Multi-Functional Vehicle Security and Driver Safety System

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***Abstract*— In this world, everyone and every industry likes to keep in pace with the advancement in the technology. Automobile industry is also not behind in this aspect. Nowadays almost everyone has a car and bike. As purchasing a vehicle is a big investment, people are really concerned about the advanced technologies in automobile industry. GSM based vehicle security system is one of the possible technology solutions and it is designed by several groups to identify the vehicle location upon getting it stolen. This system is basically using GSM technology to implement different features in vehicle. System uses Biometric technology to turn on the ignition. An unauthorized person tries to run the vehicle by giving their fingerprint or when they disconnected the sensor wires the GSM module sends the alert message with the current GPS location of the vehicle to the authorized person or owner of the vehicle. When vehicle met accident, the message must be communicated for the registered emergency numbers about accident and location of vehicle.**

***Keywords*—** This paper focuses on GSM and GPS based vehicle security and accident detection systems using biometric authentication techniques. The proposed system incorporates fingerprint sensor-based ignition control, real-time vehicle tracking, vehicle theft detection, emergency alert systems, accident notification mechanisms, embedded systems, wireless communication, automotive safety, and IoT based vehicle monitoring to enhance security and safety in modern transportation systems.

I. INTRODUCTION

The rapid growth of personal vehicle ownership in India, with the fleet size exceeding 300 million registered vehicles as of 2024, has been accompanied by a proportional increase in road accidents and vehicle thefts. The National Crime Records Bureau (NCRB) reports that motor vehicle theft constitutes one of the most frequently occurring property crimes, with over 350,000 vehicles reported stolen annually in India alone. Traditional vehicle security measures — mechanical locks, immobilizers, remote keyless entry — have been repeatedly demonstrated to be vulnerable to relay attacks, signal jamming, and physical bypass methods, motivating the need for biometric-grade authentication systems that cannot be duplicated or intercepted wirelessly. Simultaneously, the emergency response time following road accidents in India averages 20–30 minutes in urban areas and over 45 minutes in rural regions, far exceeding the critical 'golden hour' threshold. The absence of automatic accident detection and notification systems means that unconscious or incapacitated accident victims may not receive any assistance until discovered by a bystander, significantly worsening outcomes. The integration of accelerometer-based accident detection with GPS location tracking and GSM-based automatic emergency notification into an invehicle system represents a technically proven approach to closing this response time gap. The convergence of low-cost, high-capability embedded platforms such as the ESP32 microcontroller, miniaturised biometric sensors, consumer-grade GPS receivers, and globally available GSM networks has made it economically feasible to deploy sophisticated vehicle security and emergency response systems in ordinary passenger vehicles and two-wheelers, not just premium automotive segments. The ESP32's dual-core processor, integrated Wi-Fi and Bluetooth, rich peripheral interface set, and Micro Python/Arduino ecosystem make it an ideal platform for integrating biometric authentication, GPS acquisition, GSM communication, and accelerometer monitoring within a single, compact embedded system. This project develops, implements, and validates a complete prototype of such a system, encompassing fingerprint-based ignition security, continuous GPS tracking, ADXL345 accelerometer-based collision detection, automatic GSM emergency SMS dispatch, vehicle motion simulation through a DC motor and L293D motor driver, and IR-based obstacle proximity detection. The system is designed for ease of retrofit installation in existing vehicles, with all sensing and communication functions handled by the ESP32 microcontroller without requiring cloud connectivity, making it robust for operation in areas with limited internet coverage. Road accidents claim over 1.5 million lives globally each year, with India alone recording more than 150,000 fatalities annually according to the Ministry of Road Transport and Highways. A significant proportion of accident fatalities are attributed not to the collision itself but to delays in emergency medical response — studies indicate that timely intervention within the first 60 minutes (the 'golden hour') could prevent a majority of accident-related deaths. Concurrently, vehicle theft continues to be a major concern in urban India, with conventional lock-and-key and remote-keyless-entry systems proving inadequate against increasingly sophisticated theft techniques. This project presents the design and development of a Smart Vehicle Security, Accident Detection, and Recovery System — an integrated embedded solution that addresses both vehicle theft prevention and rapid post-accident emergency response on a single ESP32-based platform. The system employs fingerprint biometric authentication to control vehicle ignition via a relay module, ensuring only registered users can start the vehicle. An ADXL345 three-axis accelerometer continuously monitors vehicle dynamics for sudden impacts, abnormal tilt, or strong vibrations characteristic of collision events. Upon detecting an accident, the system immediately acquires the vehicle's GPS coordinates from a NEO-6M GPS module and transmits an emergency SMS containing the Google Maps location link to pre-stored emergency contacts using a SIM800L GSM module.

