Vehicle Accident Prevention During Overtake Using IoT System

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Abstract

The rapid increase in vehicular density and the subsequent rise in road fatalities have necessitated the development of advanced driver-assistance systems (ADAS) to mitigate human error, which remains the primary cause of traffic accidents. Overtaking is globally recognized as one of the most hazardous maneuvers, often resulting in high-impact head-on collisions due to limited visibility, blind spots, and inaccurate human judgment of oncoming traffic speed. This paper presents the design and implementation of an IoT-based intelligent system for vehicle accident prevention during overtaking. The proposed system utilizes a multi-sensor fusion approach, integrating LiDAR, ultrasonic sensors, and high-definition cameras to monitor the vehicle's surrounding environment in real-time. At its core, an ESP32- based microcontroller processes spatial data to calculate the safe distance and time- to-collision parameters required for a successful maneuver. By leveraging Internet of Things (IoT) connectivity and Vehicle-to-Vehicle (V2V) communication, the system allows nearby vehicles to exchange position and velocity data, creating a localized network of situational awareness. A fuzzy-logic-based control algorithm is implemented to categorize the overtaking environment into safe, caution, or danger zones, providing instantaneous haptic and auditory alerts to the driver when risks are detected. Furthermore, the IoT framework enables cloud-based data logging, allowing for the analysis of near-miss patterns to improve future autonomous driving algorithms. Simulation and prototype testing demonstrate that the proposed system significantly reduces decision-making latency and improves overall road safety compared to manual observation.

Keywords: Blind Spot Monitoring, Arduino Uno, Real Time Alert System Intelligent, Transportation System

1. Introduction

The global escalation in vehicular traffic has transformed road safety into a primary concern for urban planners and automotive engineers alike. As transport networks become increasingly congested, the frequency of high-impact collisions has risen, particularly those involving heavy-duty vehicles such as trucks and buses. Among the various maneuvers performed on highways, overtaking remains the most complex and high-risk activity. Statistical data indicates that a significant percentage of road fatalities are attributed to misjudged overtaking maneuvers, where drivers fail to accurately perceive the distance and velocity of oncoming traffic or are blinded by the structural dimensions of the vehicle ahead. This necessitates the development of robust, automated intervention systems that can augment human perception with digital precision[1], [2].

In contemporary automotive engineering, the integration of the Internet of Things (IoT) provides a transformative framework for addressing these safety gaps. Much like the demand for efficient energy conversion in grid systems requires sophisticated multilevel inverter topologies, the demand for road safety requires an integrated network of sensors and communication modules. An IoT-based accident prevention system acts as a real-time monitoring layer that bridges the information gap between the driver and the environment. By employing a decentralized architecture of microcontrollers and sensors, vehicles can transition from isolated mechanical units into interconnected nodes within a broader smart transportation grid, significantly reducing the margin for human error during critical lane-change maneuvers[3], [4].

The primary technical challenge in safe overtaking is the presence of "blind spots" zones around a vehicle that cannot be directly observed by the driver through traditional mirrors. For heavy vehicles, these blind spots are extensive, often spanning 20 to 30 feet, which can completely obscure smaller passenger cars or motorcycles. Current safety standards are often insufficient, as they rely heavily on driver vigilance and basic reflective surfaces. The proposed system seeks to replace this subjective observation with objective data acquisition. By utilizing a suite of ultrasonic and infrared sensors, the system can "see" into these blind spots, providing a digital safety perimeter that operates independently of ambient lighting or weather conditions[5], [6].

Central to this project is the Arduino Uno microcontroller, which serves as the computational hub, analogous to the control strategies used to regulate voltage in multilevel inverters. The Arduino processes inputs from various peripheral modules to determine the safety status of the vehicle’s immediate surroundings. The logic embedded within the controller evaluates the "Time-to-Collision" (TTC) and the "Safety Gap" by analyzing the proximity of obstacles[7], [8].

