AUTOMATED SPEED CONTROL AND EMERGENCY ROUTE CREATION IN TRAFFIC CONGESTION

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ABSTRACT Urban traffic congestion presents significant challenges, including prolonged travel times, increased fuel consumption, and critical delays in emergency response. Traditional traffic management systems lack the adaptability to regulate traffic flow dynamically based on real-time conditions. This system introduces an innovative approach, Automated Speed Control and Emergency Route Creation in Traffic Congestion, to improve vehicle movement and prioritize emergency transport. The system incorporates IR sensors positioned at strategic intervals to monitor traffic density up to 1 km ahead of intersections. The gathered data is processed using an Arduino-based controller, categorizing congestion levels into low, medium, or high and displaying real-time updates on an LCD module, enabling drivers to make informed speed adjustments to enhance traffic flow efficiency. A crucial feature of this system is emergency vehicle prioritization, implemented through RF communication, where emergency vehicles equipped with RF transmitters transmit signals to RF receivers installed at traffic signals, allowing the system to override normal traffic control mechanisms and promptly switch the signal to green, ensuring seamless passage for emergency responders. Simultaneously, the LCD provides real-time route guidance, advising emergency vehicles in high-traffic areas to take alternative routes to reduce congestion. This solution offers a cost-effective, scalable, and intelligent method for mitigating urban traffic issues by combining real-time traffic monitoring, automated signal control, and emergency response management. Experimental validation confirms improved traffic efficiency, reduced congestion delays, and enhanced emergency response times, supporting the advancement of Intelligent Transportation Systems and contributing to the development of smart city.

Keywords: Traffic congestion, emergency vehicle prioritization, RF communication, alternative routes, real-time traffic monitoring, smart city.

Volume No.6, Issue No.1 (2025)

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INTRODUCTION

Efficient transportation systems are essential for the smooth functioning of urban environments. However, rapid urbanization and increasing vehicle density have led to severe traffic congestion, resulting in extended travel times, excessive fuel consumption, and delays in critical services such as emergency response. Traditional traffic management systems rely on fixed timing mechanisms and lack the ability to adapt dynamically to changing road conditions, making them ineffective in addressing modern traffic challenges.

To overcome these limitations, this study explores the development of a system aimed at improving traffic flow and ensuring priority access for emergency vehicles. The system leverages sensor-based traffic monitoring, automated speed regulation, and real-time signal adjustments to enhance road efficiency. By deploying infrared (IR) sensors at key locations, traffic density is continuously assessed, while an Arduino-based processing unit classifies congestion levels. Furthermore, an RF communication mechanism enables emergency vehicles to bypass regular traffic signals, ensuring unimpeded movement during critical situations.

The proposed solution integrates intelligent automation and adaptive traffic management, making it a cost-effective and scalable alternative to conventional traffic control methods. By incorporating real-time data processing and automated decision-making, this system contributes to the advancement of Intelligent Transportation Systems (ITS) and the realization of smart city initiatives. This paper provides an in-depth analysis of the system's design, implementation, and potential impact on urban mobility.

LITERATURE SURVEY

Traffic congestion remains a critical challenge in urban mobility, prompting extensive research on intelligent transportation solutions. Various studies have explored traffic modeling, congestion prediction, and adaptive traffic control to enhance road efficiency and reduce delays.

Dimri et al. (2024) proposed a traffic modeling approach for optimizing vehicle waiting times at intersections, demonstrating the effectiveness of simulation-based congestion management strategies [1]. Similarly, Liu et al. (2024) introduced a graph-based framework for real-time congestion detection using multiple camera feeds, highlighting the role of computer vision in traffic forecasting [2].

Advanced prediction techniques have also been investigated. Chen et al. (2023) developed a flow feedback traffic prediction model utilizing visual quantification to enhance traffic monitoring accuracy [3]. Gu et al. (2023) proposed a fog computing-based adaptive congestion management system that dynamically regulates traffic in high-density areas [4].

