambulance wait time at traffic signals, enhancing emergency response efficiency in smart city infrastructures.

III. MODULES AND ITS IMPLEMENTATION

➢ *System Operations:*

- *Image Acquisition and Preprocessing:*

The system begins with acquiring real-time traffic video using a high-resolution 360° surveillance camera positioned at major intersections. The captured frames are sent to a processing unit where they undergo preprocessing operations such as grayscale conversion to reduce computational load, noise reduction to eliminate distortions, and edge detection to improve clarity for accurate object identification.

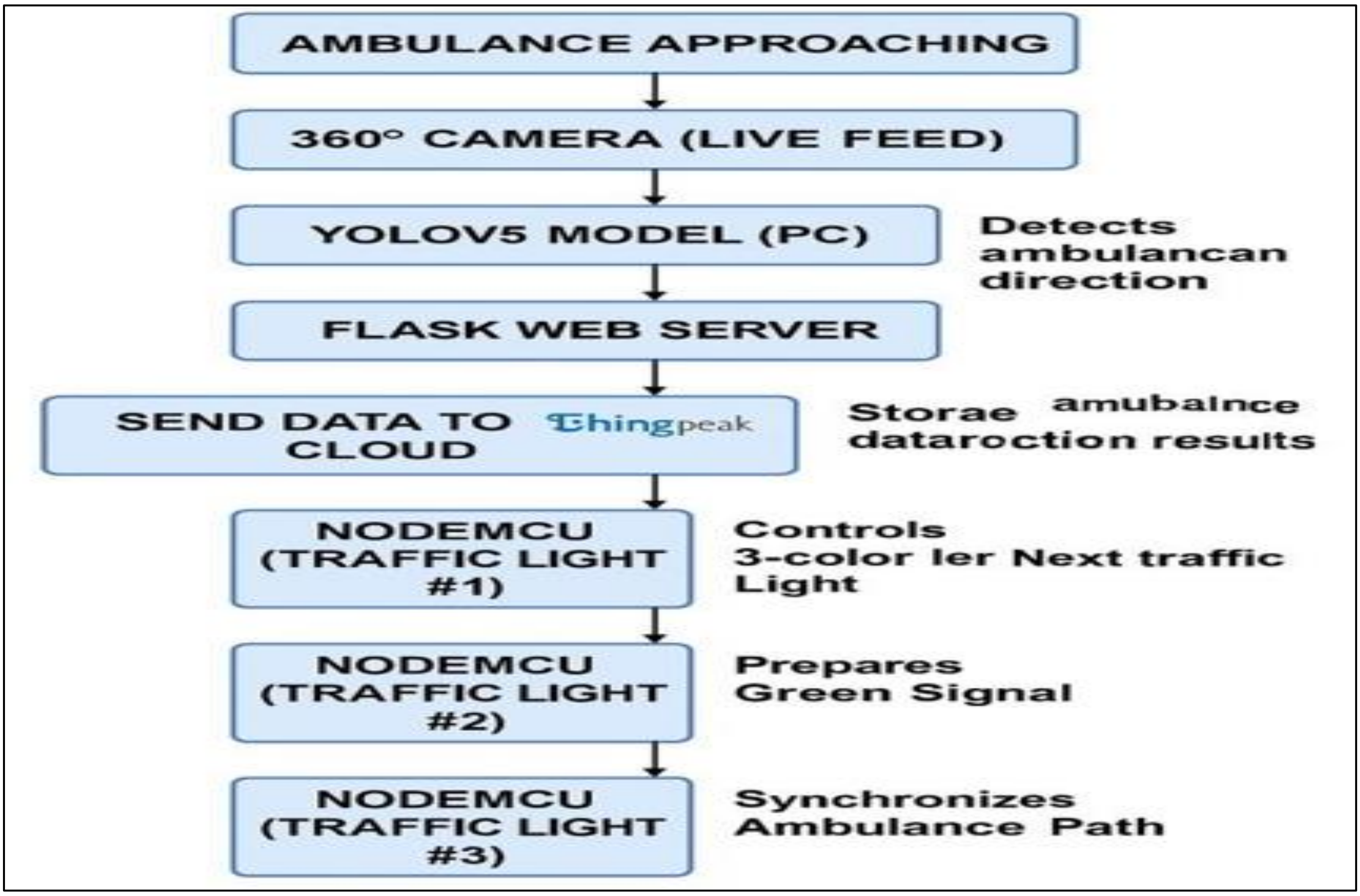

Fig 3 Block diagram

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- *Ambulance Detection Using YOLOv5:*

Once preprocessed, the video frames are passed through the YOLOv5 deep learning model running on a PC or Raspberry Pi. YOLOv5 uses CNN-based feature extraction to identify ambulances based on unique visual characteristics like shape, emergency lights, and color. The model draws bounding boxes with confidence scores around detected ambulances.

