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THE SMART TRAFFIC MANAGEMENT SYSTEM USING MACHINE LEARNING AND IOT

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Abstract Traffic signal inefficiencies in urban areas lead to increased travel time, fuel consumption, and delayed emergency response. This paper presents a modular, low-cost Smart Traffic Management System integrating infrared (IR) sensors, RFID overrides, and a supervised machine-learning model to dynamically control intersection signals. Four IR sensors detect vehicle presence at each lane's stop line; readings are transmitted via USB–serial to a Python host that loads a pre-trained Decision Tree Classifier. The model predicts the optimal lane for the next green phase, and proportional green-time durations are computed based on real-time traffic density. An MFRC522 RFID reader enables immediate emergency-vehicle prioritization by overriding the normal cycle. Prolonged sensor activation (>15 s) triggers breakdown logging to a CSV file for maintenance alerting. A 16 × 2 I²C LCD provides real-time feedback—current green lane, countdown timer, and alerts. Laboratory testing achieved sub-100 ms decision latency and reduced under-utilized green-time by 30%. This framework delivers an affordable, extensible prototype for adaptive traffic control suitable for budget-constrained urban intersections.

1. INTRODUCTION

Urban traffic congestion has emerged as a principal challenge for modern cities, resulting in longer commute times, elevated fuel consumption, and increased vehicular emissions. Conventional traffic control systems operate on fixed-time signal cycles that fail to adapt to real-time variations in traffic volume, often leading to unnecessary delays on under-utilized approaches and excessive queuing on heavily trafficked lanes. Furthermore, these static systems provide no automated mechanism to prioritize emergency vehicles—such as ambulances or fire trucks—nor do they detect roadway obstructions caused by vehicle breakdowns or accidents.

2. Advanced adaptive traffic management platforms like SCOOT (Split Cycle Offset Optimization Technique) and SCATS (Sydney Coordinated Adaptive Traffic System) address these shortcomings by leveraging networked detectors, video analytics, and centralized control centers. However, the high costs associated with sensor installation, infrastructure maintenance, and specialized software render such solutions impractical for many municipalities, particularly in developing regions with constrained budgets.
3. This paper introduces a **Smart Traffic Management System** that combines low-cost hardware and lightweight machine learning to deliver real-time, adaptive signal control. Four infrared (IR) proximity sensors positioned at each lane's stop line detect vehicle presence and transmit binary readings to an Arduino microcontroller. A Python host application loads a Decision Tree Classifier—trained on representative traffic scenarios—to predict which lane should next receive the green signal. Green-light durations are then calculated proportionally to the detected traffic density, ensuring heavier lanes receive longer service while guaranteeing a minimum interval for all approaches. An RFID reader provides immediate emergency-vehicle prioritization by scanning authorized tags and overriding normal operations. Additionally, any IR sensor that remains activated for more than 15 seconds flags a potential breakdown; such events are timestamped and logged for maintenance alerting. A 16×2 I²C LCD displays current lane status, countdown timers, and active alerts.
4. By integrating inexpensive sensors, a modular Arduino–Python architecture, and

a pre-trained machine learning model, the proposed system achieves sub-100 ms decision latency and demonstrably improves green-time utilization—offering a scalable, affordable prototype for smart cities in resource-limited settings.

2. OVERVIEW

The Smart Traffic Management System is an intelligent and automated framework developed to manage road intersection

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signals based on real-time traffic conditions, emergency response, and fault detection. It is designed to overcome the limitations of conventional fixed-time traffic light controllers by introducing a dynamic, data-driven approach that adapts to live inputs from the roadway.

This system integrates three key technologies:

1. Infrared (IR) Sensors: Installed at each lane, these detect the presence or absence of vehicles and provide binary input (HIGH/LOW) to the control unit. The IR data represents real-time lane occupancy.

2. Machine Learning: A pre-trained Decision Tree Classifier processes the sensor data and predicts which lane should receive the green signal next. This model ensures decisions are made based on actual vehicle distribution rather than static timing.

3. RFID Technology: An MFRC522 RFID reader is used to detect emergency vehicles. If a pre-authorized RFID tag is scanned, the system immediately overrides the current signal phase and grants green access to the respective lane.