In the domain of vehicle trajectory planning, Zhao et al. (2023) introduced a driver-preview mechanism for human-like navigation on curved roads, offering insights into driver behavior modeling [5]. Zhu et al. (2023) explored a scenario-based optimization approach for intelligent vehicle testing, ensuring enhanced traffic safety and efficiency [6].

Traffic congestion control mechanisms have been further refined by Zhang et al. (2023), who integrated hybrid prediction and control techniques to optimize urban traffic flow [7]. Dai et al. (2023) investigated vehicle-to-vehicle (V2V) computation offloading, improving real-time decision-making in connected transportation systems [8].

Machine learning applications have also gained prominence. Mou et al. (2023) developed an energy-efficient scheduling model for dynamic traffic environments, leveraging artificial intelligence for optimized transport logistics [9]. Mehdi et al. (2022) applied entropy-based labeling techniques for CNN-driven congestion prediction, emphasizing the role of deep learning in traffic analytics [10].

PROPOSED SYSTEM

The Automated Speed Control and Emergency Route Creation System is designed to improve urban traffic management by integrating real-time traffic monitoring, adaptive speed regulation, emergency vehicle prioritization, and route optimization. The system architecture consists of infrared (IR) sensors, an Arduino-based microcontroller, radio frequency (RF) communication modules, and an LCD display for real-time traffic alerts and guidance. The

methodology ensures efficient traffic movement while addressing emergency response delays and congestion issues.

