Arduino UNO based Autonomous Train System

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Abstract

This study presents the design and implementation of an "Autonomous Train System" intended to improve safety, efficiency, and reliability in modern railway operations. The proposed system integrates advanced technologies, including GPS modules, infrared and ultrasonic sensors, RF communication, and microcontroller-based control units to facilitate real-time obstacle detection, automatic braking, and inter-train communication. By continuously monitoring track conditions and nearby trains, the system can dynamically determine risk and execute timely responses, significantly reducing the chance of human error. The inclusion of GPS-based distance measurement using the Haversine formula ensures accurate positioning and collision avoidance. Additionally, the use of wireless communication allows trains to exchange location and status data, enhancing coordination and safety. The system's compact design, cost-efficiency, and scalability support its adoption in both urban and intercity networks. This autonomous approach not only improves operational dependability but also sets the foundation for intelligent transportation systems in the future of railway infrastructure.

Keywords: Driverless Train, Communication Protocols, Obstacle Detection, Train Control, Satellite Communication, GPS, Sensors, Transceiver Communication.

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1. Introduction

The concept of an autonomous train system was proposed to address the increasing need for safer and more efficient railway operations in modern transportation networks. Train accidents caused by human errors, obstacles, track damage, and communication failures have prompted the development of innovative solutions leveraging advanced technologies. Using state of the art technologies to improve operating efficiency, passenger safety, and overall system reliability, the “Autonomous Train System” is a revolutionary step in the field of railway transportation. With the development and application of cutting-edge technologies including stopping mechanisms, and safety regulations, this project aims to revolutionize train operations and establish new benchmarks for present railway systems [11-14].

The sophisticated sensors, communication systems, and emergency response mechanisms integrated enables passengers and other stakeholders to feel more comfortable and safer during their train journey. This system minimizes accidents, reduces delays, and enhances passenger safety and satisfaction. Its cost-effectiveness, energy efficiency, and scalability make it a viable solution for modernizing railways globally. By automating important safety mechanisms, the system eliminates human errors and ensures smoother operations. This innovative adaptation meets the growing demands of safer, more reliable, and efficient transportation, setting a new standard for railway systems worldwide. This study results in ensuring the safety of the passengers and other payloads. The devices alert adjacent passengers so they may take precautions in the case of a train accident in addition to braking.

This study provides a very reliable system that operates automatically using microcontrollers and sensors to ensure the rail safety [1]. The primary objective of this study is to enhance the security of train operations by incorporating an intelligent braking mechanism. The system utilizes sensor that detects obstacles in the train’s path and measures the distance between the train and the obstacle. The successful implementation of this automatic braking system holds immense significance for the safety and efficiency of the Indian railway system [2].

The reason is mainly due to the unbalanced growth of high operating mileage and passenger demands. In the last decades, the operating mileage has increased by five times. However, the demand for passenger transportation has increased by 15 times. There is a urgent need for sustainable development. However, with the rapid growth and changing customer expectations, the current train operation strategy cannot meet the practical demands [3]. This study examines the development and deployment of an autonomous metro rail system. The system automates train operations, guaranteeing efficiency and safety, by integrating a variety of sensors and controllers. In order to improve the functionality of metro trains, research is concentrated on obstacle detection, communication between modules, and real-time data processing [4].

By combining sensors and controls to identify obstructions and abnormalities in real-time to avoid accidents. The system intends to raise the level of dependability and safety ofrailway transportation. The potential of Arduino technology to update railway safety procedures is demonstrated by this study [5]. Two trains are installed with a GPS system, to measure the latitude and longitude. By their instantaneous velocities of the train, the system dynamically calculates the indication of the other trains, so that the trains can communicate data in between them, by communicating they can ensure that they are remain at a safe distance to avoid collision of the train [6-8].

As a result, this study is a ground-breaking effort in the development of railroad travel, demonstrating the capacity of autonomous technology to transform operations, improve passenger satisfaction, and advance safety.

