An Intelligent Driver Safety System for Heavy Commercial Vehicles: Real-Time Drowsiness Detection, Obstacle Avoidance, And Emergency Alerting Using Low-Cost Embedded Sensors

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***Abstract*—Driver fatigue and distraction remain leading causes of fatal accidents involving heavy commercial vehicles, including trucks and tankers. Existing safety systems predominantly rely on computer vision or passive warning mechanisms that are expensive, computationally intensive, and ineffective for retrofitting onto older diesel vehicles. This paper presents a low- cost, hardware-first driver safety system that integrates real- time drowsiness detection, obstacle-based speed regulation, driver presence verification, and emergency location alerting into a unified embedded platform. Using an Arduino UNO as the central controller, the system employs an infrared (IR) sensor for eye- blink monitoring, an ultrasonic sensor for continuous distance measurement, a force-sensitive resistor (FSR) for driver presence validation, and GPS-GSM modules for automated emergency communication. The system implements a 5-second no-blink threshold to classify drowsiness, triggering audible and vibratory alerts while simultaneously reducing motor speed. For obstacle avoidance, a linear PWM-based speed mapping function adjusts vehicle velocity inversely to detected distance. When critical conditions arise, the GSM module transmits SMS alerts containing live Google Maps location data. Experimental results demonstrate 100% drowsiness detection accuracy at the 5-second threshold, linear distance-to-speed mapping with ±5% variance, and 94% SMS delivery success rate. The total system cost is under $50, making it suitable for widespread deployment across existing commercial vehicle fleets. Unlike vision-dependent or alert-only solutions, this work offers a retrofittable, tamper-proof safety system for both mechanical and ECU-controlled diesel trucks.**

***Index Terms*—Driver drowsiness detection, obstacle avoidance, active speed control, Arduino UNO, ultrasonic sensor, IR sensor, GPS-GSM module, diesel truck safety, retrofittable safety system, embedded systems, commercial vehicles.**

I. INTRODUCTION

A. Background and Motivation

Road traffic accidents claim approximately 1.35 million lives annually worldwide, with commercial vehicles accounting for a disproportionate share of fatal collisions. According to the World Health Organization, driver fatigue alone con- tributes to nearly 40% of fatal truck collisions due to extended driving hours, limited rest periods, and monotonous high- way conditions [1]. The economic impact of these accidents exceeds $500 billion annually in lost productivity, vehicle damage, and healthcare costs.

The rapid growth of logistics and freight transportation has intensified the need for effective driver safety solutions. Heavy commercial vehicles including trucks, tankers, and buses present unique safety challenges due to their longer stopping distances, reduced maneuverability, and the severe consequences of collisions. Traditional safety approaches rely on periodic rest mandates, post-accident telematics, or expensive camera-based systems that are difficult to retrofit onto older vehicles.

B. Problem Statement

Existing driver safety systems suffer from three fundamental limitations. First, vision-based drowsiness detection requires high-resolution cameras and significant computational resources, making them expensive ($200-500) and impractical for older diesel trucks lacking electronic control units (ECUs). Second, most collision avoidance systems provide only audible warnings rather than active speed intervention, allowing drivers to ignore alerts. Third, commercial telematics systems track vehicles passively but lack real-time driver state monitoring and active safety responses.

C. Research Contributions

This paper presents a driver safety system with five key contributions:

1) A hardware-first approach using commodity sensors (IR, ultrasonic, FSR, GPS, GSM) achieving real-time safety monitoring at under $50 total cost
2) Active speed control coupling drowsiness detection to automatic speed limitation using PWM-based motor actuation, enabling intervention rather than just warning
3) A retrofittable, tamper-proof design suitable for diesel trucks with both mechanical and electronic fuel injection systems
4) Integrated GPS-GSM emergency response that completes the safety loop from prevention → alert → location sharing
5) Experimental validation of all subsystems with quantitative performance metrics

II. RELATED WORK

A. Driver Fatigue and Drowsiness Detection

The study of driver fatigue has evolved considerably from subjective self-reporting to objective sensor-based monitoring. Khan and Lee [1] provided a comprehensive review of driver monitoring technologies, highlighting the transition from rule-based to learning-based approaches. Their analysis indicated that commercial driver fatigue contributes to 20-30% of all road accidents.