This real-time processing ensures that the system can provide instantaneous feedback to the driver, a critical requirement given that overtaking decisions are often made in fractions of a second. The modular nature of the Arduino platform also allows for easy scaling and integration with other vehicle electronic control units (ECUs). The sensing layer of the system is comprised of high-precision ultrasonic sensors (such as the HC-SR04), which utilize sound wave reflection to calculate distance. These sensors are strategically positioned at the front, rear, and lateral points of the vehicle to ensure 360-degree coverage. When a driver initiates an overtaking sequence, these sensors scan the adjacent lane for oncoming traffic or trailing vehicles that may be moving at higher speeds. If an object is detected within a predefined danger threshold, the system triggers a multi-stage alert mechanism. This prevents the driver from merging into a occupied space, thereby eliminating the risk of side-swipe or head-on collisions that are common in rural and highway driving scenarios[9], [10].

In addition to proximity sensing, the system incorporates the ESP32-CAM module to provide visual verification. While distance sensors provide numerical data, visual data allows for more nuanced object recognition. The ESP32-CAM can stream live video feeds or capture snapshots of the overtaking lane, which can be processed to distinguish between different types of road users. This dual-layer approach combining distance sensing with visual monitoring ensures a high level of reliability and reduces the occurrence of false positives. The integration of such camera modules represents the shift toward "vision-based" safety systems that are becoming standard in modern autonomous and semi-autonomous vehicle prototypes[11], [12].

To facilitate remote monitoring and emergency response, the system utilizes Global System for Mobile Communications (GSM) and Global Positioning System (GPS) modules. The Neo-6M GPS module provides the precise coordinates of the vehicle, while the SIM800L GSM module enables the transmission of these coordinates via SMS or cellular data. In the event of a near-miss or a forced emergency stop, the system can automatically notify fleet managers or emergency services with the exact location. This connectivity aligns with the "Smart City" vision, where vehicle data is logged in the cloud to analyze accident-prone zones and improve overall traffic management strategies.

The user interface of the accident prevention system is designed to be intuitive and non-distracting. A combination of Light Emitting Diodes (LEDs) and a piezoelectric buzzer provides visual and auditory cues. A "Green" light indicates a clear path, "Yellow" warns of a closing gap, and "Red" combined with a high-frequency alarm signals an immediate collision risk. This tiered warning system ensures that the driver is not overwhelmed with information but receives clear, actionable instructions. By automating the monitoring of the environment, the system reduces the cognitive load on the driver, allowing them to focus on steering and speed control while the IoT network handles the safety calculations[13].

From a socio-economic perspective, the implementation of such technology is closely linked to the United Nations Sustainable Development Goals (SDGs), particularly Goal 3 (Good Health and Well-being) and Goal 11 (Sustainable Cities and Communities). Road accidents are a major cause of economic loss, involving medical costs, property damage, and loss of productivity. By providing an affordable, Arduino-based solution, this technology can be retrofitted into older vehicle fleets, especially in developing regions where high-end ADAS features are not commercially accessible. This democratizes road safety, ensuring that even heavy transport vehicles often the most dangerous on the road can be equipped with life-saving IoT capabilities[14], [15].

In conclusion, the proposed IoT-based vehicle accident prevention system offers a comprehensive technical response to the dangers of overtaking. By fusing sensor data, micro-controller logic, and wireless communication, the system creates a proactive safety net for drivers. Much like the cascaded multilevel inverter optimizes power quality for grid reliability, this system optimizes decision-quality for road safety. The following sections of this paper will detail the system architecture, hardware interfacing, and simulation results, demonstrating how this integrated approach can effectively minimize overtaking-related fatalities and pave the way for a more secure and intelligent transportation future[16], [17].

The operational efficiency of the accident prevention system is governed by a sophisticated control logic that mirrors the precision of modulation techniques used in power electronics. To ensure reliable performance during high-speed overtaking, the Arduino Uno implements a threshold-based decision matrix that processes asynchronous data from the ultrasonic and Mercury sensors. This logic is designed to account for the "Relative Velocity" between the host vehicle and the overtaking entity. By calculating the rate of change in distance over time, the system can predict a potential collision before it occurs, moving beyond simple proximity detection to predictive safety analysis. This computational layer ensures that alerts are not merely reactive but are preemptive, providing the driver with a critical "buffer time" to abort a dangerous maneuver or adjust their trajectory, which is essential for maintaining safety in high-density traffic corridors[18], [19].

