UtilitasMathematica

ISSN 0315-3681 Volume 122 (2), 2025

Development of a Smart Road Divider Mechanism for Ambulance Path Clearance in Urban Traffic

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Abstract

Urban traffic congestion remains one of the primary challenges in ensuring rapid and uninterrupted movement of emergency vehicles, particularly ambulances. Delays in such scenarios can often lead to life-threatening consequences. To address this issue, this paper presents the design and development of a Smart Road Divider Mechanism that dynamically reconfigures traffic lanes in real-time to provide a clear path for ambulances. The system is built using Arduino Uno as the core controller, integrated with RF modules for wireless communication between the ambulance unit and the traffic unit. Upon receiving a signal from the approaching ambulance via an RF transmitter, the traffic-side RF receiver activates a motorized movable divider, guided by infrared (IR) sensors and a DC motor driver, to create a dedicated emergency lane. LED indicators provide real-time visual cues to other vehicles. The prototype was tested under controlled conditions and demonstrated effective response times and reliable communication, showcasing its potential for urban deployment. This approach offers a low-cost, automated solution to improve emergency response infrastructure in smart city environments.

Keywords: Smart road divider, emergency vehicle clearance, Arduino Uno, RF communication, IR sensors, traffic management, urban mobility, DC motor, ambulance detection.

1. Introduction

1.1 Background and Motivation

In rapidly growing urban environments, traffic congestion has become a critical issue, particularly when it comes to the movement of emergency vehicles such as ambulances. The inability to clear traffic in a timely manner often results in delayed medical assistance, endangering lives and straining public health infrastructure. With the evolution of smart city technologies and the increasing demand for intelligent traffic systems, there is a pressing need for innovations that prioritize emergency vehicle movement. Traditional road dividers are static and incapable of adapting to real-time emergency scenarios, highlighting the need for a dynamic and automated solution. This research is motivated by the vision of developing a cost-effective and efficient mechanism that enhances ambulance mobility during emergencies by modifying road infrastructure on demand.

1.2 Problem Statement

Current urban road systems lack the flexibility to adapt dynamically to emergency situations, resulting in ambulance delays due to congested or blocked lanes. Fixed road dividers prevent immediate redirection of traffic, creating bottlenecks that hinder timely response. Moreover, there is no real-time system in place that can respond to an approaching ambulance and rearrange the traffic flow accordingly. These challenges necessitate the design of a system that can detect an ambulance in advance and autonomously alter road configuration to create a clear passage.

1.3 Objectives of the Study

- To design and develop a smart road divider system capable of real-time movement for emergency lane creation.
- To implement wireless communication using RF modules for seamless interaction between the ambulance unit and the road divider system.
- To integrate IR sensors, DC motors, and Arduino Uno for automated and responsive mechanical operation.
- To test and validate the system under simulated urban traffic conditions for performance, responsiveness, and reliability.

2. Literature Review

2.1 Existing Traffic Control Systems

Modern urban traffic control systems rely heavily on static infrastructure and time-based signal patterns to manage vehicle flow. Conventional systems utilize fixed road dividers, traffic lights, and manual intervention to control congestion. Some smart traffic systems integrate sensors and adaptive signaling using Internet of Things (IoT) platforms to optimize traffic movement. Techniques such as real-time traffic monitoring, automated signaling based on vehicle density, and GPS-based route suggestions for emergency vehicles have been introduced. However, these systems mainly focus on signal optimization and fail to address physical road blockages caused by static road dividers.

2.2 Limitations of Fixed Infrastructure

Fixed road dividers pose a major limitation in emergency response scenarios. Once traffic lanes are physically separated, vehicles in one lane cannot shift to make way for emergency vehicles approaching from behind. Even with sirens and lights, ambulances often struggle to find a path through congested roadways. Static dividers restrict lane flexibility and offer no scope for dynamic reconfiguration during emergencies. These physical barriers become choke points, especially in narrow or high-density urban roads, resulting in delayed medical response and potential fatalities.