Chauhan et al. [2] examined vision and machine learning techniques for identifying driver behavior patterns, demonstrating that facial feature extraction achieves 85-95% accuracy but requires significant computational resources (minimum 2GB RAM, 1.2GHz processor). This computational requirement makes vision-based systems impractical for low-cost embedded platforms.

Recent research has extended fatigue detection to embedded platforms using non-vision sensors. Wang et al. [4] studied eye-movement and blink-pattern analysis using low-resolution infrared cameras, achieving 89% accuracy in controlled set- tings. However, their system still required a dedicated camera module and image processing.

Lobo et al. [5] proposed a real-time drowsiness detection system based on eye closure duration using a single IR reflective sensor, implementing the PERCLOS (Percentage of Eye Closure) metric on an Arduino platform. This work demonstrated that simple IR sensors can effectively detect drowsiness without cameras, establishing the foundation for our approach. The PERCLOS metric measures the proportion of time that the eyes are closed over a specific period. When the eyes remain closed for more than 5 consecutive seconds, the driver is classified as drowsy.

B. Drowsiness Detection Using IR Sensors

The infrared sensor used in this work (TCRT5000) operates by emitting infrared light and measuring the reflected signal. When the eye is open, the cornea reflects IR light back to the sensor, producing a LOW output. When the eyelid closes, the reflection is significantly reduced, producing a HIGH output. This binary detection method is computationally trivial, requiring no image processing or feature extraction.

The 5-second threshold was selected based on human fac- tors research. The average blink duration is 100-400 milliseconds. Eye closures exceeding 1 second indicate microsleep episodes. The 5-second threshold conservatively detects significant drowsiness while avoiding false positives from normal blinking, yawning, or eye rubbing.

C. Collision Avoidance Technologies

Ultrasonic, radar, and LiDAR-based sensing have demonstrated effective front-vehicle detection in automotive applications. Research shows that ultrasonic sensors, despite limited range (typically 2-4 meters), offer distinct advantages: low cost ($3-5 per sensor), weather independence, simple signal processing, and minimal computational requirements.

Haig and Weibelzahl [15] established foundational evidence that distance-based speed regulation can prevent collisions without requiring complex computer vision. However, their work focused on warning systems rather than active speed control.

D. GPS-GSM Integration for Emergency Response

GPS and GSM-based tracking systems are widely studied for fleet monitoring and stolen vehicle recovery. However, literature reveals limited integration between monitoring and active vehicle control. Most commercial telematics systems provide passive tracking without real-time alerting based on driver state or obstacle conditions.

E. Research Gap

While existing studies individually address driver monitoring, obstacle detection, communication, or engine control, there remains a notable research gap in combining real-time driver state analysis, environment sensing, speed control, and emergency alerting into a single low-cost, retrofittable system. Table I summarizes the comparison.

TABLE I COMPARISON WITH EXISTING SYSTEMS

Feature	Proposed	Vision-based	Alert-only	Telematics
Low cost (¡$50)	Yes	No	Yes	No
Active speed control	Yes	Rare	No	No
No camera required	Yes	No	Yes	Yes
Real-time alerts	Yes	Yes	Yes	Delayed
Retrofittable	Yes	Limited	Yes	Limited
ECU-independent	Yes	Yes	Yes	No
SMS location sharing	Yes	Optional	No	Yes
Drowsiness detection	Yes	Yes	No	No

III. SYSTEM ARCHITECTURE

A. Overall System Design

The proposed system integrates four coordinated modules controlled by an Arduino UNO. The four modules are:

1) Driver Presence Module: Force Sensitive Resistor (FSR) mounted on driver seat
2) Obstacle Detection Module: HC-SR04 ultrasonic sensor for distance measurement
3) Drowsiness Monitoring Module: TCRT5000 IR sensor for eye-blink detection
4) Emergency Alert Module: NEO-6M GPS and SIM800L GSM for location-based alerts

B. Hardware Components

Table II presents the complete hardware configuration.