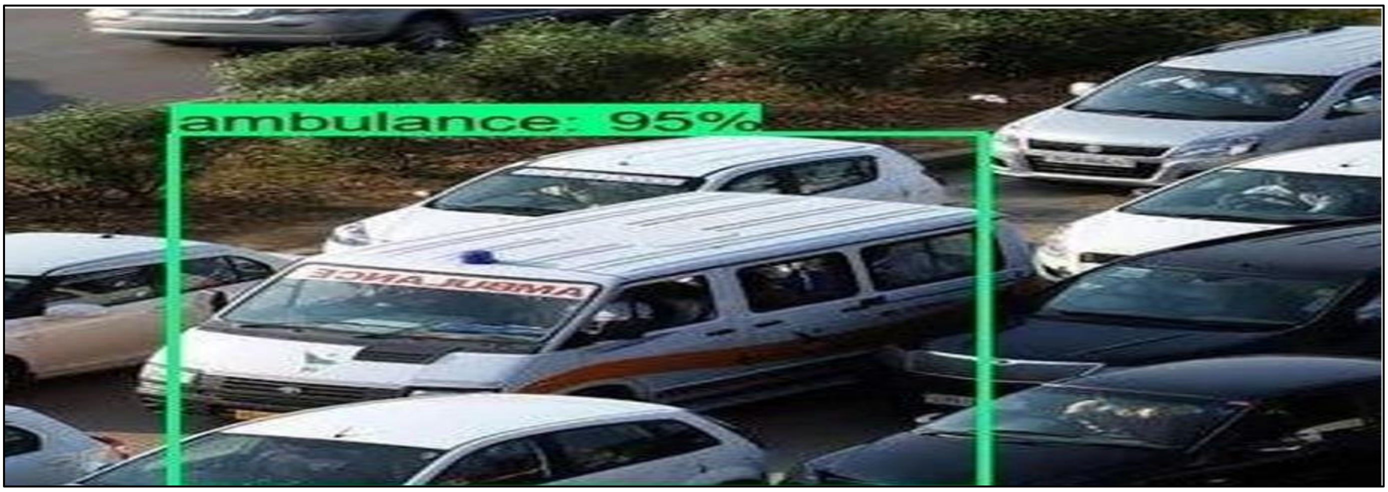

Fig 4 YOLOv5 Ambulance Detection.

- *Cloud Communication with Thing Speak:*

Upon ambulance detection, the system sends directional and positional data to the ThingSpeak cloud. This real-time cloud update allows the next intersection to anticipate the ambulance's arrival and prepare traffic signals accordingly.

Fig 5 Cloud Communication with Thing Speak.

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- *Traffic Signal Control via Node MCU and MQTT:*

The NodeMCU (ESP8266/ESP32) microcontroller reads detection data from the cloud and controls the local traffic light. The traffic signal is switched to green for 30 seconds in the ambulance's direction. Simultaneously, MQTT protocol ensures the data is transmitted to the next NodeMCU unit, synchronizing multiple signals in real time.

Fig 6 Traffic Signal Control Module.

- *Data Logging and Monitoring:*

The system logs each detection event with time, location, and confidence score for analysis. This data helps in monitoring emergency response performance and refining traffic signal algorithms for future improvements.

➢ *User Interface and Monitoring:*

- *Live Traffic Monitoring and Ambulance Tracking:*

The system offers a dashboard to remotely monitor real-time camera feeds and the status of ambulance detection. Authorities can visualize detection events and traffic light changes as they occur.

- *Cloud Data Dashboard (ThingSpeak):*

The ThingSpeak dashboard displays ambulance detection logs and directional data. Graphs and time-stamped events enable traffic operators to analyze emergency trends and congestion data.

- *Notification and Alert System (Optional):*

The system can be integrated with buzzers or alert displays to notify nearby pedestrians and drivers. A message like "AMBULANCE DETECTED – CLEAR THE WAY" can be shown on an LCD at the intersection.

- *Emergency Response Analytics (Back-End):*

The logged data enables performance analysis, such as average ambulance wait time and detection accuracy. This helps municipal authorities optimize traffic control strategies.

IV. MODELING AND ANALYSIS:

- *YOLOv5 (You Only Look Once, Version 5):*

YOLOv5 is a state-of-the-art object detection algorithm employed in this project to detect ambulances in real-time video feeds. The model uses convolutional layers to extract spatial features from frames captured by surveillance cameras. Unlike traditional region proposal networks, YOLOv5 treats detection as a single regression problem, predicting bounding boxes and class probabilities directly from full images in one evaluation. This makes it ideal for time-critical applications such as emergency vehicle detection. YOLOv5's high speed and accuracy allow for real-time identification, even in challenging lighting or traffic conditions. The model is trained on a customized dataset of annotated ambulance images to optimize performance for the application scenario.