2. Proposed System

This system is developed to increase the efficiency and the safety. The components, GPS module, IR sensor, RF transceiver, LCD, and Ultrasonic sensor are included in the block diagram. This system operates by integrating all components to ensure real-time obstacle detection and communication. The ultrasonic sensor continuously monitors the train's surroundings and sends distance data to the Arduino Uno, which processes the information. If an obstacle is detected within a critical range, the Arduino triggers and displays the obstacle details on the LCD. Simultaneously, the Arduino uses the RF transmitter to send an emergency signal to nearby trains, while the RF receiver monitors incoming signals for similar warnings. The GPS module tracks the train's location, which is displayed on the LCD for operator awareness. This system is powered by a stable power supply, and works cohesively to enhance safety and communication between trains.

The RF Transmitter of the communication module communicates control signals to the RF Receiver, which is attached to an additional Arduino Uno. To ensure coordinated movements, this secondary Arduino interprets the signals it receives and regulates a second motor driver and motor. The block diagram of train automation and communication system are shown in Figure 1.

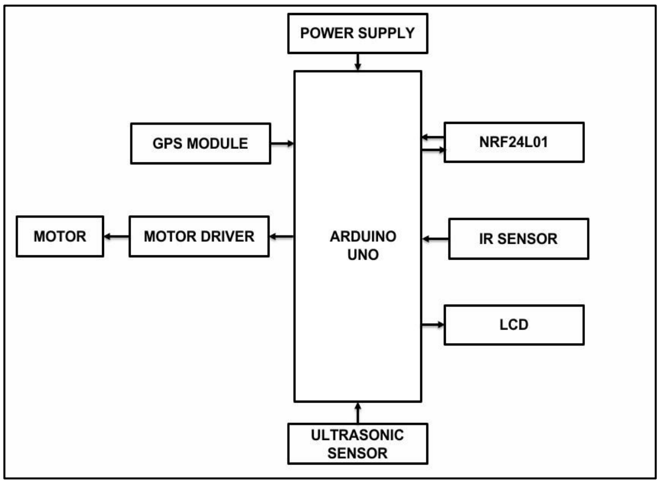

Figure 1. Block Diagram

The main components of Autonomous Train System are

1. **Arduino Board** - It interprets sensor inputs and directs outputs to other parts. It is a user-friendly hardware and software. The microcontroller, a tiny computer on an integrated circuit with a CPU core, memory, and programmable input/output peripherals, is the heart of the Arduino hardware. A vast array of parts and add-ons, including breadboards, jumper wires, sensors, and modules, are supported by the Arduino environment, which makes it incredibly flexible for creating anything from simple projects to automation systems.

2. **16x2 LCD –** It shows system information, including train heading, obstacle detection, and station number. The integration feature facilitates real-time monitoring of the train's movements by both passengers and operators, providing clear signals throughout running or stopping phases as shown in Figure1. By facilitating smooth communication between passengers and the train's control system and providing important updates about the train's operational status, this visual feedback system improves passenger

experience and safety while also making a significant contribution to the prototype model's overall functionality

3. **Motor Driver L298N Dual H-Bridge –** It manages the DC motor’s direction and speed in response to signals from the Arduino. Because of its large current capacity, this component guarantees the motors an effective power distribution, which is especially important for heavy loads and during acceleration phases [9-10]. For the purpose of preserving the best possible train operations, the dual H-bridge structure allows bi-directional control, which makes it easier to switch between forward and reverse motions with accurate speed regulation.

4. **DC Motor 12V 500 RPM Geared Motor –** It provides the train's mechanical propulsion. The ideal torque-to-speed ratio of this particular gear motor, which allows it to rotate at 500 revolutions per minute (RPM), makes it ideal for accelerating the train while retaining efficiency and control as shown in Figure.1. It enhances the overall functionality and effectiveness of the autonomous train system.

5. **Ultrasonic Sensor HC-SR04 –** It identifies the obstacles in the train's route. With its distance-measuring capabilities, the train can identify obstacles precisely and react to possible threats quickly and efficiently. To ensure thorough obstacle detection capabilities, the ultrasonic sensors are positioned strategically to cover the train's proximity [13].

6. **12-Volt Battery –** It energizes the motors and motor driver. The motor driver - L2987, which manages the motors mounted in the train's wheels. This driver effectively controls the direction and speed of the motor, which is essential for the train's autonomous motion and navigation. It also provides power supply to the essential parts, like the gear motor, LCD, motor driver, and ultrasonic sensor with uninterrupted power.