TABLE II HARDWARE COMPONENTS AND SPECIFICATIONS

Component	Model	Specifications
Microcontroller	Arduino UNO	ATmega328P, 16MHz, 32KB Flash
Ultrasonic Sensor	HC-SR04	Range: 2-400cm, Accuracy: ±3mm
IR Sensor	TCRT5000	Detection range: 1-25cm, Digital output
Force Sensor	FSR 402	Range: 0.1-10kg, Analog output
GPS Module	NEO-6M	50 channels, Update rate: 1Hz
GSM Module	SIM800L	Quad-band, SMS support
Motor Driver	L298N	Dual H-bridge, PWM support
DC Motor	12V 100RPM	Speed control via PWM
Buzzer	5V Passive	2.5kHz resonant frequency
Vibration Motor	3V Coin-type	10,000 RPM

IV. METHODOLOGY

A. Problem Formulation

The system must satisfy the following requirements:

1) Detect driver presence before system activation
2) Measure obstacle distance continuously (0-400cm range)
3) Control motor speed based on distance measurement
4) Detect drowsiness when eye closure exceeds 5 seconds

5) Generate audible and haptic alerts upon drowsiness detection
6) Send SMS with GPS location during emergency conditions.
7) Complete all operations with latency under 200ms

B. Mathematical Model

The distance measurement using ultrasonic sensor is given by:

$$d = \frac{t \times v}{2} \quad (1)$$

where t is the echo return time (seconds) and v = 34300cm/s is the speed of sound at $20^{\circ}C$.

The speed control function maps distance to PWM value:

$$S(d) = \begin{cases} 0 & \text{if } d \leq d_{min} \\ 255 \times \frac{d - d_{min}}{d_{max} - d_{min}} & \text{if } d_{min} < d < d_{max} \\ 255 & \text{if } d \geq d_{max} \end{cases} \quad (2)$$

where d_{min} = 5 cm and d_{max} = 50 cm.

C. Driver Presence Detection

The FSR 402 sensor outputs analog voltage proportional to applied force. The Arduino ADC converts this to a 10-bit digital value (0-1023). The system is activated when:

$$\text{System Active} = \begin{cases} 1 & \text{if } ADC_{FSR} > 150 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

This threshold corresponds to approximately 2kg of force, ensuring the system only activates when a driver is properly seated.

D. Drowsiness Detection Algorithm

The IR sensor monitors eye-blink activity through reflected infrared light. The sensor outputs: - LOW (0): Eye open (IR reflected by cornea) - HIGH (1): Eye closed (reduced reflection)

The drowsiness detection algorithm follows these steps:

1) Initialize eyeClosed = False, closeStart = 0
2) Read IR sensor value continuously
3) If eye closed and not previously closed, record start time
4) If eye closed continuously for 5000ms, trigger drowsiness alert
5) Upon alert: activate buzzer, activate vibration motor, set motor speed to 0, send emergency SMS
6) Reset detection when eye opens

This 5-second threshold was selected based on the PERC- LOS metric. Normal blinks last 100-400ms. Eye closure exceeding 1 second indicates microsleep. The 5-second threshold conservatively detects significant drowsiness while avoiding false positives from normal blinking.

E. Active Speed Control

The system implements proportional speed control:

$$\text{MotorSpeed} = \begin{cases} 0 & \text{if distance} \leq 5\text{cm} \\ 255 \times \frac{\text{distance} - 5}{50 - 5} & \text{if } 5 < \text{distance} < 50\text{cm} \\ 255 & \text{if distance} \geq 50\text{cm} \end{cases} \quad (4)$$

This linear mapping ensures smooth deceleration as obstacles approach, preventing abrupt stops that could cause cargo shift or following vehicle collisions.

F. GPS and GSM Integration

The NEO-6M GPS module provides location data in NMEA format. The system attempts GPS fix for 5 seconds; if unsuccessful, default coordinates are used. The GSM module sends SMS using AT commands:

AT+CMGF=1 // Set SMS text mode
AT+CMGS="+91XXXXXXXXXX" // Set recipient numb [Message content] + Google Maps URL
Ctrl+Z // Send SMS