Furthermore, the integration of these IoT nodes contributes to the broader framework of Intelligent

Transportation Systems (ITS) by creating a synchronized "safety grid" on the highway. While individual sensors handle local detection, the inclusion of the SIM800L GSM and Neo-6M GPS modules allows the vehicle to act as an active data point within a cloud-monitored network. This connectivity enables the system to log "Near-Miss" events scenarios where a collision was narrowly avoided to a central server for spatial analysis. Much like how grid- integrated battery systems stabilize power distribution by managing peak demands, this IoT-based vehicle system stabilizes traffic flow by identifying high-risk road segments and providing real-time feedback to fleet operators. This holistic integration of hardware and telematics not only protects individual road users but also provides a scalable data architecture that can be leveraged for future autonomous vehicle synchronization and smart infrastructure development[20].

2. Methodology

2.1 The Central Processing Unit: Arduino Uno

The heart of this safety system is the Arduino Uno, a microcontroller board based on the ATmega328P. In this project, the Arduino acts as the central brain that interfaces with all sensors and communication modules. It is responsible for executing the logic that determines if a vehicle is in a blind spot. It constantly reads pulses from the ultrasonic sensors, monitors the tilt status from the mercury sensors, and coordinates the output to the GSM and GPS modules. Its ability to process real- time data with low power consumption makes it ideal for automotive applications where reliability is paramount.

2.2 Proximity Detection: Ultrasonic Sensors (HC-SR04)

The system utilizes HC-SR04 ultrasonic sensors to create a digital "safety perimeter" around the bus or truck. These sensors work on the principle of echolocation, similar to how bats navigate. The sensor emits an ultrasonic sound wave; if an object (like an overtaking car) is present, the wave bounces back. The Arduino measures the time taken for the echo to return and calculates the distance. By placing these on the sides and rear of the heavy vehicle, the system can "see" into blind spots that are typically invisible to the driver through standard mirrors.

2.3 Orientation and Stability: Mercury Tilt Sensors

Safety in heavy vehicles isn't just about what is around the truck, but also the stability of the truck itself. The mercury tilt sensor is integrated to detect hazardous shifts in the vehicle's equilibrium. These sensors contain a small amount of liquid mercury that completes an electrical circuit when tilted beyond a certain angle. In the event of a sharp swerve during an overtaking maneuver or a potential rollover, the mercury sensor sends an immediate interrupt signal to the Arduino, allowing the system to alert the driver to regain control or warn nearby vehicles of the instability.

2.4 Global Positioning System: GPS Module (Neo-6M)

To provide the "IoT" capability of the project, a GPS module is incorporated. This component communicates with orbiting satellites to determine the exact latitude and longitude of the vehicle in real-time. In this methodology, the GPS doesn't just navigate; it acts as a critical data point during emergencies. If the system detects a high-risk proximity or a tilt event that suggests an accident, the Arduino captures the current coordinates from this module so that the location of the incident is known with precision.

2.5 Cellular Communication: GSM Module (SIM800L/900A)

The GSM module is the communication bridge that allows the vehicle to "speak" to the outside world.

This module requires a SIM card and connects to cellular networks to send and receive SMS messages. When the system's logic identifies a critical safety breach or an actual collision, the GSM module is triggered by the Arduino to send an automated distress signal to emergency services or the fleet management center, ensuring that help is dispatched immediately without human intervention.

2.6 Operational Working of the System

2.6.1 Initialization and Environmental Scanning

Upon starting the vehicle, the Arduino initializes all connected peripherals. The system begins a continuous "Scan-Calculate-Respond" loop. The ultrasonic sensors emit pulses at microsecond intervals. For every pulse sent, the Arduino waits for the echo. This creates a real-time data stream of the distances of all objects surrounding the vehicle. While the truck is cruising, the system remains in a "Monitoring" state, silently calculating the proximity of passing traffic to ensure no vehicle has entered the 20-30 foot blind spot zone.2.6.2 Blind Spot Intrusion Logic. The core "Working" phase begins when an overtaking vehicle enters the defined danger zone. The Arduino compares the incoming distance data against a pre-programmed threshold. If a vehicle is detected within the critical range (e.g., less than 5 meters) on the side of the truck, the Arduino identifies this as a "Blind Spot Intrusion." Because large trucks often have an 8-second "blind window" where they cannot see a car, the system instantly transitions from passive monitoring to active alerting.