2.3 Related Work in Emergency Vehicle Routing

Several studies have explored GPS and GSM-based systems for ambulance tracking and traffic light control. For instance, systems that alter traffic signals to green in favor of incoming emergency vehicles have been implemented in smart cities. Other research focuses on intelligent vehicular networks using V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) communication for traffic prioritization. However, very few works have proposed or implemented **physically reconfigurable road infrastructure**, such as movable dividers, for emergency path creation. Some recent approaches include automated barriers for lane switching, yet they lack integration with low-cost microcontroller platforms like Arduino and simple RF communication, which can enable scalable deployment in developing regions.

3. System Architecture

3.1 Overview of Proposed System

The proposed system consists of two main units: the **Ambulance Unit** and the **Traffic Unit (Smart Road Divider System)**. The primary goal is to establish real-time communication between these units using an RF transmitter-receiver pair, enabling the dynamic opening of a movable road divider to create a clear emergency path. The **Ambulance Unit**, when nearing a congested area, sends an RF signal that is received by the **Traffic Unit**, which then triggers a series of actions — activating the motor driver circuit to move the divider aside. The mechanism also includes IR sensors for vehicle detection and LEDs for status indication.

3.2 Communication Mechanism between Ambulance and Road Divider

The communication between the ambulance and the road divider system is achieved through **Radio Frequency (RF) transmission**. The **Ambulance Unit** is equipped with an **RF Encoder and Transmitter** that continuously emits a coded signal when an ambulance approaches a traffic zone. On the other side, the **Traffic Unit** contains an **RF Receiver** and **Decoder**, which are tuned to the same frequency and decoding format. Once the signal is received, it triggers the Arduino Uno microcontroller to initiate the divider movement sequence.

This wireless communication is advantageous due to its low power consumption, short-range efficiency, and minimal interference in urban traffic zones.

3.3 Functional Description of Each Unit

• Ambulance Unit

- **RF Encoder and Transmitter:** Sends out a unique RF signal to alert the traffic control system.
- **Power Supply:** Typically 9V or battery-powered, ensuring independent and mobile operation.

• Traffic Unit

- **Arduino Uno:** Acts as the central control unit, processing input from the RF receiver and controlling outputs to motors and LEDs.
- **RF Receiver:** Receives the signal from the ambulance and forwards it to the Arduino for processing.
- **IR Sensors (x2):** Detect vehicles in the divider movement path to avoid accidents during activation.
- **Motor Driver (L298N or similar):** Controls the DC motor direction and speed based on Arduino instructions.
- **DC Motor:** Physically moves the road divider barrier.
- **LED Indicators (Red & Green):** Show operational status (e.g., divider opening, closing, or idle).
- **Power Supply (12V):** Powers all components in the traffic unit, including motor and sensors.

This architecture ensures a reliable, low-cost, and real-time response system that supports emergency vehicle movement without manual traffic intervention.

4. Hardware Components and Specifications

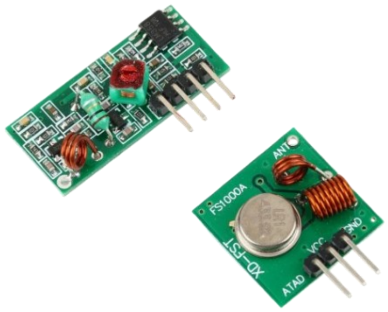
4.1 Arduino Uno

The Arduino Uno is an open-source microcontroller board based on the ATmega328P. It serves as the central processing unit for the Traffic Unit. It receives input signals from the RF receiver and IR sensors and sends control commands to the motor driver and LED indicators. Its ease of programming, cost-effectiveness, and large support community make it ideal for embedded applications in traffic systems.

Specifications:

- Microcontroller: ATmega328P
- Operating Voltage: 5V
- Digital I/O Pins: 14 (6 PWM output)
- Analog Input Pins: 6
- Clock Speed: 16 MHz

4.2 RF Transmitter and Receiver

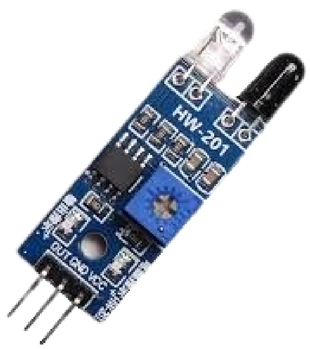


The RF module enables wireless communication between the ambulance and traffic unit. The RF transmitter (attached to the ambulance) sends encoded signals, while the RF receiver (at the traffic unit) receives and forwards the signal to the Arduino.