G. Arduino Implementation

```
#include <SoftwareSerial.h>
#include <TinyGPS++.h>

#define TRIG_PIN 4
#define ECHO_PIN 5
#define IR_PIN 7
#define FSR_PIN A0
#define IN1 9
#define BUZZER_PIN 10
#define VIBRATION_PIN 11
#define MIN_DISTANCE 5
#define MAX_DISTANCE 50
#define DROWSY_THRESHOLD 5000

SoftwareSerial gpsSerial(2, 3);
TinyGPSPlus gps;

long duration;
int distance, motorSpeed, eyeClosed = 0;
```

```
unsigned long closeStartTime = 0;
int systemActive = 0;

void setup () {
pinMode(TRIG_PIN, OUTPUT);
pinMode(ECHO_PIN, INPUT);
pinMode(IR_PIN, INPUT);
pinMode(FSR_PIN, INPUT);
pinMode(IN1, OUTPUT);
pinMode(BUZZER_PIN, OUTPUT);
pinMode(VIBRATION_PIN, OUTPUT);
Serial.begin(9600);
gpsSerial.begin(9600);
}

void loop() {
int fsrValue = analogRead(FSR_PIN);

if (fsrValue > 150) {
if (!systemActive) systemActive = 1;
measureDistance();
applySpeedControl();
checkDrowsiness();
checkEmergencyConditions();
} else {
if (systemActive) {
systemActive = 0;
motorSpeed = 0;
analogWrite(IN1, motorSpeed);
}
}
delay(100);
}

void measureDistance() {
digitalWrite(TRIG_PIN, LOW);
delayMicroseconds(2);
digitalWrite(TRIG_PIN, HIGH);
delayMicroseconds(10);
digitalWrite(TRIG_PIN, LOW);
duration = pulseIn(ECHO_PIN, HIGH);
distance = duration * 0.034 / 2;
}

void applySpeedControl() {
if (distance <= MIN_DISTANCE) {
motorSpeed = 0;
} else if (distance >= MAX_DISTANCE) {
motorSpeed = 255;
} else {
motorSpeed = map(distance, MIN_DISTANCE, MAX_DISTANCE, 0, 255);
}
analogWrite(IN1, motorSpeed);
}

void checkDrowsiness() {
if (digitalRead(IR_PIN) == HIGH) {
if (!eyeClosed) {
eyeClosed = 1;
closeStartTime = millis();
} else if (millis() - closeStartTime >= DROWSY_THRESHOLD) {
activateAlerts();
motorSpeed = 0;
analogWrite(IN1, motorSpeed);
sendEmergencySMS();
}
} else {
eyeClosed = 0;
}
}

void activateAlerts() {
digitalWrite(BUZZER_PIN, HIGH);
delay(3000);
digitalWrite(BUZZER_PIN, LOW);
for (int i = 0; i < 10; i++) {
digitalWrite(VIBRATION_PIN, HIGH);
delay(500);
digitalWrite(VIBRATION_PIN, LOW);
delay(500);
}
}
```

V. EXPERIMENTAL RESULTS

A. Experimental Setup

The prototype was tested under controlled laboratory conditions:

- Distance range: 5cm to 150cm (50 trials)
- IR blink simulation: Manual eyelid closure (5 test sub- jects, 10 trials each)
- GPS testing: Outdoor line-of-sight conditions (50 trials)
- GSM testing: Cellular network coverage area (50 SMS transmissions)

B. Distance Measurement Results

Table III presents the distance-to-speed mapping results.

TABLE III DISTANCE-TO-SPEED MAPPING RESULTS

Distance (cm)	Theoretical Speed	Measured Speed
< 5	0	0
5	0	0
10	28	26-30
15	57	55-59
20	85	82-88
25	114	110-118
30	142	138-146
35	171	168-174
40	199	195-203
45	228	224-232
50	255	255
> 50	255	255

The measured speed values fell within ±5% of theoretical values, confirming reliable PWM control.

C. Drowsiness Detection Results

Table IV summarizes drowsiness detection performance.

TABLE IV DROWSINESS DETECTION RESULTS

Test Condition	Detections	Success Rate
Normal blinking (10 sec)	0/5	100% (no false positive)
Eyes closed 3 sec	0/5	100%
Eyes closed 5 sec	5/5	100%
Eyes closed 7 sec	5/5	100%
Rapid blinking	0/5	100%

The system achieved 100% detection accuracy at the 5- second threshold with zero false positives.

D. GPS and SMS Performance

- GPS Fix Time: Average 18 seconds (open sky), 45 seconds (urban canyon)
- SMS Delivery Success: 94% (47/50 transmissions)
- Average SMS Delivery Time: 4.2 seconds
- Location Accuracy: ±5 meters (GPS), ±20 meters (de- fault)

E. System Response Time

Table V presents end-to-end latency measurements.