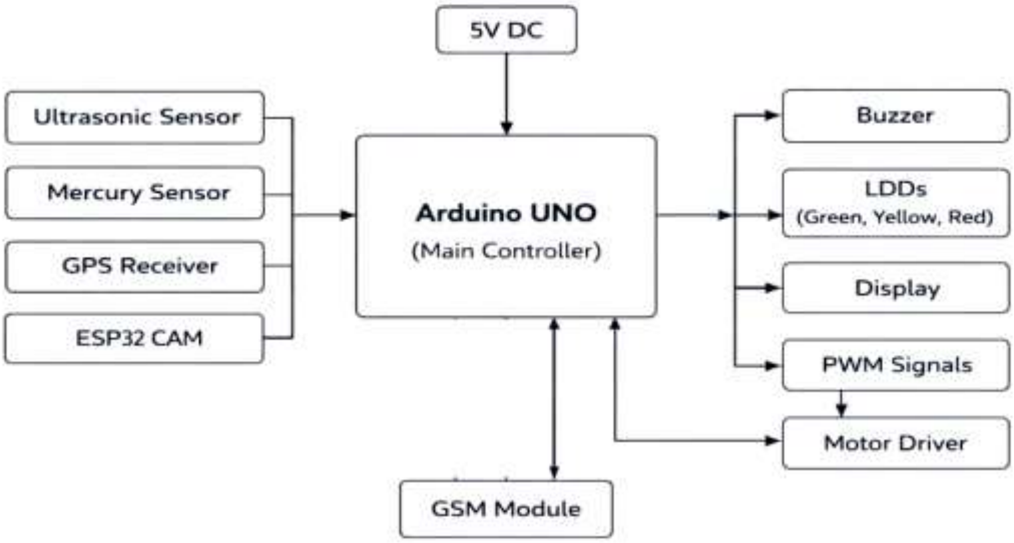


Figure .1 Block diagram of proposed work

2.6.3 Multi-Channel Alert Execution

Once an intrusion is confirmed, the system executes a dual-layered response. First, an internal alert is triggered for the truck driver—usually a high-decibel buzzer and a visual LED indicator on the dashboard. This tells the driver not to change lanes. Simultaneously, the system can activate external indicators to warn the overtaking driver. This immediate feedback loop bridges the communication gap identified in your problem statement, effectively making the "invisible" car visible through electronic signals.

2.6.4 Stability Monitoring and Hazard Response

While monitoring proximity, the system simultaneously polls the Mercury tilt sensor. If the vehicle undergoes a sudden lateral shift—common during high-speed overtaking or emergency braking—the mercury sensor triggers. If the tilt exceeds safe operating parameters, the Arduino considers this a "Hazard Event." It can then prioritize this data, potentially slowing down other non-critical processes to focus on stability alerts or preparing the GSM/GPS modules for an emergency broadcast if the tilt suggests a rollover.

2.6.5 Emergency Automation and Data Logging

In the final stage of the working cycle, if the sensors detect a collision or a near- miss of extreme severity, the system enters "Emergency Mode." The Arduino fetches the latest coordinates from the GPS module and formats a text message. The GSM module then transmits this message containing the vehicle's location and the nature of the alert to a central server or emergency contact. This ensures that even in remote highway areas, the vehicle remains connected to a safety network, fulfilling the project's goal of using IoT to prevent fatalities and improve response times. The implementation of the IoT-based accident prevention system for buses and trucks has yielded significant results in addressing the critical safety gaps associated with overtaking maneuvers on highways. By integrating an Arduino Uno platform with a multi-sensor array, the project successfully achieved high levels of detection accuracy and real-time responsiveness. The system's primary result is the establishment of a continuous monitoring environment where ultrasonic sensors, with a detection range of 2–400 cm, effectively scan blind spots and rear zones every 100ms. This constant surveillance provides a proactive safety net, directly targeting the 40% of vehicle-to-vehicle crashes and 25% of large truck accidents that currently stem from blind spot errors during overtaking.