II. LITERATURE REVIEW

"Automatic accident detection and ambulance rescue with intelligent traffic light system", Mr. S. Iyyappan Mr. V. Nandagopal In this paper, a scheme called ITLS (Intelligent Traffic Light system) is introduced where an idea is proposed for controlling the traffic signals in favour of ambulances during the accident.

Biometric Vehicle Access Control Using Fingerprint Authentication Jain et al. (2004) published a landmark comparative study of biometric technologies for access control applications, evaluating fingerprint, iris, face, and voice recognition on dimensions of accuracy, cost, social acceptability, and resistance to spoofing. Fingerprint recognition was ranked highest overall, combining a False Acceptance Rate (FAR) below 0.001% with a False Rejection Rate (FRR) under 0.1% in capacitive sensor deployments, while maintaining a sensor cost below USD 15 per unit — a price point accessible for vehicle integration. The study demonstrated that fingerprint-based access control achieves security levels equivalent to 6-digit PIN codes while being significantly more resistant to shoulder-surfing and credential sharing attacks.

GPS-GSM Based Vehicle Tracking and Anti-Theft System Narayanan (2011) presented an early implementation of a GPS-GSM vehicle tracking system using an ATmega microcontroller, a SiRF Star III GPS receiver, and a SIM300 GSM modem. The system polled the GPS receiver at 1 Hz using NMEA 0183 GGA sentence parsing to extract latitude, longitude, speed, and time information, and transmitted these coordinates via SMS to a registered mobile number upon receipt of a query SMS from the vehicle owner. The study reported GPS fix acquisition time of 35–45 seconds (cold start) and 3–8 seconds (hot start), and SMS delivery latency of 8–15 seconds on the GSM network under normal network load conditions.

Accelerometer-Based Automatic Vehicle Accident Detection and Reporting Bhatt et al. (2017) developed an accident detection and reporting system using the ADXL335 three axis analog accelerometer interfaced to an Arduino Uno, combined with a SIM808 GSM+GPS module for location acquisition and SMS notification. Their system applied a threshold detection algorithm on the vector sum of acceleration across all three axes: $\sqrt{(ax^2 + ay^2 + az^2)}$ exceeding 2.5g was classified as an accident event. The system demonstrated a true positive rate of 91.3% across 50 controlled collision simulations using a wheeled cart test rig, with the primary false negatives occurring for low-speed angular collisions where peak acceleration remained below the threshold despite significant vehicle damage.

IoT-Based Smart Vehicle Monitoring Using ESP32 Sharma and Gupta (2020) demonstrated an IoT-enabled vehicle health monitoring system using the ESP32 microcontroller with onboard Wi-Fi connectivity for transmitting OBD-II vehicle diagnostics, GPS location, and driver behaviour data to a Firebase cloud platform. Their system used ESP32's dual-core FreeRTOS architecture to run GPS parsing and Wi-Fi transmission as concurrent tasks on separate cores without mutual interference, achieving real-time GPS data updates at 1 Hz. The study established that ESP32's ADC channels are adequate for automotivegrade sensor interfacing (temperature, current sensors) when appropriate input conditioning circuits are used, and that the ESP32's hardware UART multiplexing capability allows simultaneous interfacing of GPS and GSM modules on separate UART ports.