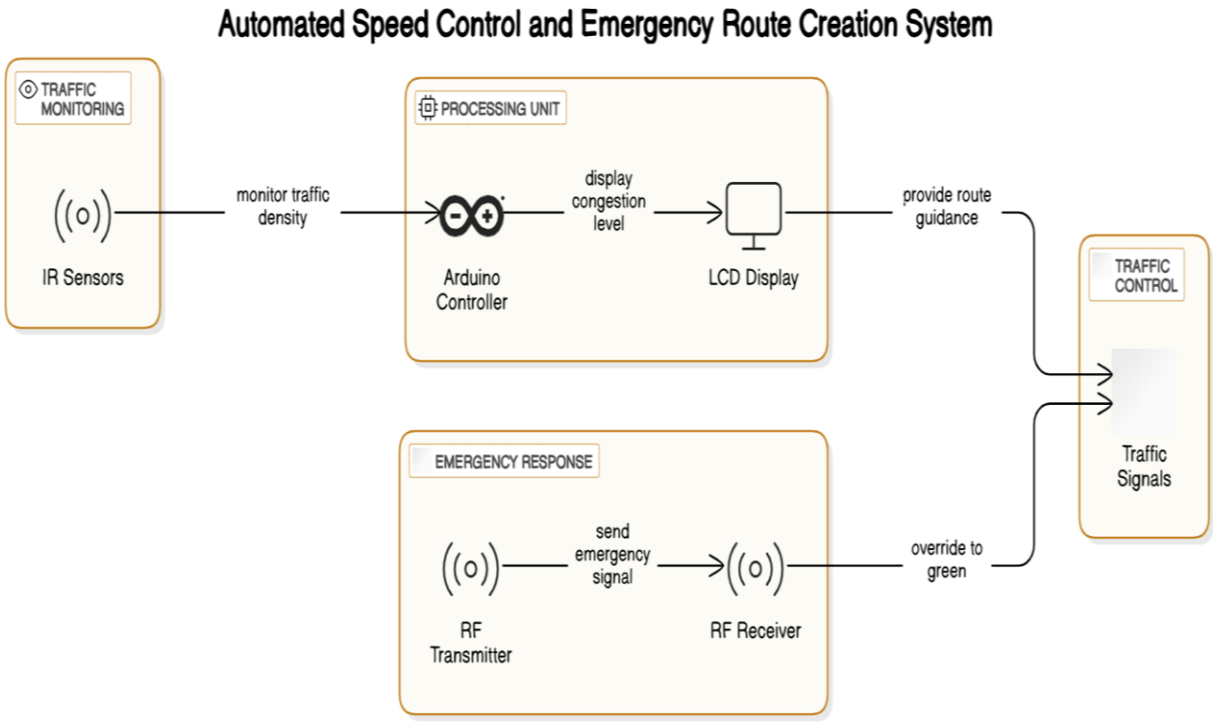


Figure 1 Functional Block Diagram

1. Traffic Density Detection and Categorization

Efficient traffic management begins with accurate real-time monitoring of vehicle density on roads. The system employs infrared (IR) sensors, strategically positioned near intersections, to detect vehicle presence and track traffic flow. These sensors continuously collect data and transmit it to an Arduino-based microcontroller, where the traffic density is analyzed and categorized. Traffic conditions are classified into three distinct levels to optimize signal operations effectively:

- Low Traffic: When vehicle density is minimal, indicating smooth movement without congestion. In this case, standard traffic signals remain unchanged to maintain normal operations.
- Medium Traffic: Represents a moderate level of congestion, requiring optimized signal timing to maintain a steady vehicle flow. Adjustments to signal durations help prevent unnecessary build-ups.

- High Traffic: Indicates severe congestion, leading to prolonged delays at intersections. In such scenarios, the system dynamically adjusts traffic signals to alleviate congestion and enhance road capacity.

By categorizing traffic levels in real-time, the system proactively manages road conditions and minimizes excessive congestion, ensuring smooth vehicular movement across intersections.

2. Adaptive Speed Control Alerts

One of the key factors in congestion buildup is inconsistent vehicle speeds, which often result in sudden braking and traffic bottlenecks. To address this issue, the system incorporates an adaptive speed regulation mechanism that provides drivers with real-time speed recommendations based on current traffic density. These recommendations are displayed on LCD screens positioned at strategic points along roadways.

The system adjusts speed recommendations as follows:

- Low Traffic: Displays "Maintain Speed" to prevent vehicles from slowing down unnecessarily, ensuring steady movement.
- Medium Traffic: Suggests a moderate speed adjustment to help vehicles maintain uniform flow and avoid abrupt braking.
- High Traffic: Alerts drivers to reduce speed due to congestion ahead, preventing sudden stoppages and improving lane discipline.

By implementing adaptive speed control, the system minimizes traffic irregularities, reduces accident risks, and enhances road safety, ultimately improving the efficiency of urban transportation networks.

3. Emergency Vehicle Detection and Signal Override

Emergency response times are often delayed due to heavy congestion, posing a serious risk in critical situations. To mitigate this challenge, the system employs an RF communication module, which allows emergency vehicles—such as ambulances, fire trucks, and police units—to override normal traffic signals when necessary.

Each emergency vehicle is equipped with an RF transmitter, which sends a signal to an RF receiver installed at the traffic signal when approaching an intersection. Upon detecting the signal, the system instantly switches the traffic light to green, providing immediate clearance for the emergency vehicle to pass. This process is fully automated, ensuring a seamless and uninterrupted emergency route.

Once the emergency vehicle has cleared the intersection, the system automatically restores normal traffic control based on real-time conditions. This capability significantly reduces response delays, enhancing the effectiveness of emergency services and ultimately saving lives in critical situations.

4. Real-Time Traffic Alerts and Route Diversion

Drivers, especially emergency responders, often struggle with limited access to real-time traffic data, making it difficult to select optimal routes. To address this, the system integrates a real-time traffic alert mechanism that displays live congestion updates on LCD screens. These alerts enable drivers to make informed route decisions by providing clear congestion level indicators—low, medium, or high.

In scenarios where congestion reaches high levels, the system suggests alternative routes to help emergency vehicles bypass heavily congested areas. This route optimization feature enhances traffic distribution, preventing excessive build-up in specific locations. By continuously updating road conditions, the system ensures efficient traffic flow management, reducing delays and optimizing road utilization.

FLOW DIAGRAM:

A detailed flowchart outlines the decision-making process of the system, describing how traffic conditions are analyzed and how signals are adjusted dynamically.