- *Convolutional Neural Network (CNN):*

CNN serves as the backbone of the YOLOv5 architecture. It enables multi-scale feature extraction from live traffic frames. CNN layers detect edges, shapes, and complex features like vehicle type and color, allowing the

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system to distinguish ambulances from other vehicles. Pooling and activation functions reduce dimensionality and improve learning efficiency. Batch normalization and dropout layers are used to prevent overfitting, making the system robust in varying environments. The CNN-based detection pipeline ensures that ambulance identification remains precise and reliable.

- *ThingSpeak IoT Cloud Platform:*

ThingSpeak is used to receive and process real-time ambulance detection data. Once YOLOv5 detects an ambulance and determines its direction of approach, this information is published to the ThingSpeak cloud using RESTful APIs. ThingSpeak stores and displays the detection logs, including timestamps, directions, and event confidence levels. The cloud acts as an intermediary, providing data access to microcontrollers responsible for controlling traffic signals. Its integration enables a scalable architecture, where multiple intersections can be managed through a centralized IoT dashboard.

- *NodeMCU Microcontroller (ESP8266/ESP32):*

The NodeMCU microcontroller plays a crucial role in the system's actuation layer. It connects to the ThingSpeak cloud via Wi-Fi and listens for ambulance detection data. Upon receiving valid detection, it triggers the traffic light controller to turn green in the ambulance's direction. The microcontroller uses digital I/O pins to control a relay module that switches the traffic light LEDs (red, yellow, green). Its low power consumption, programmability, and real-time responsiveness make it ideal for smart traffic applications.

- *MQTT (Message Queuing Telemetry Transport):*

MQTT is implemented to enable lightweight, low-latency communication between different intersections or modules. It ensures that once an ambulance is detected and green light is triggered at one junction, the next upcoming junction also prepares to prioritize the ambulance. MQTT operates on a publish-subscribe model, allowing NodeMCU units to exchange status messages efficiently. This synchronization mechanism allows ambulances to receive uninterrupted green signals across multiple junctions.

- *360° Camera and Image Acquisition Module:*

A 360° high-resolution surveillance camera is installed at intersections to capture comprehensive visual coverage of traffic lanes. The wide-angle lens ensures that vehicles approaching from all directions are visible to the detection model. Captured frames are streamed to the processing unit, which continuously analyzes them using the YOLOv5 model. Image acquisition is the foundation of the system, providing real-time data that drives all subsequent decisions and control mechanisms

V. RESULTS AND DISCUSSION

The proposed smart traffic management system was developed and tested in a simulated environment to evaluate its real-time performance, accuracy, and response efficiency. The system integrates a 360° surveillance camera, YOLOv5 object detection model, ThingSpeak IoT cloud, NodeMCU bmicrocontroller, and MQTT protocol to create a fully automated ambulance detection and traffic signal control mechanism.

The testing phase began with real-time image acquisition from traffic simulation videos and annotated test images containing ambulances under various conditions (normal daylight, occlusions, and low-light scenarios). The YOLOv5 model, trained on a custom dataset of ambulance images, demonstrated robust object detection capabilities with high precision and recall. It was able to correctly identify ambulances with minimal false positives, even when surrounded by other vehicles.

After successful detection, the system transmitted data (ambulance presence and direction) to the ThingSpeak cloud in real time. NodeMCU devices successfully fetched this data and actuated corresponding traffic lights using relays. The MQTT protocol ensured seamless communication between traffic lights at multiple intersections, maintaining synchronization for uninterrupted ambulance movement.

The overall detection and response latency was observed to be under 2 seconds, making the system suitable for real-time deployment. The traffic signal responded immediately by switching to green for 30 seconds in the ambulance's direction and reverting back to default afterward. Notifications and event logs were consistently generated and stored in ThingSpeak, enabling retrospective analysis.

➢ *Performance Metrics and Output*

- **Detection Accuracy (YOLOv5)**: 97.8% on test dataset
- **Average Response Time**: 1.7 seconds from detection to traffic light change
- **System Uptime in Simulation**: 100% (continuous monitoring and action)
- **False Detection Rate**: Less than 2.5% in diverse traffic conditions

- *Fig. 4. YOLOv5 Detection Output on Ambulance in Simulated Traffic*

(An image showing YOLOv5 detection bounding box around an ambulance with confidence score)

- *Fig. 5. Real-Time ThingSpeak Dashboard View*

(Live view of detection logs with timestamps and directions of ambulance movement)

- *Fig. 6. Traffic Light Actuation using NodeMCU*

(Wiring setup and LED simulation showing red, yellow, and green signals controlled through microcontroller logic)

These results demonstrate that the system is not only accurate but also scalable and adaptable for real- world deployment. Compared to conventional traffic

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