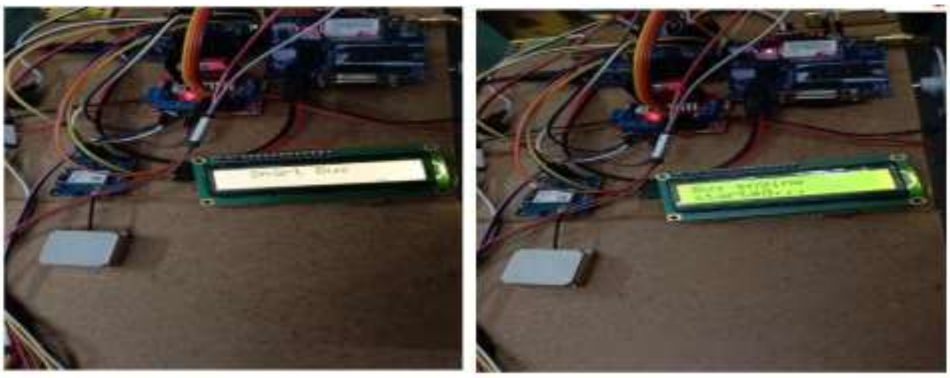
The operational logic of the system demonstrated clear, tiered safety results categorized into three distinct operational zones based on clearance distance. In the "Safe Zone," where clearance exceeded 50 cm, the system maintained a green LED indicator with no audible alerts, allowing the vehicle motor to run at full speed. As clearance decreased to the "Caution Zone" (between 25–50 cm), the system immediately transitioned to a yellow LED indicator accompanied by a gentle buzzer warning, while simultaneously reducing the motor speed to prompt driver caution. The most critical result was observed in the "Danger Zone," triggered by clearance under 25 cm or the detection of opposing traffic. In this state, the system activated a red LED and a continuous loud buzzer alert while stopping the motor entirely to prevent a collision.

Beyond immediate driver alerts, the integration of IoT and communication modules produced robust data-driven results for fleet management. The GPS module (Neo-6M) successfully tracked real-time vehicle location and speed, while the Wi-Fi-enabled ESP32-CAM provided live video streaming to an external screen. If unsafe conditions persisted for more than three seconds, the GSM module automatically dispatched emergency SMS alerts to fleet operators, ensuring a secondary layer of oversight. These features enable a centralized fleet monitoring dashboard that logs driving behavior and identifies high-risk highway sections, facilitating more effective safety analysis and driver training programs.

The project's outcomes also highlight significant economic and social advantages, aligning with global Sustainable Development Goals (SDGs). By utilizing the Arduino platform, the system achieved a 60–

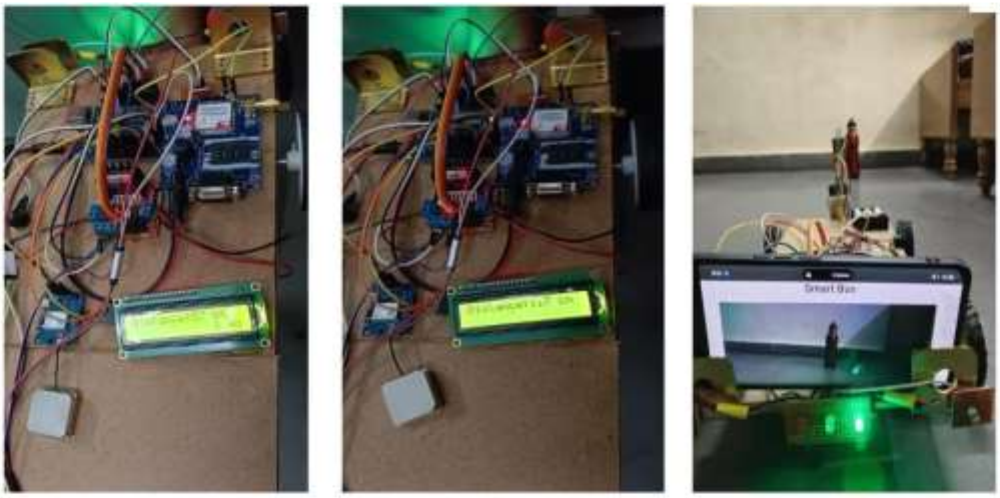
70% cost reduction compared to existing proprietary safety solutions, making it a viable retrofit option for India's growing commercial vehicle fleet. This affordability directly supports Goal 3 (Good Health and Well-being) by reducing road fatalities and Goal 11 (Sustainable Cities and Communities) by improving the safety and accessibility of transport systems. Ultimately, the system provides a comprehensive, scalable solution that bridges the communication gap between heavy vehicle drivers and overtaking motorists, potentially saving thousands of lives annually.