- Start: The system initiates its operation.
- Detect Traffic Density: IR sensors monitor the number of vehicles approaching an intersection.
- Categorize Traffic: Based on sensor data, traffic is classified into three levels:
    - Low Traffic: Minimal vehicle presence, smooth movement.

- Medium Traffic: Moderate congestion, requiring normal signal operations.
- High Traffic: Heavy congestion, requiring traffic alerts and route diversion.

- Display Traffic Alerts: The system provides real-time notifications:
  - Low Traffic Alert: Informs drivers about free-flowing movement.
  - Medium Traffic Alert: Indicates moderate congestion and advises maintaining speed.
  - High Traffic Alert: Warns drivers of heavy congestion and suggests alternative routes to reduce traffic density.

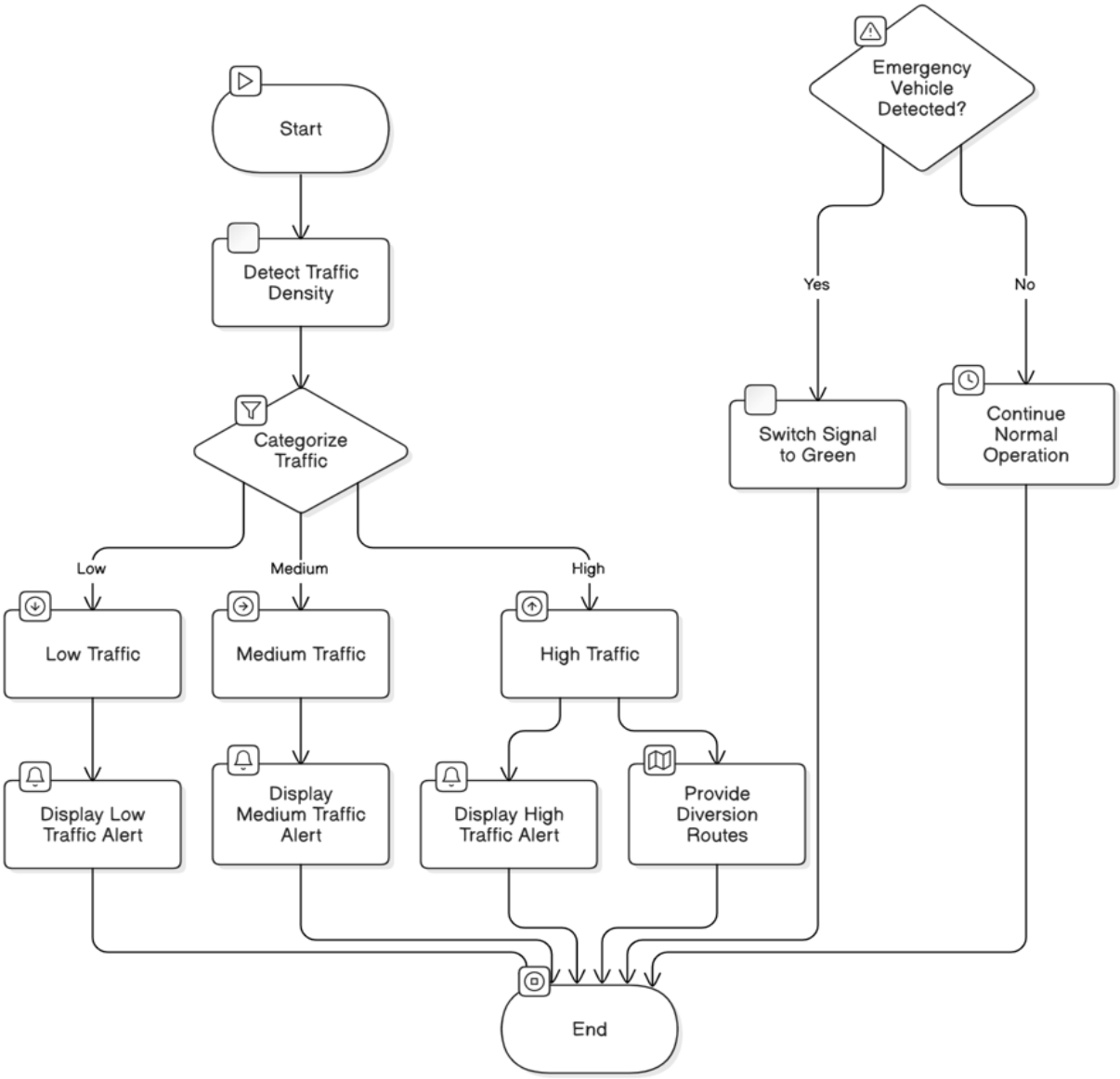


Figure 2 Flow Chart

- Provide Diversion Routes (for High Traffic): Recommends alternative pathways to ease congestion in high-traffic areas.
- Check for Emergency Vehicles: The system detects emergency vehicles using RF communication.
    - If an emergency vehicle is detected: The system overrides normal traffic operations. The traffic signal switches to green, ensuring uninterrupted passage.
    - If no emergency vehicle is detected: The system continues normal traffic signal operations.
- End Process: The system finalizes its decision-making cycle and continuously monitors real-time traffic conditions for further iterations.

IMPLEMENTATION:

The implementation of Automated Speed Control and Emergency Route Creation in the Traffic Congestion system involves integrating hardware and software components to manage traffic efficiently. The process includes setting up the hardware, developing the software, integrating both into a functional system and evaluating performance. Each stage is carefully designed to ensure smooth traffic flow, adaptive speed regulation, and emergency vehicle prioritization.

1. Hardware Implementation

The hardware components serve as the backbone of the system, enabling real-time traffic monitoring and control. A microcontroller (Arduino-based) processes data from infrared (IR) sensors installed at intersections to measure traffic density. These sensors classify congestion levels into low, medium, or high, allowing the system to make appropriate decisions. Additionally, an RF transmitter and receiver facilitate communication between emergency vehicles and the traffic signal system, ensuring a green light for emergency passage. An LCD and LED indicators provide real-time updates to drivers, while the traffic signal interface dynamically adjusts the lights based on the detected congestion levels. Each hardware component is individually tested before full system integration to ensure accuracy and efficiency.