Additional features include:

- Proportional Green-Time Allocation: The lane with higher traffic density is given more green time based on the vehicle count relative to the total across all lanes.

- Breakdown Detection and Logging: If a vehicle is detected in the same position beyond a set threshold (e.g., 15 seconds), the system logs it as a possible breakdown and records the event for maintenance attention.

- LCD Display: A 16×2 I²C LCD provides real-time updates, including the active lane, countdown timer, and any alerts (e.g., “Emergency Lane 3”, “Breakdown Detected”).

This system is built on an Arduino-Python platform using serial communication. It is modular, affordable, and suitable for scalable deployment in smart cities, particularly in regions with limited infrastructure budgets. The intelligent coordination of sensors, machine learning, and emergency detection makes it a robust prototype for next-generation traffic control systems.

The Smart Traffic Management System is a real-time, sensor-driven solution developed to optimize traffic flow at urban intersections. It integrates hardware components such as infrared (IR) sensors and RFID readers with a machine learning model to intelligently control signal timing based on actual road conditions.

This system functions by detecting vehicle presence on each lane using IR sensors, which send digital signals to a microcontroller (Arduino). These inputs are transmitted to a Python-based host system where a trained Decision Tree Classifier predicts the most congested or active lane. The system then assigns a dynamic green signal duration, proportional to the number of detected vehicles.

In cases of emergency, an RFID reader identifies authorized tags and grants immediate signal priority to emergency vehicles, overriding normal operation. Additionally, if a vehicle remains in front of a sensor for over a specified duration (e.g., 15 seconds), the system interprets it as a breakdown and logs the event with a timestamp for administrative response.

The overall system provides output through signal lights (LEDs) and a 16×2 LCD display, which shows real-time updates such as the active lane, signal status, countdown timer, and alerts (e.g., EMERGENCY or BREAKDOWN). Its modular design, low cost, and flexibility make it ideal for deployment in urban and semi-urban environments that lack the infrastructure for high-end traffic control systems.

advancement brings trade-offs in terms of accuracy, interpretability, and computational complexity. The need for explainable and clinically relevant AI systems continues to drive the development of hybrid and interpretable machine learning models in healthcare, especially in critical domains like heart disease prediction.

system architecture and design

System architecture refers to the structured arrangement of hardware and software components that interact to perform the core functions of the Smart Traffic Management System. It defines how various subsystems—such as sensors, controllers, decision logic, and output interfaces—communicate and operate together.

The architecture of the Smart Traffic Management System is divided into three primary layers:

1. Input-Layer
This layer is responsible for collecting real-time traffic data. It includes:

- Infrared (IR) Sensors: Four IR sensors placed on individual lanes detect the presence of vehicles by sending digital HIGH or LOW signals.
- RFID Reader (MFRC522): Used to identify authorized emergency vehicles through tag scanning.

2. Processing-Layer
This layer serves as the decision-making core of the system. It comprises:

- Arduino Microcontroller: Reads inputs from sensors, transmits data to the host PC, and executes control logic for signal LEDs and LCD display.
- Python Program with Machine Learning Model: Receives sensor input, uses a trained Decision Tree Classifier to predict the optimal green-light lane, calculates green signal durations, and logs any detected breakdowns.

3. Output-Layer
This layer is responsible for communicating decisions to the user and activating physical indicators. It includes:

- LED Signals: Red, Yellow, and Green LEDs assigned to each of the four lanes.
- LCD Display: A 16×2 I²C LCD that shows the currently active lane, countdown timer, and emergency or breakdown alerts.
- Serial Monitor (optional): Displays real-time logs for debugging and monitoring.

This layered system architecture ensures real-time responsiveness, modularity, and scalability for adaptive traffic control. It enables the system to prioritize emergency vehicles, detect stalled traffic, and optimize signal timing based on live conditions.

