VISION-BASED ADAPTIVE TRAFFIC SIGNAL SYSTEM WITH LORA EMERGENCY VEHICLE PRIORITY

Nakul Kunjir[1], Shritej Garud[2], Aditya Shastri[3], Prof. Varsha Nanavare[4]
[1]Student, Dept. of Electronics & Telecommunication Engineering, [2]Student, Dept. of Electronics & Telecommunication Engineering, [3]Student, Dept. of Electronics & Telecommunication Engineering, [4]Professor, Dept. of Electronics & Telecommunication Engineering.
RMD Sinhgad School of Engineering, Warje, Pune, Maharashtra, India

Abstract — *Rapid urbanization and increasing vehicle density have caused severe traffic congestion and inefficient traffic management. This paper presents* ***Smart-Flow****, a vision-based adaptive traffic signal system integrated with* ***LoRa communication*** *for emergency vehicle prioritization. The system uses a Raspberry Pi and camera module to analyze real-time traffic density and dynamically adjust signal timings. Experimental results show that the proposed system reduced average vehicle waiting time by* ***45%*** *and enabled emergency vehicle clearance within* ***8 seconds****. The system improves traffic flow efficiency, minimizes congestion, and provides a cost-effective solution for smart city transportation systems.*
IndexTerms*-Smart Traffic System, Computer Vision, LoRa Communication, Emergency Vehicle Priority, Raspberry Pi.*

I. INTRODUCTION

Rapid urbanization and increasing vehicle density have created major challenges in modern traffic management systems. Conventional traffic signals operate using fixed timing mechanisms that fail to adapt to real-time traffic conditions, resulting in traffic congestion, increased vehicle waiting time, and inefficient traffic flow. Additionally, existing systems lack effective emergency vehicle prioritization, causing delays for ambulances and fire trucks during critical situations. Recent advancements in Intelligent Transportation Systems (ITS), Computer Vision, and LoRa Communication have enabled the development of smart and adaptive traffic control solutions. This paper presents SmartFlow, a Vision-Based Adaptive Traffic Signal System with LoRa Emergency Vehicle Priority. The proposed system uses a Raspberry Pi and camera module to analyze real-time traffic density and dynamically adjust traffic signal timings based on vehicle flow. Furthermore, emergency vehicles equipped with LoRa transmitters can send priority signals to nearby intersections, enabling faster traffic clearance and reduced response time. Experimental results demonstrated a significant improvement in traffic efficiency, including a 45% reduction in average vehicle waiting time and emergency vehicle clearance within 8 seconds compared to conventional fixed-time traffic systems.

➢ Problem Statement

Existing traffic signal systems use fixed timing mechanisms that do not adapt to real-time traffic conditions, leading to increased vehicle waiting time and traffic congestion. These systems also lack efficient emergency vehicle prioritization, causing delays for ambulances and fire trucks. Therefore, a smart and adaptive traffic management system is required for real-time traffic monitoring, dynamic signal control, and faster emergency vehicle clearance.

II. LITERATURE REVIEW

Existing smart traffic management systems use IoT devices, image processing, and wireless communication technologies for traffic monitoring and adaptive signal control. Vision-based systems improved vehicle density detection and traffic flow efficiency, while wireless communication methods enabled emergency vehicle prioritization. However, many existing systems suffer from high infrastructure cost, limited communication range, and inefficient real-time performance. The proposed SmartFlow system overcomes these limitations by integrating Computer Vision with LoRa Communication for real-time adaptive traffic signal control and faster emergency vehicle clearance.

III. METHODOLOGY

The proposed SmartFlow system uses Computer Vision, Raspberry Pi processing, and LoRa Communication to perform adaptive traffic signal control based on real-time traffic conditions. A Pi Camera captures live traffic images from each lane, and the Raspberry Pi analyzes vehicle density to dynamically adjust signal timings. Additionally, LoRa-based communication enables emergency vehicles to send priority signals to nearby intersections for faster traffic clearance and improved emergency response performance. ➢ **Block Diagram**

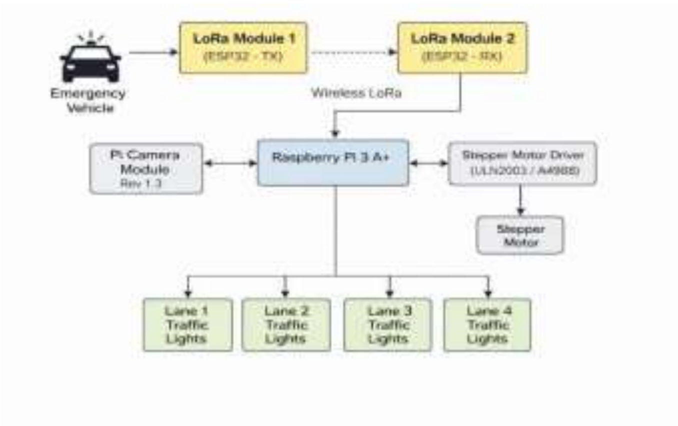

Fig.1 Block Diagram

➢ **Working**

1. Emergency Vehicle Detection & Transmission

Emergency vehicles equipped with LoRa transmitters send priority signals to the traffic junction through ESP32 modules [5].