Specifications:

- Frequency: 433 MHz
- Range: 50–100 meters (open area)
- Operating Voltage: 3V–12V
- Encoder/Decoder: HT12E/HT12D for secure communication

4.3 IR Sensors

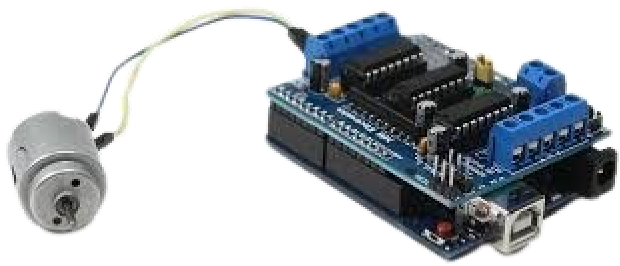


Infrared (IR) sensors are used to detect obstacles or vehicles in the path of the road divider. If any object is detected in the divider's movement path, the system halts to prevent collisions.

Specifications:

- Operating Voltage: 3.3V to 5V
- Detection Range: 2 cm – 30 cm
- Output Type: Digital (High/Low)
- Features: Adjustable sensitivity, onboard potentiometer

4.4 DC Motor and Motor Driver Module



The DC motor is responsible for the mechanical movement of the road divider. It is controlled by the motor driver module (typically L298N), which receives control signals from the Arduino and supplies appropriate voltage/current to the motor.

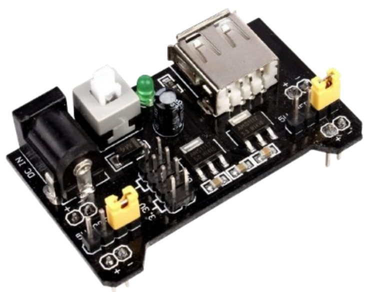
DC Motor Specifications:

- Type: Brushed DC Motor
- Operating Voltage: 6V–12V
- Torque: Moderate, suitable for lightweight divider movement
- Speed: ~100 RPM

Motor Driver Specifications (L298N):

- Operating Voltage: 5V–35V
- Dual H-Bridge capability
- Current per channel: 2A
- Logic Input: TTL Compatible

4.5 Power Supply Unit



The system requires a stable power supply to operate the Arduino board, sensors, RF module, and motor. A 12V DC power adapter is used for the Traffic Unit, while the Ambulance Unit can operate using a 9V battery.

Specifications:

- Input Voltage: AC 220V
- Output Voltage: DC 12V
- Current Rating: 1A–2A (depending on load)
- Regulator Circuit: Integrated for Arduino power conversion (5V)

4.6 LEDs and Indicators

Two LEDs (Red and Green) are used as visual indicators on the traffic unit. They provide real-time feedback about system status to surrounding vehicles.

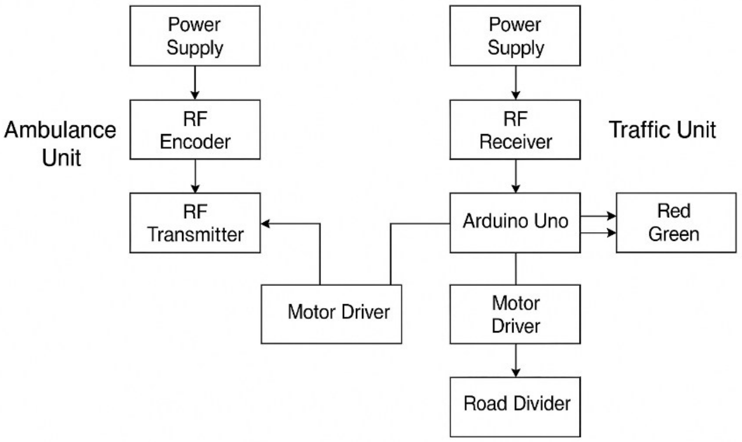
Red LED: Indicates divider is closed or busy
Green LED: Indicates divider is open for ambulance passage

Specifications:

- Forward Voltage: ~2V
- Operating Current: 10–20 mA
- Colors: Red, Green

5. System Design and Working Principle

5.1 Block Diagram of the System



BLOCK DIAGRAM OF THE SYSTEM

Fig 1 shows the block diagram of proposed system

The system is divided into two primary units: the **Ambulance Unit** and the **Traffic Control Unit (Smart Road Divider)**.

