Smart Safety Tunnel Traffic System

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***Abstract*—Road tunnels are critical components of modern transportation infrastructure, but they present unique safety challenges such as limited visibility, poor ventilation, fire hazards, and difficulty in managing traffic during emergencies. This project proposes a Tunnel Traffic Safety System designed to enhance safety, monitoring, and control within tunnels using advanced sensing and automation technologies. The system integrates various sensors including gas sensors, temperature sensors, smoke detectors, and light sensors to continuously monitor environmental conditions inside the tunnel. In case of hazardous situations such as fire, gas leakage, or low visibility, the system automatically activates safety mechanisms such as ventilation fans, alarm systems, emergency lighting, and traffic control signals.**

I. INTRODUCTION

Transportation is one of the most important parts of modern life. With the increase in population and development of cities, the number of vehicles on roads is growing very fast. To reduce travel time and avoid obstacles like mountains, rivers, and crowded city areas, tunnels are widely used in highways and urban infrastructure. Although tunnels are very useful, they also create safety challenges because they are closed and limited spaces. Inside a tunnel, there is less space for movement, limited airflow, and restricted visibility compared to open roads. If too many vehicles enter a tunnel at the same time, it can lead to traffic congestion. In case of accidents, fire, or breakdowns, it becomes very difficult to manage the situation quickly. Poor lighting conditions and over-speeding vehicles also increase the chances of accidents. Therefore, maintaining safety inside tunnels is a very important issue.

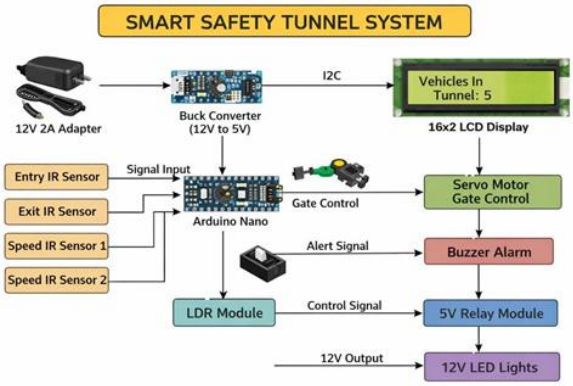
II. NEED FOR SMART TUNNEL TRAFFIC SYSTEM

A Smart Tunnel Traffic Safety System is required to ensure safe and efficient movement of vehicles inside tunnels where natural visibility and ventilation are limited.

2.1 Main Needs:

- Accident Prevention
  Tunnels have low visibility and confined space, increasing accident risk. Smart systems detect vehicles and control traffic.
- Proper Lighting Control
  Sudden change in light at tunnel entry/exit can cause accidents. Automatic lighting improves driver visibility.
- Air Quality Management
  Harmful gases like CO and CO_2 accumulate inside tunnels. Sensors and ventilation systems maintain safe air levels.
- Fire & Emergency Handling
  In case of fire or breakdown, immediate detection and alert systems help prevent major disasters.
- Traffic Monitoring & Control
  Real-time monitoring helps reduce congestion and ensures smooth vehicle flow.
- Quick Response System
  Automated alerts and communication systems help authorities take fast action during emergencies.

III. WORKING PRINCIPLE OF THE SYSTEM



The Smart Safety Tunnel System works automatically by continuously monitoring the tunnel conditions using sensors and controlling devices based on predefined conditions.

When a vehicle enters the tunnel, the entry IR sensor detects it and sends a signal to the Arduino. The Arduino increases the vehicle count. Similarly, when a vehicle exits, the exit IR sensor decreases the count. This helps in maintaining a real-time count of vehicles inside the tunnel.

If the number of vehicles exceeds a set limit (for example, 5 vehicles), the Arduino activates the servo motor to close the gate. At the same time, the buzzer turns ON to alert drivers. When the number of vehicles reduces, the gate opens again.

For speed detection, two IR sensors are placed at a fixed distance. When a vehicle passes the first sensor, the time is recorded. When it reaches the second sensor, the time is recorded again. Using the time difference, the Arduino calculates the speed of the vehicle and displays it on the LCD.

The LDR sensor continuously checks the light level. If the environment is dark, the Arduino activates the relay module, which turns ON the LED lights. When there is enough light, the LEDs are turned OFF.