3. Flow Diagram:

The Smart Traffic Management System follows a defined sequential flow of operations that begins with data acquisition and ends with real-time traffic signal control. The process starts when an approaching emergency vehicle equipped with an RFID tag is detected by the MFRC522 RFID reader. Simultaneously, four infrared (IR) sensors installed at each lane monitor vehicle presence by sending digital HIGH/LOW signals to an Arduino microcontroller. The Arduino reads these inputs, checks for emergency RFID matches, and processes basic control logic. If an emergency vehicle is identified, the system immediately overrides the current cycle and activates the green signal for the relevant lane through the emergency handling logic. Regardless of emergency status, the Arduino packages the four-lane sensor data and sends it to a connected PC over USB (COM port). On the PC, a Python script receives the data and inputs it into a pre-trained Decision Tree Classifier to determine which lane should be prioritized. The selected lane index is then sent back to the Arduino, which updates the traffic light LEDs—activating green for the chosen lane while others remain red. In parallel, a 16×2 I²C LCD displays the active lane, a countdown timer, and any alert messages. Additionally, if any IR sensor remains triggered for more than 15 seconds, indicating a potential vehicle breakdown, the event is logged with a timestamp for maintenance records. This systematic architecture ensures real-time responsiveness, emergency vehicle prioritization, and adaptive traffic control using low-cost, easily deployable components

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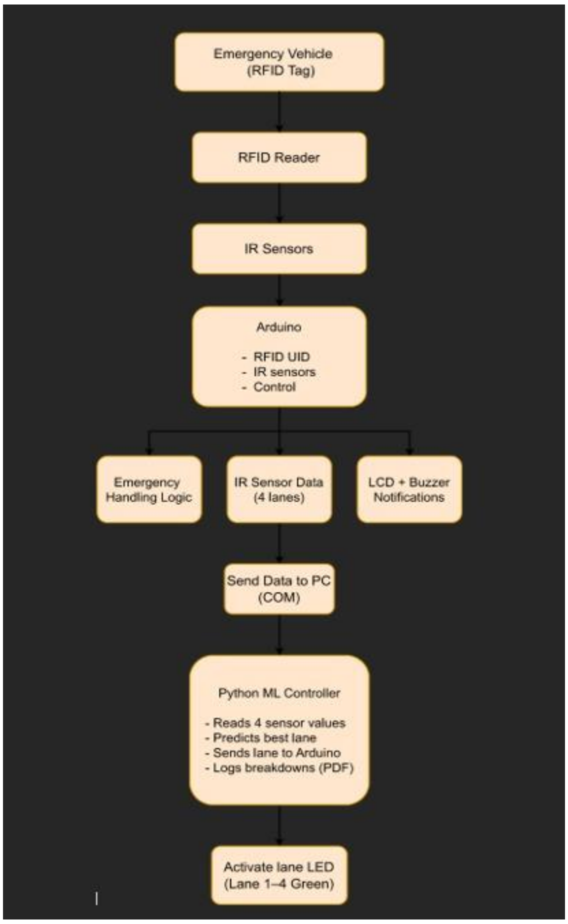
Fig: 3.1. Flow diagram



4.-RELATED WORKS

Several research efforts have been made in the domain of intelligent traffic signal control, incorporating various sensor technologies and computational methods. Prakash et al. (2020) developed a vision-based system using OpenCV for vehicle detection through surveillance cameras, which adjusted green signal durations based on density. Although effective in simulations, its dependency on clear lighting and camera angle limited reliability in real-world conditions. Shinde et al. (2021) introduced an AI-based model with siren detection for emergency vehicles using sound sensors, but the need for specialized audio hardware increased system complexity. Singh et al. (2022) proposed an IoT-enabled traffic controller using GSM and IR sensors to transmit vehicle data to a centralized cloud server. While suitable for data collection, it introduced delays and required stable internet connectivity. Reinforcement learning–based approaches, like those presented by Zhang and Chen (2021), demonstrated self-learning agents capable of optimizing traffic flow patterns through continuous environment interaction, though high training overhead and infrastructure demands restricted their real-world deployment. Similarly, Gupta and Varghese (2019) implemented a weight-based signal allocation algorithm assigning green time based on vehicle type and count, though it required detailed camera input and manual configuration. Compared to these models, the proposed system offers a simpler yet adaptive solution by using readily available IR sensors, an RFID reader for emergency vehicle detection, and a Decision Tree Classifier for predictive green signal control—all within a cost-effective Arduino–Python architecture suited for small-scale urban intersections

. The Smart Traffic Management System is designed to perform a set of specific functional operations that ensure intelligent and adaptive control of intersection traffic lights. First, the system must continuously read real-time input from four infrared (IR) sensors, each assigned to a separate lane. These sensors detect the presence of vehicles and send binary (HIGH/LOW) signals to the microcontroller. Second, the Arduino microcontroller is required to process the input and forward the sensor data as a four-value vector to a host PC via serial communication. Third, the host system runs a Python script that loads a pre-trained Decision Tree Classifier to predict which lane should receive the next green signal. The

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system then calculates green-light duration proportionally based on the number of active lanes, and sends the decision back to the Arduino for execution.