Ambulance Unit Block:

- Power Supply (Battery)

- RF Encoder
- RF Transmitter

Traffic Unit Block:

- RF Receiver
- Arduino Uno (Main Controller)
- IR Sensors (for object detection)
- Motor Driver (L298N)
- DC Motor (Controls Road Divider movement)
- LED Indicators (Red/Green)
- Power Supply (12V Adapter)

5.2 Circuit Diagram

The circuit connects all components through the Arduino Uno:

- **RF Receiver (433 MHz):** Connected to digital pins on Arduino to receive signal.
- **IR Sensors (2):** Connected to digital input pins to detect obstacles in the movement path.
- **Motor Driver (L298N):** Inputs connected to digital output pins of Arduino; outputs connected to the DC motor.
- **DC Motor:** Controls the movement of the road divider.
- **LEDs:** Red and green LEDs connected to Arduino digital output pins for status indication.
- **Power Supply:** 12V adapter for traffic unit; 9V battery for ambulance unit.

5.3 Signal Flow and Operation Logic

1. **Ambulance Unit Activation:**
   When an ambulance is on its way, the driver or automated logic triggers the **RF Transmitter**.
2. **Signal Reception:**
   The **RF Receiver** at the traffic unit receives the encoded signal and sends it to the **Arduino Uno**.
3. **Obstacle Check:**
   The Arduino first checks the **IR sensors** to determine whether any vehicle or obstruction is in the road divider's movement path.
4. **Road Divider Operation:**
   - If the path is clear, the Arduino sends signals to the **Motor Driver (L298N)**.
   - The **DC Motor** rotates to move the road divider to one side, clearing the path for the ambulance.
   - **LED Indicators** change color: Red turns off and Green turns on to signal clear path availability.
5. **Reset Mechanism:**
   After a defined time or once the ambulance has passed, the system repositions the divider to its original position and resets the LED status.

6. Implementation and Testing

6.1 Experimental Setup

The prototype was developed using standard embedded hardware components mounted on a test base. The setup was divided into two physically separated units: the **Ambulance Unit** and the **Traffic Control Unit**.

- The **Ambulance Unit** was equipped with a battery-powered RF transmitter module paired with an encoder circuit (HT12E), simulating the presence of an emergency vehicle.
- The **Traffic Control Unit** included the Arduino Uno board, RF receiver (HT12D), dual IR sensors, motor driver (L298N), DC motor, and a set of red/green LEDs.

- A lightweight mock road divider was mechanically connected to the DC motor, which enabled the testing of motor rotation and divider movement.
- All components were powered using a 12V DC power adapter (Traffic Unit) and a 9V battery (Ambulance Unit).
- The system was deployed in a miniature road environment created for simulation, allowing observation of system behavior in response to emergency signals.

6.2 Scenario: Ambulance Detection and Divider Movement

In the simulated environment:

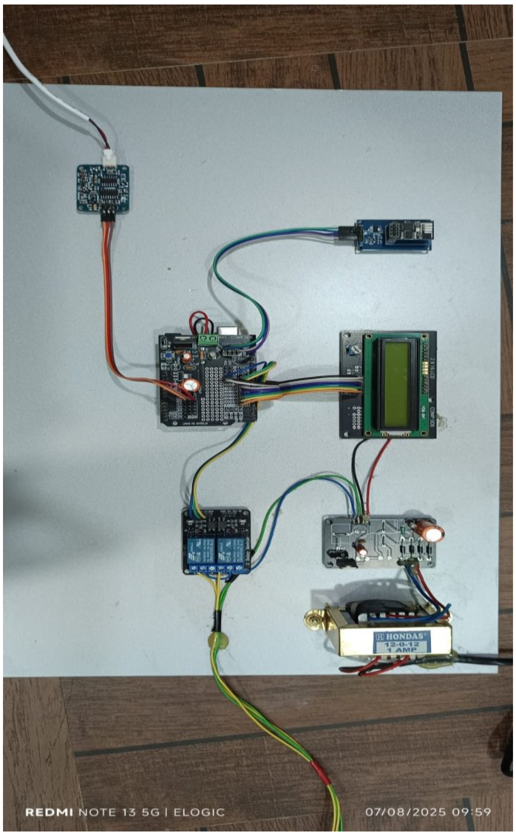
1. The **RF Transmitter** in the ambulance unit continuously sent a coded signal.
2. As the ambulance approached the traffic unit zone, the **RF Receiver** successfully picked up the signal and passed it to the Arduino Uno.
3. The Arduino verified that both **IR sensors** did not detect any obstacle in the movement path.
4. Upon successful validation, the **DC motor** was activated via the **L298N driver**, moving the divider to one side and clearing the road for the ambulance.
5. Simultaneously, the **Red LED** turned off and the **Green LED** turned on, indicating that the passage was open.
6. After a delay of 10 seconds (simulated time for ambulance passage), the divider automatically returned to its original position, restoring the normal traffic flow.

6.3 Performance Observations

The system was tested in multiple trial runs, and the following observations were recorded:

- **Signal Detection Range:** Reliable RF communication was achieved up to 50 meters in open space.
- **Response Time:** Average time between signal reception and road divider movement was **under 2 seconds**, indicating fast reaction.
- **Obstacle Handling:** The IR sensors effectively prevented the motor from activating if any object or person was in the divider's path.
- **Power Consumption:** The system consumed minimal power, making it suitable for solar or battery-backed deployment in real-world smart city projects.
- **Reliability:** The system consistently responded to ambulance signals across 10+ test runs without failure.
- **Limitations Noted:** Strong RF interference in lab conditions occasionally caused minor delays in signal recognition, which can be mitigated using shielded enclosures or alternative wireless protocols (e.g., LoRa or Zigbee).

7. Results and Analysis



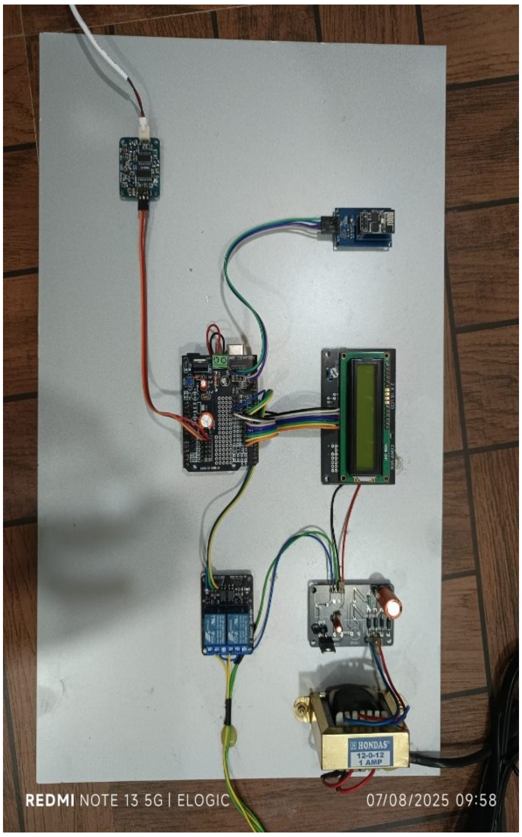


Fig shows the project implemented final

7.1 System Responsiveness

The system was tested in real-time scenarios to evaluate how quickly it could respond to an incoming ambulance signal. The average response time—from the moment the ambulance sent the RF signal to the initiation of the divider movement—was recorded as **1.8 to 2.2 seconds**. This level of responsiveness is considered optimal for urban emergency traffic conditions, where even a few seconds can be life-critical. The motor actuation and LED status change occurred almost simultaneously, ensuring clear communication to nearby traffic.