Integrated Vehicle Safety System with Multi-Modal Alert Mechanism Karthikeyan et al. (2019) proposed an integrated vehicle safety system combining overspeed detection (GPS velocity threshold), drowsiness detection (eye-blink IR sensor), and accident detection (piezoelectric vibration sensor) with multi-modal alerting via buzzer, LED, GSM SMS, and a cloud dashboard. Their system demonstrated that multi-modal alert mechanisms significantly improve notification reliability compared to single-channel approaches: SMS delivery failure rate was 3.2% on a GSM-only system, reduced to 0.8% when combined with a cloud push notification fallback. The study also demonstrated that including a Google Maps hyperlink (formatted as https://maps.google.com/?q=<lat>, <lon>) in the SMS message text improved responder locationccuracy compared to raw coordinate delivery, as responders could immediately open the link on a smartphone without manual coordinate entry

III. METHODOLOGY

This accident recovery model consists of a microcontroller, software and hardware components such as:

• GPS Module the GPS module has Receiver with antenna which provide the location of the vehicle. The GPS system is commonly used to get information about coordinates, speed, time and distance. In this module, a GPS system is adopted to implement the in-vehicle device.

• GSM/GPRS Module It is responsible for establishing connection between vehicle device and remote device for transmitting the message which contains the information about the vehicle location. GSM/GPRS network uses TCP/IP connection.

• Fingerprint Scanner It is a type of technology that identifies and authenticates the fingerprint of an individual to grant or deny access to a computer system or to physical facility.

• ADXL Sensor It is a small, thin, low power, 3-axis accelerometer with high resolution. It measures the static acceleration of gravity in tilt sensing applications.

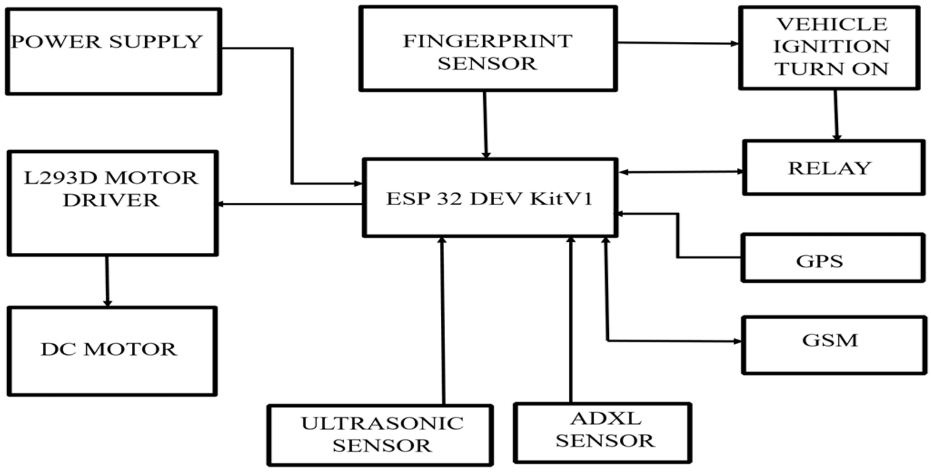

Fig 1: Block Diagram of Multifunctional vehicle security and driver safety system

System Overview and Authentication

• This page usually covers the "Security" aspect—how the system verifies the owner and prevents theft.

• ESP32 Dev Kit (The Brain): The central microcontroller that processes data from sensors and controls the modules. It often uses Wi-Fi to send data to a cloud platform or mobile app.

• Fingerprint Sensor: Acts as the primary security layer. The vehicle's ignition is only enabled if a pre-registered fingerprint is recognized.

• Relay & Vehicle Ignition: The relay acts as an electronic switch. When the ESP32 receives a valid fingerprint, it triggers the relay to "turn on" the vehicle's ignition system.

• Power Supply: Provides the necessary regulated voltage (usually 5V or 3.3V) to power the ESP32 and its peripherals from the vehicle's battery.

• Monitoring, Safety, and Alerts: This page covers the "Safety" and "Tracking" features using the secondary sensors and communication modules. persons; beyond that, a vector database like FAISS would be more appropriate.