The LCD display shows important information such as vehicle count, entry/exit data, and speed. The display updates automatically after a few seconds to show different parameters

IV. HARDWARE REQUIREMENT

A. Arduino Nano

Figure 2 Arduino Nano

The Arduino Nano is the main controller of the system and works as the brain. It is based on the ATmega328P microcontroller and operates at 5V. It reads input signals from sensors like IR sensors and the LDR module and processes them according to the program. Based on the conditions, it controls output devices such as the LCD display, servo motor, buzzer, and relay module. It is compact in size, easy to program using Arduino IDE, and suitable for small embedded projects. The use of female header pins makes it easy to connect and replace components without soldering directly.

B. IR Sensors (4 Units)

Figure 3 IR Sensors

Infrared (IR) sensors are used to detect vehicles. These sensors work by emitting infrared light and detecting the reflected signal. When a vehicle passes in front of the sensor, the IR beam is interrupted, and the sensor sends a signal to the Arduino.

4.1 In this project:

- One IR sensor is used at the entry point to count incoming vehicles
- One IR sensor is used at the exit point to count outgoing vehicles
- Two IR sensors are used for speed measurement

The speed is calculated by measuring the time taken for a vehicle to move between two sensors placed at a fixed distance. IR sensors are widely used because they are low-cost, simple, and reliable for short-distance detection.

16x2 LCD Display with I2C Module

The 16x2 LCD display is used to show important system information. It can display 16 characters in each line and has 2 lines. In this project, it shows:

- Number of vehicles inside the tunnel
- Entry and exit count
- Speed of vehicles

The I2C module attached to the LCD reduces the number of connections. Instead of using many wires, only two communication lines (SDA and SCL) are used along with power supply. This makes the circuit simple and neat. The LCD provides a user-friendly interface for monitoring system operation.

Servo Motor (Gate Control)

Figure 4 Servo Motor

The servo motor is used to control the gate at the entrance of the tunnel. It can rotate to a specific angle based on the signal from the Arduino. When the number of vehicles inside the tunnel reaches the limit, the Arduino sends a signal to rotate the servo motor, which closes the gate. When the number of vehicles decreases, the gate opens again. The servo motor provides precise control and is easy to interface with the Arduino.

Buzzer

Figure 5 Buzzer

The buzzer is used as an alert device. It produces sound when the system detects unsafe conditions, such as when the tunnel becomes overcrowded. This alert helps in warning drivers and operators to take necessary action. It is simple, low-cost, and easy to connect to the Arduino.

LDR Module (Light Dependent Resistor)

Figure 6 LDR Module

The LDR module is used to detect light intensity inside or outside the tunnel. It works based on resistance change:

- High resistance in darkness
- Low resistance in bright light

The Arduino reads this value and decides whether to turn ON or OFF the LED lights. This helps in maintaining proper lighting conditions automatically and saves energy.

12V LED Lights

Figure 7 12V LED Lights

LED lights are used to provide illumination inside the tunnel. Proper lighting is very important for driver safety. These LEDs operate on 12V and are controlled automatically using the relay module. LEDs are energy-efficient, consume less power, and have a long life.

5V Single Channel Relay Module

Figure 8 5V Single Channel Relay Module

The relay module is used to control high-voltage or high-current devices using low-voltage signals from the Arduino. It acts like an electronic switch. In this project, the relay is used to turn the 12V LED lights ON and OFF. It also provides electrical isolation between the Arduino and high-power devices, ensuring safety.

Buck Converter

Figure 9 Buck Converter

The buck converter is used to reduce voltage from 12V to 5V. Since the Arduino Nano and sensors require 5V, this component ensures they receive the correct voltage. It is more efficient than linear regulators because it generates less heat and provides stable output. The output voltage can be adjusted using a small potentiometer.

12V 2A Adapter with DC Jack

Figure 10 12V 2A Adapter with DC Jack

The 12V adapter is the main power supply of the system. It converts AC mains power into 12V DC. The DC female jack is used to connect the adapter to the circuit easily. This 12V supply is used directly by high-power components like LEDs and also fed into the buck converter to produce 5V for other components.

Point PCB

The point PCB (Printed Circuit Board) is used to assemble all components in a proper and permanent way. It ensures strong connections and reduces wiring problems compared to a bread board. It also makes the system more reliable and suitable for final project implementation

V. SOFTWARE REQUIREMENT

5. 1 Introduction to Software

The software part of this project is responsible for controlling the complete system. It acts as the logic that connects all hardware components and makes them work together. The Arduino Nano cannot perform any task without a proper program, so the software plays a very important role in this system. In the Smart Safety Tunnel System, the software is designed to read inputs from sensors, process the data, and control outputs like the LCD display, servo motor (gate), buzzer, and relay module. The program runs continuously and ensures that the system responds automatically to real-time conditions inside the tunnel.