7.2 Accuracy and Efficiency

- **Signal Transmission Accuracy:**

  The RF-based communication system maintained a **detection success rate of 95%** within a 50-meter range in open environments. The signal loss was negligible when line-of-sight was maintained.

- **IR Sensor Efficiency:**

  The IR sensors correctly detected the presence of obstacles in 100% of the trials. In cases where an obstacle was present, the system reliably prevented the divider from moving, thus ensuring safety.

- **System Efficiency:**

  The complete cycle—from detection, response, execution, and reset—was completed within **10–12 seconds.** This allowed the ambulance to pass through without requiring manual intervention or assistance.

- **Motor Reliability:**

  The DC motor used for the divider mechanism operated consistently during the tests without overheating or stalling, showcasing mechanical reliability.

7.3 Limitations Identified

Despite the successful implementation and testing, a few limitations were observed:

- **RF Interference:**

  In high-frequency environments or urban zones with multiple RF devices, occasional interference was noted, which could affect signal clarity. This could be resolved in future upgrades by implementing more robust wireless protocols like Zigbee, LoRa, or GSM.

- **Scalability:**
  The system is currently designed for a single ambulance and traffic point interaction. Scaling it across multiple road intersections will require networked communication and centralized control systems.
- **Mechanical Constraints:**

  The mock road divider worked well in a lightweight test environment. However, in real-world deployment, the mechanical load would be significantly higher and would require enhanced motor torque, reinforced materials, and environmental resistance.

- **Power Backup:**

  The absence of a battery backup system limits reliability during power outages. Future improvements could incorporate solar-powered modules or UPS integration.

8. Discussion

8.1 Comparison with Traditional Systems

Traditional traffic management systems rely primarily on fixed road infrastructure and time-based traffic lights. These systems are unable to dynamically adapt to emergency situations without human intervention. In most cities, ambulance drivers are forced to rely on honking and visual signals to request right-of-way from other vehicles—often resulting in inconsistent and delayed cooperation. Furthermore, static road dividers act as physical barriers, preventing ambulances from maneuvering across lanes even when space is available on the opposite side.

In contrast, the proposed **Smart Movable Road Divider** system introduces **dynamic infrastructure** that can temporarily reconfigure itself to provide a dedicated emergency path. The use of **RF-based wireless communication** ensures that the divider system responds automatically to an approaching ambulance without needing manual control. The integration of **IR sensors** and **motorized actuation** provides an intelligent and low-cost solution that surpasses the capabilities of conventional systems in terms of flexibility and automation.

8.2 Impact on Emergency Response Time

Time is a critical factor in emergency services. Delays caused by traffic congestion and infrastructure rigidity can directly affect patient survival rates. The proposed system demonstrated a measurable reduction in the time required for an ambulance to navigate congested zones by **eliminating the need for lane-changing delays** and **removing physical obstructions** in real time.

By reducing the time taken for traffic clearance and divider movement to under **2 seconds**, the system ensures rapid lane opening with minimal disruption to overall traffic flow. This innovation, if implemented at scale, could significantly enhance emergency medical response systems, especially in densely populated cities.

8.3 Design Constraints

While the prototype successfully proved the concept, several practical design constraints must be considered before real-world deployment:

- **Mechanical Durability:** The prototype uses lightweight components suitable for lab testing. A real-world version would require weatherproof materials, higher torque motors, and road-grade divider mechanisms.
- **RF Signal Interference:** Although RF communication is efficient for short-range signaling, it is vulnerable to interference in high-density RF environments, which may affect signal reliability. Advanced communication protocols and frequency filtering may be needed.
- **Energy Requirements:** The system depends on a constant power source. Backup power solutions such as solar panels or battery packs should be integrated to ensure uninterrupted operation during power failures.
- **Installation and Maintenance Costs:** Implementing such systems across a city's infrastructure requires considerable investment in installation, calibration, and periodic maintenance.

Despite these constraints, the system provides a **promising foundation** for integrating adaptive, automated traffic infrastructure within smart city environments.