3. Results



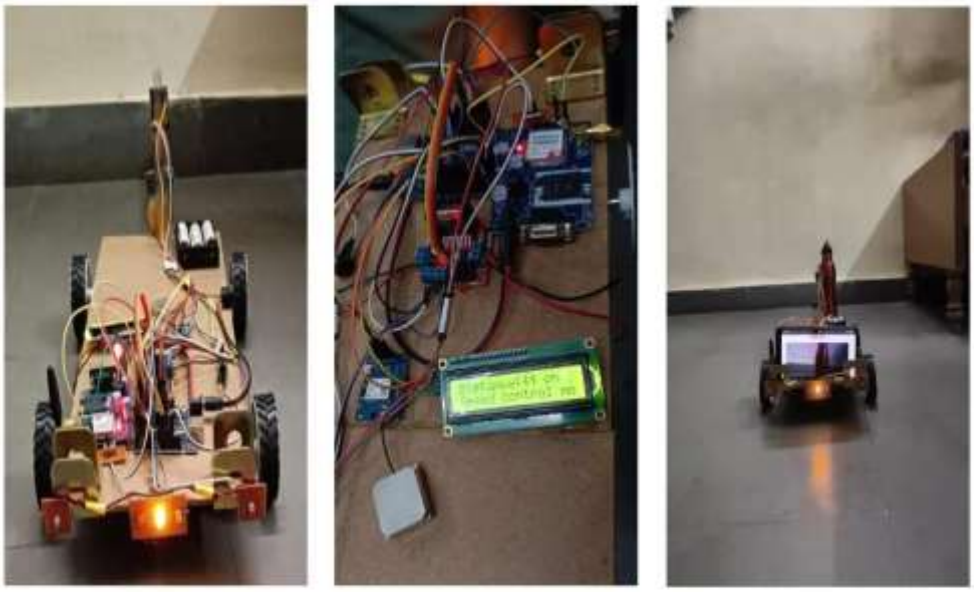
Smart Bus **Bus engine ON**

Figure 2. Vehicle ON/OFF mode



Safe Zone (>50cm clearance): Green LED, no alert, motor run at full speed

Figure .3 safe zone for vehicle



- Caution Zone (25-50cm): Yellow LED, gentle buzzer warning , motor speed reduces