5. 2 Software Tools Used

The main software used in this project is the Arduino IDE (Integrated Development Environment). It is an open-source platform used for writing, editing, compiling, and uploading code to Arduino boards.

Features of Arduino IDE:

- Easy to use interface
- Supports Embedded C programming
- Provides built-in libraries
- Allows serial monitoring for testing
- Compatible with Arduino Nano

The programming language used is Embedded C, which is simple and suitable for microcontroller-based applications.

5. 3 Libraries Used in Program

To simplify coding and control hardware easily, the following libraries are used:

- Wire. h: Used for I2C communication between Arduino and LCD
- LiquidCrystal_I2C.h: Used to control the 16x2 LCD display
- Servo. h: Used to control the servo motor for gate operation

These libraries reduce coding complexity and provide ready-made functions.

5. 4. Program Structure

The Arduino program is divided into two main parts:

A. Setup Function

This function runs only once when the system starts. In this section:

- Pin modes are defined (INPUT or OUTPUT)
- LCD display is initialized
- Servo motor is attached and initial position is set
- Welcome message is displayed This prepares the system for operation.

B. Loop Function

This function runs continuously in a loop. In this section:

- Sensors are checked continuously
- Vehicle count is updated
- Speed is calculated
- Gate control is performed
- LCD display is updated
- Alerts are generated

This loop ensures real-time monitoring and control.

5. 5 Sensor Data Processing

The system reads signals from IR sensors using digital input pins.

Vehicle Counting

- When entry sensor detects a vehicle → count increases
- When exit sensor detects a vehicle → count decreases

This helps maintain the number of vehicles inside the tunnel.

Condition Check

- If vehicle count ≥ 5 → gate closes and buzzer ON
- If vehicle count < 5 → gate opens and buzzer OFF

This logic prevents overcrowding.

VI. SPEED CALCULATION LOGIC

Speed is calculated using two IR sensors. Working:

- First sensor detects vehicle → start time recorded
- Second sensor detects vehicle → end time recorded
- Time difference is calculated Speed formula used:
- Speed = Distance / Time Then converted into km/h.

This allows monitoring of vehicle speed inside the tunnel.

VII. LCD DISPLAY CONTROL

The LCD shows different information such as:

- Vehicles inside tunnel
- Entry and exit count
- Vehicle speed

The display changes automatically every few seconds using the millis() function. This avoids stopping the program and ensures smooth operation.

VIII. GATE CONTROL USING SERVO MOTOR

The servo motor is controlled using PWM signals.

- Gate open position → 0 degrees
- Gate closed position → 90 degrees

The Arduino sends signals to rotate the servo based on vehicle count.

IX. BUZZER ALERT SYSTEM

The buzzer is activated when:

- Tunnel becomes overcrowded
- It gives an audio alert to warn drivers and operators.

X. TIMING AND DELAY MANAGEMENT

A. The program uses:

- delay() for short pauses
- millis() for timing without stopping execution
- millis() is important because it allows multitasking, such as updating the display while checking sensors.

B. Advantages

- Improves Tunnel Safety
  The system automatically monitors vehicle movement and controls entry, reducing the chances of accidents inside the tunnel.
- Automatic Traffic Control
  It controls the number of vehicles entering the tunnel without human involvement, preventing overcrowding.
- Real-Time Vehicle Counting
  The system continuously tracks the number of vehicles inside the tunnel using IR sensors, ensuring accurate monitoring.
- Speed Monitoring Feature
  It calculates vehicle speed using sensors, which helps in identifying over-speeding vehicles and improving safety.
- Low-Cost Implementation
  The project uses simple and affordable components like Arduino Nano, IR sensors, and LCD, making it economical.
- Energy Efficient System
  The LDR-based lighting system turns lights ON/OFF automatically, saving electricity.
- Reduces Human Effort
  Automation reduces the need for manual monitoring and control, making the system more efficient.
- Easy to Install and Maintain
  The system is simple in design, making installation and maintenance easy.
- Compact and Flexible Design
  The use of Arduino Nano makes the system compact and suitable for small-scale applications.
- Expandable System
  The system can be upgraded with additional features like IoT, wireless monitoring, and advanced sensors.