7. **GPS Module NEO-**6M GPS, promotes inter-train communication to avoid collisions. Using a GPS module in a railway system, it provides real-time and accurate location of the train, helping to precisely measure the distance between two trains. Also, the system plans accordingly to efficient route and speed adjustments based on train positions. GPS integration supports automation and improved time scheduling for smoother operation of trains.

8. **IR Sensor LM393 -** It is a key component for detecting faults and cracks in the railway track, ensuring the safety and reliability of the train's operation. Positioned strategically, the IR sensor monitors the continuity of the track by emitting infrared light and detecting its reflection. Any deviation or irregularity in the reflected signal indicates a crack or a fault in the track. When such a fault is detected, the IR sensor sends a signal to the Arduino Uno, which processes the information and immediately stops the train to prevent derailments or accidents. This proactive approach to fault detection significantly enhances passenger safety and minimizes risks associated with damaged tracks. The IR sensor's role is essential in real-time track monitoring, enabling the system to maintain a high level of safety and operational efficiency.

2.1 obstacle detection

The flowchart for obstacle detection outlines the logical sequence followed to identify and respond to obstacles in the train's path. It begins by initializing the sensors and continuously monitoring the environment using ultrasonic sensors as shown in Figure.2. When an obstacle is detected within a predefined range, the system triggers an alert and automatically halts the train. If no obstacle is detected, the train continues to operate as usual. This systematic approach ensures the safety and reliability of the train operation.

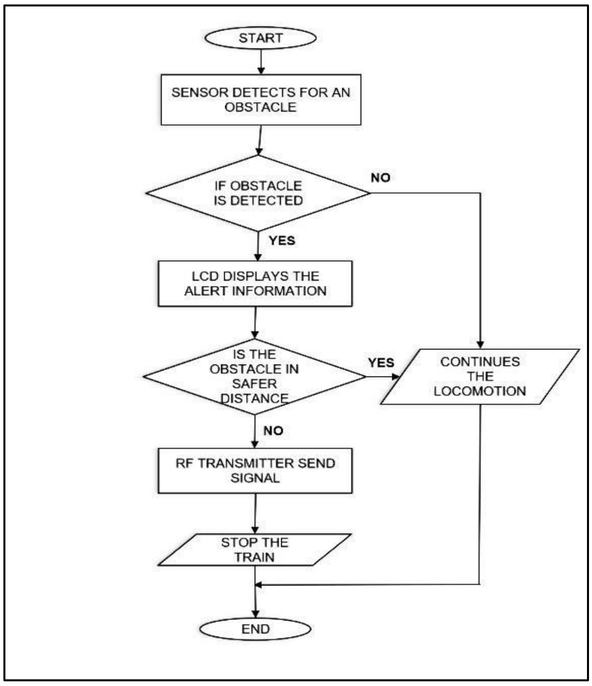

Figure 2. Flowchart for Obstacle Detection

2.2 Crack Detection

The detection of cracks in the railway track system is important to preventing accidents such as derailments and collisions. An IR sensor is used to identify track faults by emitting infrared light and analysing the reflected signal. When a crack is present, the reflection pattern is disrupted, signalling a fault. This data is processed by the Arduino Uno, which immediately halts the train to avoid further risks. The IR sensor ensures real-time monitoring of the track's condition, enabling swift action to address structural issues and enhance the overall safety of train operations. The flowchart which is employed to detect the crack in the track system is shown in Figure.3

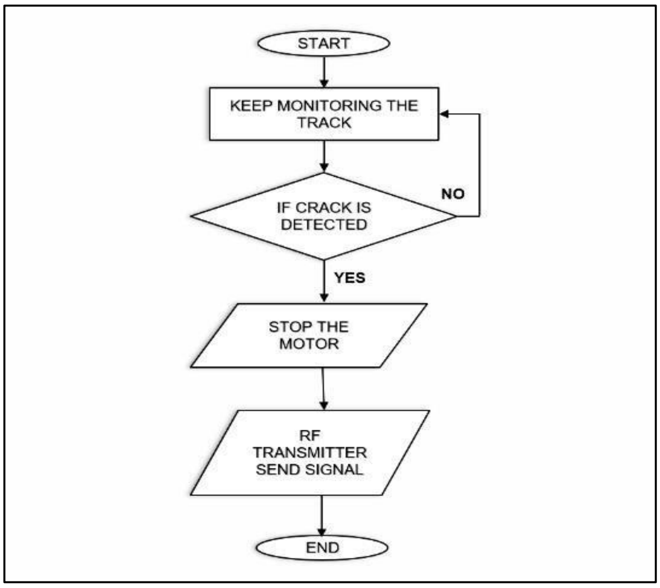

Figure 3. Flowchart for Crack Detection

2.3 Haversine Formula

In this research, the Haversine formula is used for determining the distance between two trains based on their GPS coordinates. This calculation is essential for ensuring safe operation and communication between the trains, as it helps to maintain a safe distance and avoid collisions. The latitude and longitude of the two trains are:

TRAIN 1

Latitude 1: 11.026060, $\phi_1 = 11.026060$, $\lambda_1 = 77.021966°$ Longitude 1: 77.021966

TRAIN 2

Latitude 2: 11.016686, $\phi_2 = 11.016686$, $\lambda_2 = 77.033599°$ Longitude 2: 77.033579

To find $\Delta\phi, \Delta\lambda$: $\Delta\phi = \phi_2 - \phi_1, \Delta\lambda = \lambda_2 - \lambda_1$

$\Delta\phi$ = 0.192232 - 0.192399 = -0.000167 rad

$\Delta\lambda$ = 1.344830 - 1.344620 = 0.000210 rad

HAVERSINE FORMULA: The Haversine formula can be expressed as,

$$a = sin^2(\Delta\varphi / 2) + cos(\varphi_1) \cdot cos(\varphi_2) \cdot sin^2(\Delta\lambda / 2)$$

Where ‘a’ is defined as the differences in latitude and longitude between the two 19 points and this is used to determine the square of the chord length between two points on the globe.

$$c = 2 \cdot atan2(\sqrt{a}, \sqrt{(1 - a)})$$

Where ‘c’ is considered as the variable that represents the angular distance (in rad)

$$d = R \cdot c$$

Where ‘d’ is the distance between two points on the surface of the Earth (in km) and ‘R’ is the Earth radius which is considered as 6371 km.

Calculation

To find a:

$a = \sin^2(-0.000167 / 2) + \cos(0.192399) \times \cos(0.192232) \times \sin^2(0.000210 / 2)$

$a = (6.947 \times 10^{-9}) + (0.981936 \times 0.981542 \times 1.102 \times 10^{-8})$

$a = 1.328 \times 10^{-8}$

To compute C:

$$C = 2 \times arcsin(\sqrt{1.328 \times 10^{-8}})$$

C = 0.000230 rad

To compute D:

D = 6371 × 0.000230 D = 1.637 km

To calculate the real-time distance between two moving trains, the Haversine formula is employed. This formula is particularly useful for calculating the distance with latitudes and longitudes. This formula works by first converting the geographic coordinates (latitude and longitude) of the trains from degrees to radians.

3. Simulation Results

The circuit simulation was performed using Proteus 8 Professional software. Code was uploaded using Arduino IDE (v1.8.19). The simulation result of the locomotion of the train system is shown in the Figure 4.

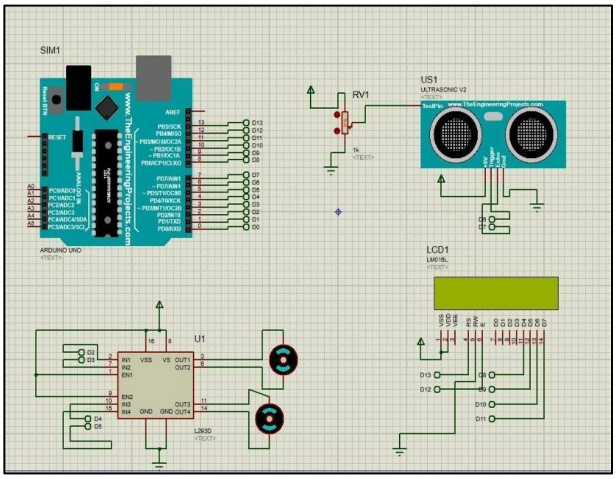

Figure 4. Locomotion of Train system

This simulation demonstrates the train's forward and reverse locomotion. The train will run continuously until an object is detected. An ultrasonic sensor measures the distance to any object in front of the train, and this distance is displayed on the LCD. Upon detecting a stationary object, the train will stop. If a moving object is detected, the motor will reverse, causing the train to move backward. The Arduino controls both the motor's speed and direction. In this simulation, a potentiometer is used to simulate varying the object's distance. Adjusting the potentiometer allows for increasing or decreasing the train's speed, which is also displayed on the LCD.