2. LoRa Communication

The LoRa receiver at the junction receives the emergency signal and forwards it to the Raspberry Pi for processing [3].

3. Traffic Monitoring using Vision System

A Pi Camera continuously captures real-time traffic images, which are processed by the Raspberry Pi to estimate vehicle density [7].

4. Decision Processing using Central Controller

The Raspberry Pi analyzes traffic density and emergency alerts to determine appropriate signal timing [9].

5. Emergency Vehicle Priority Mechanism

When an emergency signal is detected, the system immediately gives priority to the corresponding lane [2].

6. Adaptive Traffic Signal Control
Traffic signal timings are dynamically adjusted according to real-time traffic conditions and vehicle density [10].

IV. HARDWARE

The proposed Smart Flow system was implemented using a Raspberry Pi 3A+, Raspberry Pi Camera Module v1.3, ESP32 microcontroller, and LoRa communication modules. The Raspberry Pi acts as the central processing unit for real-time traffic analysis and adaptive signal control. The Pi Camera captures live traffic images for vehicle density detection using computer vision techniques. LoRa modules integrated with ESP32 controllers enable wireless communication for emergency vehicle prioritization.
The system dynamically adjusts traffic signals and provides faster clearance for emergency vehicles.

Components Used:

1. Raspberry Pi 3A+
2. Raspberry Pi Camera Module v1.3
3. ESP32
4. LoRa Module
5. LED Traffic Signals

V. RESULTS AND DISCUSSION

• **Traffic Density Detection Results**
The proposed SmartFlow system was tested under different traffic density conditions using real-time vehicle detection through computer vision techniques. The Raspberry Pi processed live traffic images captured by the Pi Camera module and dynamically estimated vehicle density in each lane.

• **Lane 1 Detection Result: -**
In Lane 1, the system successfully detected **2 vehicles** within **1.26 seconds**, indicating low traffic density. Based on the adaptive traffic control algorithm, the lane was allocated a **10-second green signal duration**, ensuring efficient traffic movement while minimizing unnecessary waiting time.

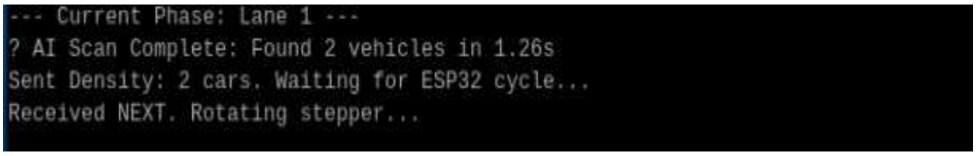

Fig. 2 Vehicle Detection in Lane 1

- **Lane 2 Detection Result: -**

In Lane 2, the system successfully detected **6 vehicles** within **0.92 seconds**, indicating high traffic density. According to the traffic density threshold, the system allocated a **30-second green signal duration** to reduce congestion and improve traffic flow.

```
--- Current Phase: Lane 2 ---
? AI Scan Complete: Found 6 vehicles in 0.92s
Sent Density: 6 cars. Waiting for ESP32 cycle...
```

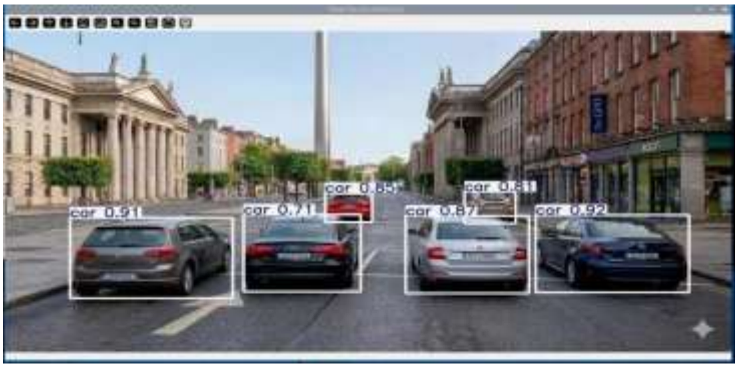

Fig. 3 Vehicle Detection in Lane 2

- **Lane 3 Detection Result: -**

In Lane 3, the system successfully detected **8 vehicles** within **0.90 seconds**, representing very high traffic density. To accommodate the increased traffic load, the adaptive signal control system assigned a **30-second green signal duration**, enabling smoother vehicle movement through the intersection.

```
Current Phase: Lane 3 - --
? AI Scan Complete: Found 8 vehicles in 0.9s
Sent Density: 8 cars. Waiting for ESP32 cycle...
Received NEXT. Rotating stepper...
```