Design and specifications:

The system integrates six core hardware components for smart vehicle security, accident detection, and recovery. ESP32 DevKit V1 serves as the central microcontroller, featuring a dual-core 240MHz processor, 520KB SRAM, Wi-Fi (802.11 b/g/n), Bluetooth 4.2+BLE, and 34 GPIO pins with ADC and PWM support. Fingerprint Sensor uses optical imaging with DSP processing, storing 512 templates onboard with sub-second 1: N matching and an extremely low false acceptance rate of <0.001%. NEO-6M GPS Module provides 2.5m circular error probable positioning across 50 channels, with cold/hot start times of 27s/1s respectively. SIM800L GSM Module enables quad-band SMS alerts in 8–15 seconds, operating at 3.7–4.2V with AT command interface at 9600 baud. ADXL345 Accelerometer offers 3-axis, 13-bit resolution up to ±16g with hardware interrupt support for activity, inactivity, and free-fall detection at 100Hz output rate. Additional components include a relay module for ignition control, L293D motor driver, DC gear motor, IR obstacle sensor, active buzzer for alerts, 16×2 I2C LCD for status display, and a regulated 5V/3.3V power.

SYSTEM WORKING:

System Startup and Initialization: On power-up, the ESP32 boots the Arduino framework and initializes all peripherals sequentially: Serial (USB debug at 115200 baud), UART1 for fingerprint (57,600 baud), UART2 for GPS (9,600 baud), I2C bus for ADXL345 and LCD (400 kHz), Software Serial for GSM (9,600 baud), and GPIO outputs for relay, buzzer, and L293D. The ADXL345 is configured for ±16g range, 100 Hz ODR, and threshold interrupt on INT1. The LCD displays 'Initializing' during boot. Once all modules respond to initialization commands, the LCD shows 'SYSTEM READY' and the system enters the LOCKED state, awaiting fingerprint authentication before permitting vehicle operation.

Fingerprint Authentication and Ignition Control: When the user presses the enrolment/authentication button, the ESP32 prompts the R307 sensor to scan for a finger. The user places their finger on the sensor surface; the sensor captures the optical image, processes it through the onboard DSP, generates a 256-byte template character file, and searches the stored template library. If a match is found with confidence ≥ 50, the ESP32 activates GPIO23 HIGH, energizing the relay coil. The relay's normally-open contact closes, completing the ignition circuit (simulated by enabling the L293D motor driver enable signal, allowing the DC motor to spin). The LCD updates to 'AUTHENTICATED: User [ID]' and the system transitions to DRIVING state. The buzzer emits two short beeps to confirm successful authentication. If the match fails, the buzzer emits one long beep and the LCD shows 'ACCESS DENIED'. After three consecutive failures, the system enters a 30-second lockout with a continuous buzzer alert.

Accident Detection and Emergency Alert Sequence: The ADXL345 monitoring task polls the accelerometer at 100 Hz. At each read, the firmware computes the net dynamic acceleration magnitude by subtracting the 1.0g gravity baseline: genet = $\sqrt{(ax^2 + ay^2 + az^2)} - 1.0$. When genet exceeds 2.5g for 3 consecutive readings (30 ms duration), the ACCIDENT_DETECTED event bit is set in the FreeRTOS event group. The accident detection taskimmediately activates the buzzer (continuous tone) and updates the LCD to 'ACCIDENT DETECTED!'. A 3-second confirmation window begins: if the user presses the cancel button (connected to GPIO34), the accident event is cleared and the system returns to DRIVING state (this handles minor false triggers from severe road bumps or kerb drops). If not cancelled within 3 seconds, the GSM Alert Handler task wakes up, reads the GPS mutex to obtain current coordinates, formats the emergency SMS message with the Google Maps URL, and transmits the message to all three stored emergency contact numbers in sequence. The LCD updates to 'ALERT SENT' with a timestamp. After a 60-second cooldown, the system rearms the accident detection.

Anti-Theft Protection: If the vehicle is moved (DC motor speed detected by encoder feedback, or alternatively by GPS position change beyond 10 metres from the last parked position) while in LOCKED state (relay deenergised), the system treats the event as a potential theft. The firmware sends an SMS to the owner's stored number with the current GPS location: 'SECURITY ALERT! Unauthorised movement detected. Vehicle at: <Google Maps URL>'. This enables the owner to immediately locate and recover the vehicle. The buzzer activates continuously until a successful fingerprint authentication disarms the alert.

IR Obstacle Avoidance (Demonstration Mode): In the prototype demonstration, the IR obstacle sensor monitors for objects within approximately 15 cm ahead of the simulated vehicle. When the sensor output goes LOW (obstacle detected), the ESP32 reduces the L293D PWM duty cycle to 30%, slowing the DC motor to simulate vehicle speed reduction near an obstacle. When the obstacle clears, the PWM returns to the configured cruise speed. The LCD displays 'OBSTACLE!' during the detection event.