3.1 Integration of GPS Module

In modern transportation, especially autonomous systems, reliable communication and precise distance tracking are vital. This study integrates GPS modules into each train for real-time communication and accurate distance measurements, forming the core of autonomous operations. GPS modules collect signals from orbiting satellites, broadcasting their position and time [10]. Onboard receivers calculate distance using signal delays and the Haversine formula, providing continuous latitude and longitude updates as trains move. This positional data enables real-time location sharing between trains, essential for maintaining safe distances and preventing collisions in autonomous operation.

3.2 Integration of Transmitter and Receiver

The RF (Radio Frequency) transmitter and receiver system is integrated with a GPS module to enable real-time communication between autonomous trains. The GPS module provides accurate location data (latitude and longitude), while the RF communication system ensures the timely transmission and reception of this data between the trains [12]. This combination is essential for maintaining safe distances and coordinating the movement of multiple trains on the same or intersecting tracks

3.3 Data Collection and Transmission

The onboard GPS module collects the train's current position (latitude and longitude) and sends this data to the microcontroller. The microcontroller compiles this positional data. The RF transmitter sends this data packet wirelessly to other trains in the system. The Simulation result of Signal Transmission is shown in Figure 5.

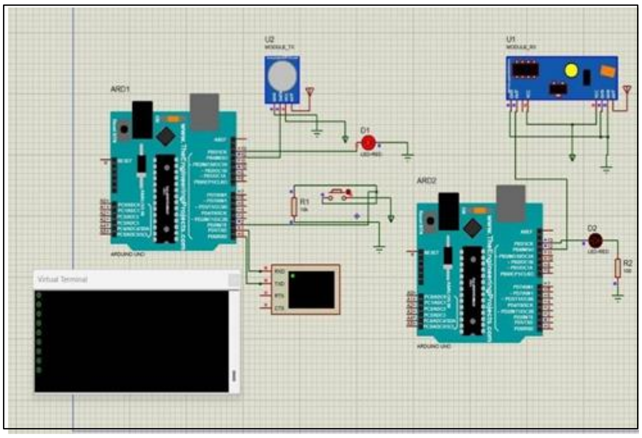

Figure 5. Signal Transmission

In the above simulation, By using the RF (Radio Frequency) transmitter the signal will be sent to the other system. Here the virtual terminal, push button, LED is used. The virtual terminal is used for displaying the signal response in digital medium. When the transmitter starts transmitting the signal, the virtual display shows 0 in the display. Also, the function the LED is to indicate the response of the communication system. The LED will glow in the case of signal transmission and will not glow if the signal is not transmitted. The push button is used for the simulation purpose. If push button is closed the signal will be transmitted to the receiving side and if not, the signal will not be transmitted. .

3.4. Data Reception and Processing

The RF receiver on another train receives the data that was transmitted. The receiver prolongs the incoming RF signal, extracts the positional and speed data of the train's data, and sends it to the microcontroller for processing. The microcontroller then uses the Haversine formula to calculate the real-time distance between the two trains based on their respective GPS coordinates. If the distance between two trains falls below a safety threshold range, the control system initiates restorative actions such as slowing down or stopping the train to prevent an accident. The simulation result of the logic status of the receiver signal is shown in Figure 6.