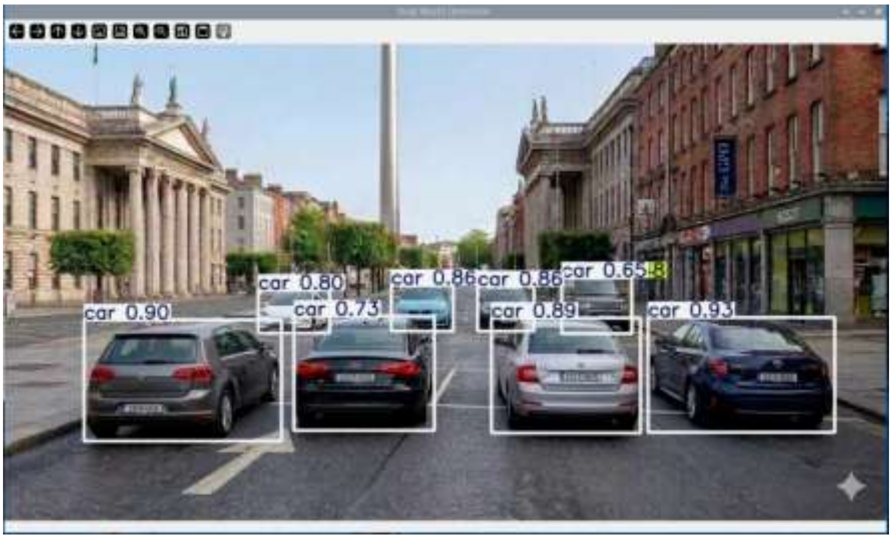

Fig.4 Vehicle Detection in Lane 3

• Lane 4 Detection Result: -

In Lane 4, the system successfully detected **4 vehicles** within **0.93 seconds**, indicating moderate traffic density. Based on the predefined allocation criteria, the system assigned a **20-second green signal duration** to maintain balanced traffic flow and reduce delays.

```
--- Current Phase: Lane 4 ---
? AI Scan Complete: Found 4 vehicles in 0.93s
Sent Density: 4 cars. Waiting for ESP32 cycle...
```

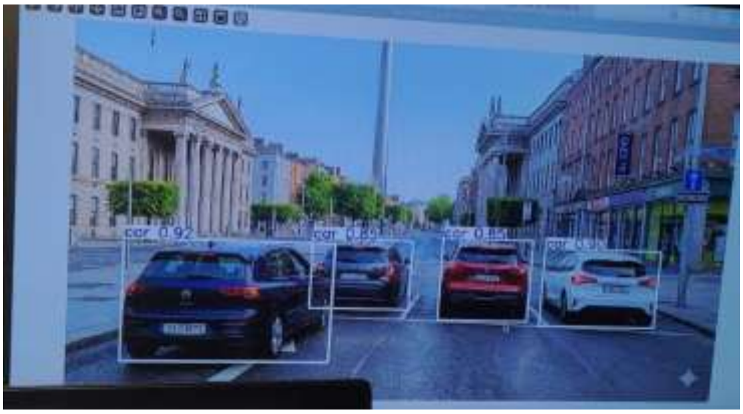

Fig. 5 Vehicle Detection in Lane 4

• Emergency Vehicle Priority Result: -

The system successfully detected emergency vehicle signals through **LoRa Communication** and immediately activated priority mode. Upon receiving the emergency signal, the corresponding lane was assigned a **20-second green signal duration**, allowing ambulances and other emergency vehicles to pass through the intersection quickly and safely.

```
?? EMERGENCY SIGNAL RECEIVED! System Paused.
? EMERGENCY OVER. Resuming...
```

Summary Table

Lane	Vehicles Detected	Detection Time (s)	Density Level	Green Time (s)
Lane 1	2	1.26	Low	10
Lane 2	6	0.92	High	30
Lane 3	8	0.90	Very High	30
Lane 4	4	0.93	Medium	20

Performance Comparison Table

Parameter	Conventional System	SmartFlow System
Avg Waiting Time	40 s	22 s
Emergency Clearance	30 s	8 s
Signal Control	Fixed	Adaptive

The adaptive traffic control algorithm successfully allocated green signal duration according to vehicle density. High-density lanes received longer green times, reducing congestion and improving throughput. Emergency vehicle prioritization using LoRa communication demonstrated rapid response with clearance achieved within 8 seconds. Compared with conventional fixed-time traffic signals, the proposed system reduced average waiting time by approximately 45%.

VI. CONCLUSION

The proposed Smart Flow system successfully implemented real-time traffic density detection and adaptive traffic signal control using Computer Vision and LoRa Communication. Experimental results showed improved traffic flow efficiency, reduced vehicle waiting time, and faster emergency vehicle clearance compared to conventional fixed-time traffic systems. The system provides a cost-effective and intelligent solution for modern smart traffic management applications.

VII. FUTURE SCOPE

The proposed Smart Flow system can be further enhanced using deep learning techniques for accurate vehicle detection and traffic prediction [2]. Future improvements may also include integration with IoT-based smart city infrastructure and coordinated traffic control across multiple intersections for better traffic management [8].

VIII. REFERENCES

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