2. Software Implementation

The software component is responsible for processing sensor data and executing traffic control decisions. The microcontroller is programmed using the Arduino IDE with embedded C, enabling efficient real-time system operation. The software processes data from IR sensors to classify traffic conditions, allowing dynamic traffic signal adjustments. It also detects emergency vehicles through RF signals and automatically overrides the signal to green for their passage. Furthermore, the display module updates drivers with traffic congestion alerts, speed recommendations, and alternate route suggestions. By ensuring smooth integration between hardware and software, the system enhances traffic flow and safety.

3. System Integration

After developing the hardware and software components, they are integrated to form a fully operational prototype. The IR sensors and microcontroller are connected for real-time traffic monitoring, ensuring accurate data collection. The RF communication module is linked with the traffic signal system to enable emergency vehicle prioritization. The LCD and LED indicators are synchronized with traffic operations to provide clear updates for drivers. The system is then tested under various traffic conditions to ensure dynamic signal adjustments and efficient congestion management. Successful integration ensures that the system functions seamlessly in real-world traffic scenarios.

4. Deployment and Scalability

The system is deployed in a controlled environment, such as a traffic intersection or a smart city pilot project. The deployment process is designed to be cost-effective and easily adaptable for large-scale urban traffic management. Incorporating IoT and cloud computing will enable advanced traffic monitoring and data-driven decision-making, ensuring long-term feasibility and adaptability.

5. Performance Evaluation

The system undergoes rigorous testing to assess its efficiency, accuracy, and responsiveness under real-world traffic conditions. Traffic detection accuracy is evaluated by comparing sensor data with actual vehicle flow. Signal adaptation efficiency is measured based on the response time between traffic detection and signal adjustments. The emergency vehicle

prioritization feature is tested by analyzing the system's ability to detect and override signals for emergency vehicles without delay. Traffic flow optimization is assessed through simulations and real-world testing, examining its impact on congestion management. The system's reliability and stability are tested under varying environmental conditions to ensure consistent performance.