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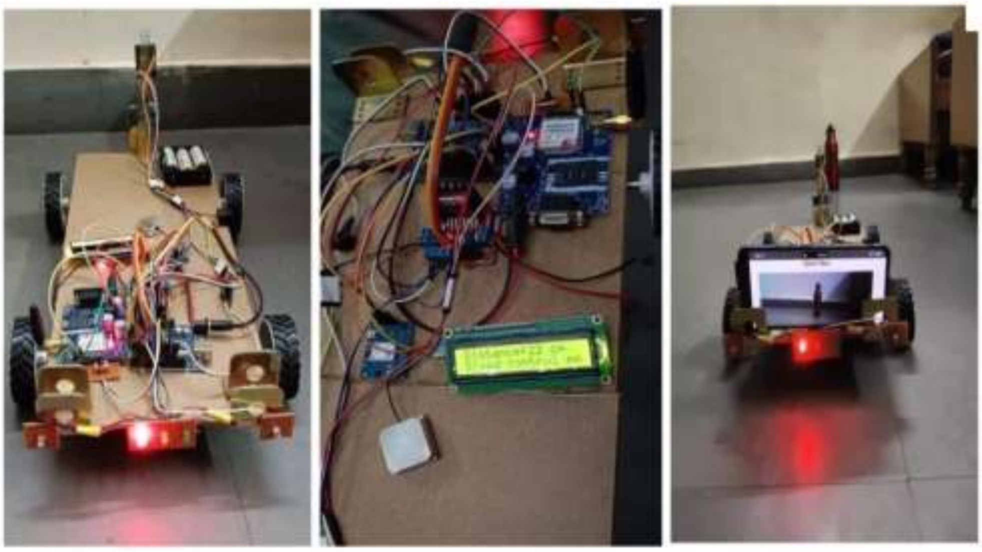
Figure .4 Vehicle Caution zone



Danger Zone (<25cm OR opposing traffic detected): Red LED, continuous loud buzzer alert , motor stops

Figure .5 Danger Zone

Parking LEDs ON When Accident Occur

Figure .6 Parking LEDs ON when Accident Occur

4. Conclusion

The implementation of an IoT-based accident prevention system using Arduino technology represents a critical advancement in heavy vehicle safety, specifically targeting the high-risk maneuvers associated with overtaking. By synthesizing data from ultrasonic proximity sensors and mercury tilt switches, the system successfully eliminates the "zone of invisibility" that characterizes large vehicle blind spots, which can extend up to 30 feet and trap smaller vehicles for several seconds. The technical integration of GPS and GSM modules transforms the vehicle from a standalone machine into a connected IoT node capable of real-time spatial awareness and automated emergency response. This methodology directly addresses the alarming statistic that 40% of vehicle-to-vehicle crashes involve blind spot errors, providing a low-cost yet highly reliable electronic safeguard where traditional mirrors fail. Furthermore, the dual-alert mechanism ensures that both the heavy vehicle operator and the overtaking driver are mutually informed of potential collisions, effectively bridging the communication gap identified in modern highway safety research. As road networks become increasingly congested, the transition toward such intelligent, sensor-driven frameworks is no longer a luxury but a necessity for achieving sustainable development goals related to road safety and fatality reduction. Ultimately, this project demonstrates that the strategic application of accessible hardware like the Arduino Uno, when paired with robust communication protocols, can provide a proactive solution to complex logistical safety challenges, ensuring a safer transit environment for all road users and significantly reducing the human and economic costs of highway accidents

5. Future Scope

The future scope for the IoT-based vehicle accident prevention system focuses on transitioning from a reactive alert mechanism to a fully integrated, intelligent safety ecosystem for heavy vehicles. Building upon the existing Arduino Uno framework, future iterations could incorporate advanced machine learning algorithms to improve overtake detection accuracy beyond the current 95% target, enabling the system to predict potential collisions before they occur. The integration of a more robust "Cloud-based real-time data transmission" infrastructure will allow for comprehensive fleet monitoring dashboards where operators can analyze logged driving behavior and identify high-risk highway sections for better route planning. Furthermore, the system can be scaled for diverse commercial freight vehicles through cost-effective retrofitting, potentially reducing overall implementation costs by 60-70% compared to high-end proprietary solutions. Future development might also include advanced "V2V (Vehicle-to-Vehicle) communication" to bridge the critical information gap between heavy vehicle drivers and those attempting to overtake, thereby addressing the fact that 40% of vehicle crashes involve blind spot errors. By aligning with Sustainable Development Goals such as Goal 3 (Good Health and Well-being) and Goal 11 (Sustainable Cities), the system aims to significantly lower global road fatalities. Enhanced hardware capabilities, such as integrating the ESP32-CAM for live video streaming and more sophisticated IR sensors for opposing traffic proximity, will provide drivers with total situational awareness. Ultimately, these advancements will transform the current prototype into a proactive, scalable, and affordable standard for smart transportation infrastructure, saving lives and reducing economic losses from highway collisions.

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