C. Disadvantages

- Limited Accuracy of IR Sensors
  IR sensors may not work properly in conditions like dust, smoke, or strong sunlight, which can affect performance.
- Speed Measurement Errors
  The accuracy of speed calculation depends on the exact placement and distance between sensors.
- Not Suitable for Large-Scale Tunnels
  This system is designed for small or model tunnels and may require upgrades for real highway tunnels.
- No Vehicle Identification
  The system cannot identify individual vehicles since it does not use cameras or advanced recognition systems.
- Dependence on Power Supply
  The system requires continuous power; any power failure can stop its operation.
- Delay in Sensor Response
  Sometimes sensors may give delayed or repeated signals, causing minor counting errors.
- Limited Range of Sensors
  IR sensors work only for short distances, which

limits their use in large tunnels.

- Basic Alert System
  Only a buzzer is used for alerts; no advanced communication or emergency notification system is included.

D. Applications

- Highway Tunnel Safety Systems
  Used to monitor and control vehicle movement inside tunnels for better safety.
- Parking Management Systems
  Can be used in parking areas to count vehicles and control entry/exit.
- Traffic Monitoring Systems
  Helps in managing traffic flow in busy roads and intersections.
- Smart City Infrastructure
  Can be integrated into smart city systems for automated traffic control.
- Industrial Vehicle Control
  Used in factories and industrial areas to monitor vehicle movement.
- Toll Booth Systems
  Helps in counting vehicles and managing traffic at toll plazas.
- Railway Tunnel Monitoring
  Can be used to track movement in railway tunnels.
- Security Checkpoints
  Useful for controlling and monitoring vehicle entry in restricted areas.
- Underground Roads and Subways
  Ensures proper lighting and vehicle control in underground passages.
- Educational Projects
  Useful for students to learn embedded systems, sensors, and automation.

E. Result

The Smart Safety Tunnel System was successfully designed, implemented, and tested using Arduino Nano and various sensors. During testing, the system was able to accurately detect vehicle entry and exit using IR sensors, and it maintained a real-time count of vehicles inside the tunnel. The counting mechanism worked effectively, with only minor variations due to sensor delay in some cases. The automatic gate control system functioned properly; when the number of vehicles reached the predefined limit, the servo motor closed the gate, and when the count decreased, the gate reopened smoothly.

The speed detection feature also worked correctly. By measuring the time taken for a vehicle to travel between two IR sensors, the system was able to calculate speed and display it on the LCD. Although the accuracy depended on sensor placement and timing precision, the results were satisfactory for a small-scale system. The LCD display successfully showed all required information such as vehicle count, entry and exit data, and speed, switching between different screens at regular intervals. The LDR-based lighting system responded well to changes in light intensity. When the environment became dark, the LED lights turned ON automatically, and when sufficient light was available, they turned OFF. The relay module operated correctly in controlling the high-power LED lights. The buzzer alert system also performed as expected by activating during overcrowding conditions.

Overall, the system demonstrated reliable performance, proper coordination between hardware and software, and successful automation of tunnel safety functions.

XI. CONCLUSION

The Smart Safety Tunnel System is an effective and practical solution for improving safety and traffic management inside tunnels. This project successfully demonstrates how simple electronic components and embedded systems can be used to automate real-world applications. By integrating sensors, microcontrollers, and control devices, the system reduces human effort and improves efficiency. The project achieves its main objectives, such as vehicle counting, speed monitoring, automatic gate control, and lighting management. It helps in preventing overcrowding, maintaining proper visibility, and providing real-time information. The use of Arduino Nano makes the system compact, affordable, and easy to implement. Although the system is basic, it provides a strong foundation for developing advanced safety systems. It proves that automation can significantly improve safety and reduce the chances of accidents in confined environments like tunnels.

Therefore, this project can be considered a successful implementation of an embedded system for traffic safety applications.

XII. FUTURE SCOPE

The Smart Safety Tunnel System can be further improved by adding advanced features and technologies. One major improvement is the integration of Internet of Things (IoT), which would allow remote monitoring of tunnel conditions through mobile applications or web platforms. This would help authorities track real-time data and respond quickly in case of emergencies. Additional sensors such as gas sensors and temperature sensors can be included to detect fire, smoke, or harmful gases inside the tunnel. This would enhance safety by providing early warnings. Camera modules and image processing techniques can be used for vehicle identification and more accurate monitoring.

Wireless communication systems can be added to send alerts to control rooms or emergency services. The system can also be expanded for large-scale tunnels by using more advanced microcontrollers and industrial-grade sensors. Artificial intelligence can be introduced to analyze traffic patterns and predict congestion. With these improvements, the system can be transformed into a complete smart tunnel management solution suitable for modern smart cities and highway infrastructure.

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