RESULTS AND DISCUSSION:

1. Environmental Setup

The hardware setup includes components such as the Arduino microcontroller, infrared sensors, and an LCD display. This setup enables real-time traffic monitoring and control.

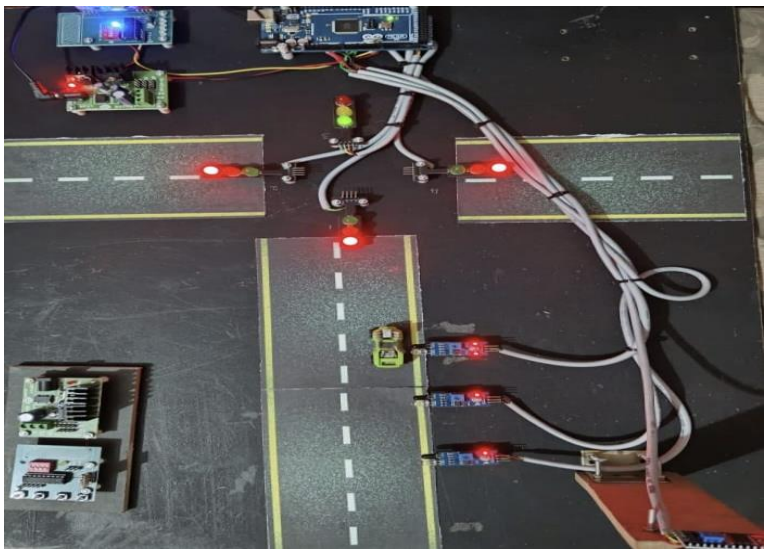


Figure 3 Environmental Setup

2. Circuit Simulation

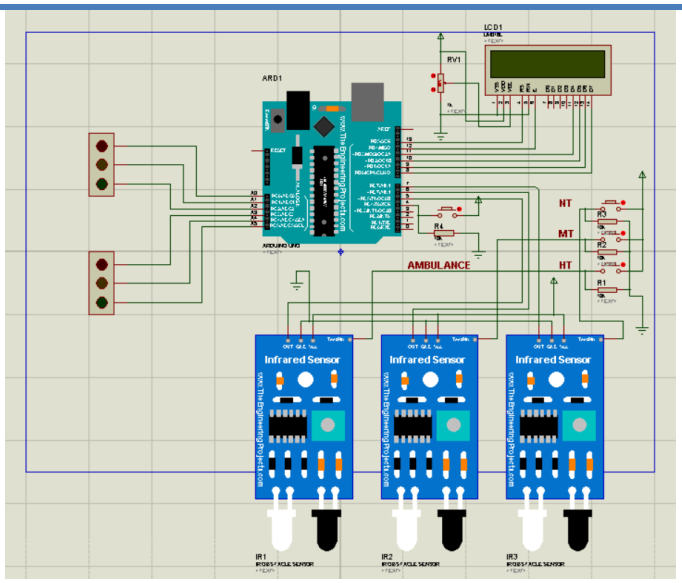
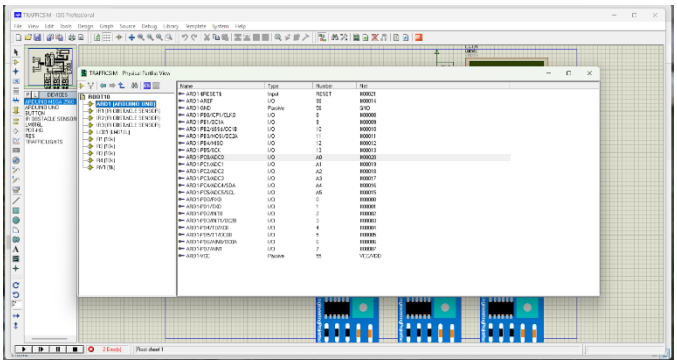


Figure 4 Circuit Simulation

This simulation diagram visualizes the system's functioning in Proteus software, demonstrating how various components interact under different traffic conditions.