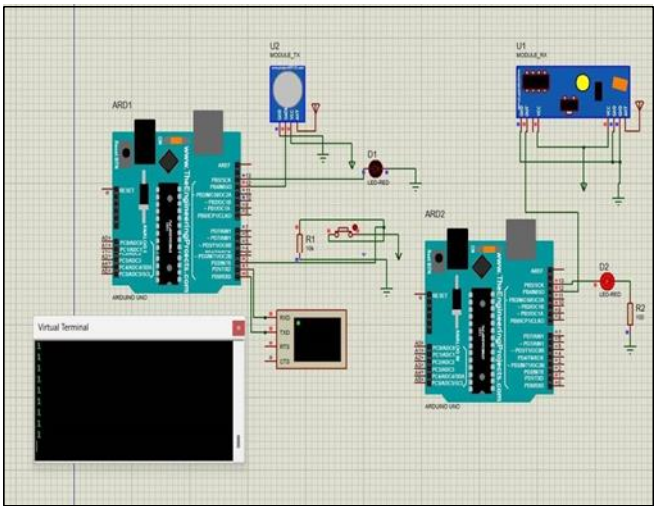

Figure 6. Logic Status of Receiver's Signal

The above simulation circuit refers the receiver communication system. After the push button is closed, the signal is transmitted to the receiver side. Once the signal is received, the LED on the receiver side will glow. That indicates the information is received by the receiver, and the proper communication takes place. At the same time, the virtual terminal will show 1 in the display. The wireless communication system is reliable and portable to use. Also, this technology can be implemented in real real-time application also. For the communication system, the simulation output is shown and verified by using a virtual terminal.

4. Prototype Model

The train uses an ultrasonic sensor to detect the obstacles that lie ahead. It measures the distance of objects by sending out ultrasonic waves and 35 receiving the reflected signals. If an obstacle is detected within a set range (10 to 20 cm), the train will move continuously. If it exceeds the predefined value, the train will stop and move in the reverse direction until it reaches a safer distance, and it will be shown on the LCD. Trains communicate with each other using the NRF transmitter and receiver modules. All this information will be communicated to the other train using NRF. Ultrasonic is applicable only to a small distance as mentioned earlier. To overcome this problem, GPS is used to find the train’s real-time location by communicating with satellites. The module calculates the train's latitude and longitude, and the microcontroller processes this data to track its position. A fan was included in the prototype to monitor the locomotion direction, are preprogrammed in the microcontroller according to the feedback from the sensors. In detail, when the fan is in the reverse direction means that the object or obstacle was very close to the train and was detected by the sensors. In this simulation, the fan serves as a visual representation of the train's wheel, demonstrating the interaction between sensors and locomotion controls. It is not part of the final train automation system. Figure 7 presents a prototype of the autonomous train system that is currently under development.

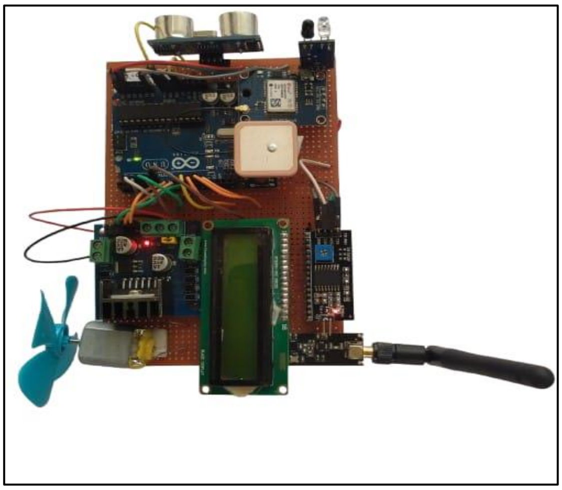

Figure 7. Prototype Model

In normal operations, when there is no obstacle detected, the train moves normally as shown in Figure 8. The LCD display is used for showing the current status of the train and the obstacle detection.

Figure 8. LCD Display

To prevent accidents caused by objects or obstacles on the track, a sensor is used to monitor the path ahead. If an obstacle is detected, the train will stop, and information about this event will be displayed on the LCD for passengers to understand the system's operation. The obstacle detection information shown on the LCD display is illustrated in Figure 9.

Figure 9. Obstacle Detected

5. Conclusion

This research enables a robust and scalable solution to enhance railway safety and operational efficiency. By integrating GPS tracking, wireless communication modules, and automatic braking systems, it ensures that trains can prevent collisions autonomously, without the need for constant human intervention. This approach significantly reduces the risk of accidents and delays, providing a safer and more reliable transportation system. The ability to calculate the distance between trains in real-time and trigger emergency braking when necessary, enables a highly responsive safety mechanism, reducing the risk of accidents and improving overall operational reliability. Moreover, this study demonstrates the potential of sensor-based automation to transform the railway industry, ensuring a safer, more efficient, and cost-effective future for train transportation. Real-time implementation improves safety and also allows for better traffic management by transmitting live data to control centers, enabling proactive responses to potential hazards. This sets the future integration of advanced technologies such as machine learning, 5G connectivity, and AI which can further elevate the system's capabilities, making it more adaptive and intelligent.

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