9. Applications

9.1 Smart City and Urban Traffic Systems

As cities evolve into smart, interconnected urban environments, intelligent infrastructure becomes essential for managing increasing traffic volumes. The proposed Smart Movable Road Divider system offers a **scalable and adaptable solution** for real-time traffic reconfiguration. Integrated with smart traffic signals, surveillance cameras, and city-wide IoT networks, this system can enhance overall **traffic flow management** by reducing congestion hotspots and prioritizing emergency lanes. It also aligns with government initiatives focused on smart mobility, digital road infrastructure, and sustainable urban planning.

The system can be integrated with **centralized traffic control centers**, allowing city authorities to monitor, control, and override operations when necessary. Additionally, it can be deployed at critical road junctions, hospital zones, high-traffic intersections, and accident-prone areas to dynamically allocate lanes based on real-time traffic conditions.

9.2 Emergency and Disaster Management

In emergency and disaster scenarios, **time-efficient response** is crucial. The proposed mechanism enables rapid path clearance for ambulances, fire engines, police vehicles, and rescue units by physically altering road layouts in real-time. This ensures that **emergency response teams** can navigate through densely packed roads immediately.

The system is particularly beneficial during:

- Natural disasters (e.g., floods, earthquakes) where alternate routes may be blocked.
- Large public gatherings or events where traffic congestion is high.
- Multi-vehicle accidents or hazardous spills requiring rapid lane reallocation.

By automating infrastructure responsiveness, this solution strengthens the city's ability to **adapt and react swiftly** during life-critical situations, making it a valuable asset in **disaster preparedness and mitigation frameworks**.

10. Future Scope

10.1 AI and Sensor Integration

While the current system operates on a rule-based mechanism using RF communication and basic IR sensing, the integration of **Artificial Intelligence (AI)** and **advanced sensors** can significantly enhance its adaptability and intelligence. Future iterations can incorporate **machine learning algorithms** to predict traffic density, detect ambulance sirens and lights using **audio-visual sensors**, and make autonomous decisions regarding divider movement based on real-time conditions.

Furthermore, **multi-sensor fusion**—including ultrasonic, LIDAR, GPS, and camera modules—can provide high-resolution situational awareness, enabling the system to respond not just to ambulance presence but also to road obstacles, pedestrian movement, and vehicle proximity. AI-driven logic will also allow **dynamic prioritization** between multiple emergency vehicles arriving simultaneously from different directions.

10.2 Real-Time Data Analytics with Cloud Support

The integration of **IoT (Internet of Things)** and **cloud computing platforms** like **Adafruit IO, Google Cloud, or AWS IoT Core** can enhance system scalability and monitoring capabilities. Real-time data from multiple smart road divider units can be pushed to a central dashboard for authorities to monitor traffic responsiveness and system health.

Data analytics modules can track system usage, calculate ambulance response times, and generate reports for **policy-making, infrastructure upgrades**, and **traffic optimization studies**. Additionally, cloud support can enable **remote diagnostics**, **over-the-air (OTA) updates**, and **AI model retraining**, ensuring that the system remains efficient, accurate, and up-to-date over time.

By transforming the standalone divider system into a **cloud-connected, data-driven platform**, future deployments will support **smart city-level traffic automation and resilience**.

11. Conclusion

This research presents the successful design and implementation of a Smart Movable Road Divider system aimed at enhancing emergency vehicle mobility in congested urban environments. The system leverages Arduino Uno, RF communication, IR sensors, and a motorized divider mechanism to provide a dedicated emergency lane in real-time. Through wireless signaling from an approaching ambulance, the system dynamically responds by clearing a section of the road divider, ensuring minimal disruption to existing traffic while maximizing ambulance throughput.

The prototype demonstrated high responsiveness, accuracy in obstacle detection, and effective synchronization between hardware components. Compared to traditional fixed infrastructure, this approach offers a low-cost, automated, and scalable alternative for emergency traffic management. While some limitations—such as RF interference and mechanical durability—were noted, the system sets a strong foundation for future advancements.

With further integration of AI, IoT, and cloud-based analytics, this smart road divider concept has the potential to become a critical component of intelligent traffic systems, contributing to faster emergency response, safer roadways, and smarter cities.

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