A section of the program code responsible for traffic control is depicted, explaining the logic used for speed regulation and signal adjustments.

3. Emergency Vehicle Detection

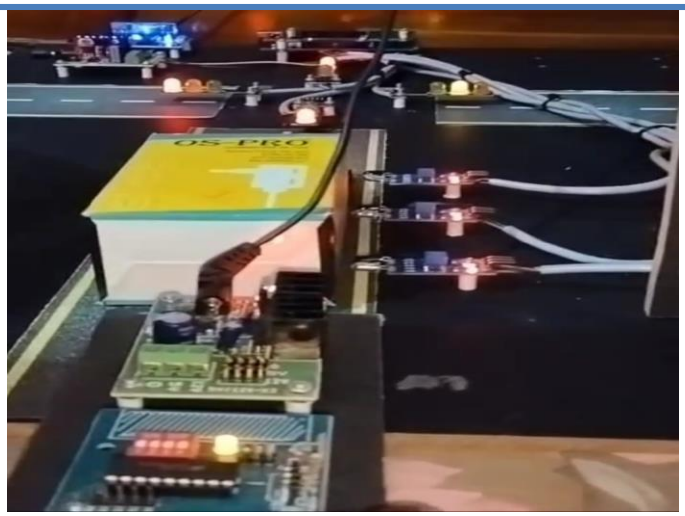


Figure 5 Emergency Vehicle Detection

Here, the system successfully identifies an approaching emergency vehicle, activating a priority mechanism to provide a clear route by switching signals accordingly.

4. Emergency Response

Figure 6 Signal Override Operation

This image showcases how the system dynamically alters traffic signals based on emergency vehicle presence, ensuring smooth flow and minimal delays.

Figure 7 Take Diversion Alert

Figure 8 Emergency Vehicle Prioritization

5. Traffic Density Categorization

The LCD display presents real-time traffic information, including congestion level and signal status, enhancing user awareness. The system categorizes the traffic conditions into low, medium, and high congestion levels.

Figure 9 Heavy Traffic

Figure 10 Medium Traffic

Figure 11 Normal Traffic

CONCLUSION:

The proposed system offers an efficient solution to urban traffic congestion by integrating real-time traffic monitoring, automated signal control, and emergency vehicle prioritization. Through the use of IR sensors, microcontrollers, and RF communication, it ensures dynamic signal adjustments, reducing delays and improving traffic flow. Emergency response times are significantly enhanced by allowing automatic signal overrides for priority vehicles. Additionally, the system aids in traffic redistribution by suggesting alternative routes and minimizing congestion in high-density areas.

While challenges such as environmental interference and infrastructure modifications exist, future enhancements like AI-driven traffic monitoring, IoT integration, and GPS-based navigation can further optimize its performance. Overall, the system provides a cost-effective and scalable solution, aligning with the vision of smart cities and Intelligent Transportation Systems (ITS) to create a safer and more efficient urban mobility framework.

FUTURE ENHANCEMENT:

To further enhance the effectiveness of the system, several advancements can be incorporated. These improvements will enable a more intelligent, adaptive, and energy-efficient urban traffic management solution. One key enhancement is the integration of GPS-based real-time tracking for emergency vehicles. This will allow traffic signals to be adjusted proactively before the vehicle reaches an intersection, minimizing delays and ensuring a faster response time during emergencies. Another potential improvement involves the application of machine learning algorithms to optimize signal timings dynamically. By analyzing historical traffic patterns and

real-time congestion data, the system can predict traffic behavior and adjust signals accordingly. The development of a mobile application can provide real-time traffic congestion updates and alternative route recommendations for drivers. With instant access to traffic conditions on their smartphones, commuters can make informed decisions, reducing unnecessary delays and redistributing traffic efficiently.

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