TABLE V SYSTEM RESPONSE TIME ANALYSIS

Operation	Average Time
Ultrasonic measurement	40 ms
Speed calculation & PWM update	5 ms
Drowsiness detection cycle	100 ms
Alert activation	10 ms
GPS acquisition (warm start)	18 seconds
SMS transmission	4.2 seconds
Control loop latency	<150 ms

F. Cost Analysis

Table VI presents the bill of materials.

TABLE VI BILL OF MATERIALS

Component	Cost (INR)
Arduino UNO HC-SR04 Ultrasonic TCRT5000 IR Sensor FSR 402 NEO-6M GPS SIM800L GSM L298N Motor Driver DC Motor + Wheel Buzzer + Vibration Motor Miscellaneous	1,500 200 150 350 1,200 1,500 300 400 100 300
Total Bulk Production Cost	6,000 INR ($72) 2,500 INR ($30)

G. Comparative Performance

Table VII compares our system with existing approaches.

TABLE VII PERFORMANCE COMPARISON

Metric	Proposed	Vision-based	Alert-only
Detection Accuracy	100%	85-95%	N/A
False Positive Rate	0%	5-15%	N/A
Response Time	<150ms	200-500ms	>1s
Cost	$30-70	$200-500	$20-50
Power Consumption	200mA	500mA+	100mA
Camera Required	No	Yes	No
ECU Integration	Optional	Required	No

VI. DISCUSSION

A. Key Findings

The experimental results demonstrate three key findings. First, simple IR sensors can effectively detect driver drowsiness without cameras, achieving 100% accuracy at the 5- second threshold. This finding challenges the assumption that vision-based systems are necessary for reliable fatigue detection.

Second, proportional speed control using PWM provides smooth, predictable vehicle deceleration as obstacles approach. The linear mapping function eliminates abrupt braking events that could cause cargo shift or following collisions.

Third, the integration of local safety control with GPS- GSM emergency alerting creates a complete safety loop: detection → intervention → notification. This closed-loop approach ensures that even if the driver becomes incapacitated, assistance can be dispatched to the exact location.

B. Advantages Over Existing Systems

The proposed system offers three distinct advantages:

1) Cost Advantage: At $30-70 for prototype and $30 for bulk production, the system is significantly cheaper than vision-based alternatives ($200-500).
2) Retrofitability: The system operates independently of the vehicle's native ECU, requiring only 12V power.
3) Robustness: Unlike camera-based systems affected by lighting conditions, the IR and ultrasonic sensors function reliably in darkness, direct sunlight, and adverse weather.

C. Limitations

Several limitations warrant acknowledgment:

1) IR sensor requires precise alignment with the driver's eye
2) Ultrasonic range limited to 4 meters, insufficient for highway-speed braking
3) GPS-dependent for location services
4) System does not accommodate driver changes during a trip
5) Current prototype lacks data logging for fleet management

VII. FUTURE WORK

Several enhancements are planned:

1) Camera-based AI: Add low-cost ESP32-CAM with lightweight CNN for eye tracking, yawning detection, and head position analysis using TensorFlow Lite Micro
2) Adaptive Cruise Control: Extend to full speed control integrated with vehicle braking systems using PID control
3) Fleet Management Dashboard: Mobile application for owners to view live data, vehicle speed, location, and driver drowsiness history
4) Data Logging: SD card module to store drowsiness events and driving patterns for driver behavior analysis
5) Additional Sensors: Integrate alcohol detection (MQ- 3), lane departure warning, cabin temperature monitoring (DHT11), and heart rate monitoring (MAX30100)

VIII. CONCLUSION

This paper presented a low-cost, retrofittable driver safety system that integrates real-time drowsiness detection, obstacle- based speed control, driver presence verification, and GPS- GSM emergency alerting on an Arduino UNO platform. The system successfully demonstrates that commodity sensors can achieve reliable safety monitoring without expensive cameras or complex AI models.

The experimental results validate the system's effectiveness:

1) 100% drowsiness detection accuracy at the 5-second threshold with zero false positives
2) Linear distance-to-speed mapping with ±5% variance
3) 94% SMS delivery success rate with 4.2-second average delivery time
4) Total system response time under 150ms for control loop operations
5) Prototype cost of $72 (production cost under $30)

The system addresses a critical gap in commercial vehicle safety by providing active speed intervention rather than passive warnings, ECU-independent operation for retrofit applications, and complete safety loop from detection to notification.

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