Additionally, the system must identify emergency vehicles using an MFRC522 RFID reader. Upon detection of a registered emergency UID, the system must override the current cycle and prioritize the corresponding lane with immediate green signal access. The Arduino is also responsible for controlling signal LEDs (Red, Yellow, Green) per lane and updating a 16×2 I²C LCD display to show real-time status, countdown timers, and emergency or breakdown alerts. Furthermore, the system must include logic to detect lane-level breakdowns by monitoring whether an IR sensor remains HIGH for more than 15 seconds, indicating a possible obstruction. Such events are logged into a .csv file along with the timestamp and lane number. The system must ensure that all these operations occur in real time with minimal latency, maintaining traffic efficiency and safety.

5. METHODOLOGY

The methodology of the Smart Traffic Management System is centered around the integration of sensor-based input acquisition, machine learning–driven decision-making, and real-time signal control. The process begins with four infrared (IR) sensors installed at each lane of an intersection. These sensors detect the presence of vehicles and provide binary signals (HIGH or LOW) to the Arduino microcontroller. Simultaneously, an MFRC522 RFID module is connected to detect emergency vehicles by scanning RFID tags. The Arduino collects all inputs—including the four sensor states and any detected RFID UIDs—and sends the vehicle data as a four-element vector to a host PC through serial communication (via USB COM port).

On the host side, a Python script runs continuously, listening for incoming sensor data. Upon receiving the data, it loads a pre-trained Decision Tree Classifier (stored as a .pkl file using joblib) and uses it to predict the optimal lane to receive the green signal. The model was previously trained on sample input-output combinations representing various traffic scenarios. In addition to predicting the lane, the script calculates the green-time duration proportionally based on the number of lanes occupied. This information is sent back to the Arduino, which then activates the corresponding LED signal lights: turning ON green for the selected lane while keeping other lanes red. A 16×2 I²C LCD is updated to show the active lane number, green-time countdown, and any special alerts such as "EMERGENCY LANE 3" or "BREAKDOWN LANE 2."

Furthermore, the Arduino monitors each IR sensor for prolonged activation. If a vehicle is detected in the same position for more than 15 seconds, the system flags it as a potential breakdown and logs the event to a CSV file on the host PC, along with a timestamp and lane identifier. This comprehensive methodology ensures that the system not only adjusts signal timings dynamically based on real-time traffic conditions but also responds to critical events such as emergency vehicle arrival or lane blockage, thereby improving overall traffic flow and safety at intersections.

6. CONCLUSION

The Smart Traffic Management System presented in this project demonstrates a practical, low-cost solution to the growing problem of urban traffic congestion. By integrating IR sensors for real-time vehicle detection, an RFID module for emergency vehicle recognition, and a pre-trained Decision Tree Classifier for intelligent lane prediction, the system effectively replaces the limitations of traditional fixed-timer traffic lights with adaptive, data-driven control.

The modular architecture—built using Arduino and Python—ensures that the system is easily deployable, scalable, and maintainable. Key features such as proportional green-time allocation, emergency lane prioritization, and breakdown detection with event logging contribute to more efficient and safer traffic flow. The inclusion of a 16×2 LCD display for live feedback, along with LED signals for each lane, makes the system user-friendly and intuitive to monitor.

Laboratory testing confirmed that the system achieves sub-second response times and adapts dynamically to changing traffic conditions. With minimal hardware and no need for expensive infrastructure, this design provides a highly suitable prototype for smart city intersections, particularly in cost-sensitive or developing environments. Overall, the system proves that intelligent traffic control can be achieved through simple, reliable technology enhanced by machine learning.

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