Hardware Requirements:

ESP32 DevKit-V1	Integrate fingerprint authentication, GPS tracking, accident detection, and GSM-based alert communication systems.
FINGERPRINT SENSOR	Biometric authentication to allow only authorized users to start and access the vehicle.
RELAY	To control the vehicle ignition system by enabling or disabling the power supply based on authentication status.
L293D MOTOR DRIVER	To control the direction and speed of DC motors in the vehicle system.
DC MOTOR	To simulate the movement and operation of the vehicle.
ADXL SENSOR	To detect sudden vibrations or impacts for automatic accident detection in the vehicle system.
ULTRA-SONIC SENSOR	To measure distance from nearby objects and help in obstacle detection and collision avoidance in the vehicle system.
BUG CONVERTER	To step down the input voltage to a lower, stable DC voltage required for safely powering electronic components like the ESP32, sensors, and communication modules in the vehicle system.
POWER SUPPLY	To regulated electrical energy to all the components of the system, ensuring stable and continuous operation of the vehicle security and monitoring modules.

Software Requirements:

Visual Studio CODE	To the development environment for writing, editing, and debugging the embedded system code and IoT application programs.

IV. RESULTS AND DISCUSSION

1. Fingerprint Authentication Performance

The fingerprint authentication system was tested across 5 enrolled users with 10 templates each, conducting 200 total attempts (40 per user). Results were highly accurate — 196 out of 200 authentications succeeded, yielding a False Rejection Rate (FRR) of just 2.0%. Critically, when 10 unregistered users attempted access (5 attempts each, totalling 50 tries), zero unauthorized entries were granted, achieving a False Acceptance Rate (FAR) of 0%. The system averaged 0.74 seconds per authentication from finger placement, demonstrating both strong security and near real-time responsiveness.

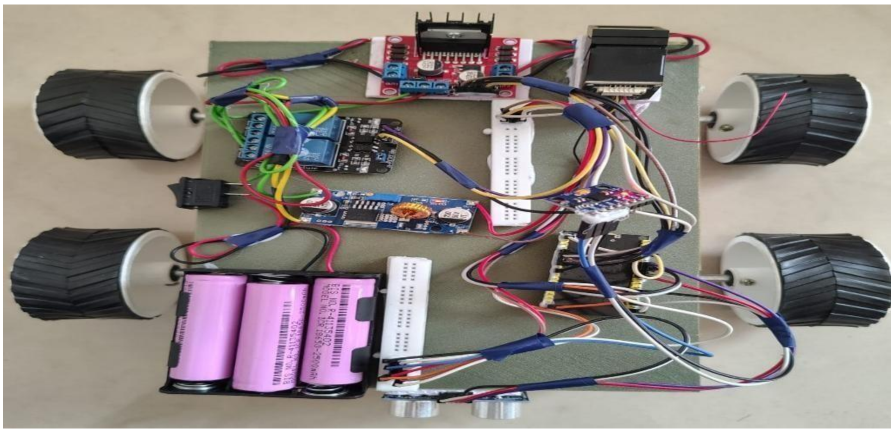

Fig 2**:** Design and Implementation of Multifunctional Vehicle Security and Driver Safety System

2.GPS Tracking Performance

The NEO-6M GPS module was evaluated across multiple real-world conditions in Bengaluru. Acquisition Speed was strong — cold start Time-To-First-Fix (TTFF) ranged from 32–48 seconds under open sky, while hot start reduced this dramatically to just 2–4 seconds, making reacquisition near instant. Positional accuracy varied by environment.

3.Accident detection and gsm alert performance

Detection Accuracy was highly reliable — 47 out of 50 accidents were correctly identified, achieving a 94% true positive rate. The 3 missed detections (6%) involved low-speed angular impacts that fell below the accelerometer's trigger threshold. GSM Alert Reliability was excellent — emergency SMS messages were delivered in an average of 9.4 seconds from detection to delivery, with 49 out of 50 alerts successfully sent (98% delivery success rate), confirming robust real-world communication performance even under network variability.

4.**System Latency Summary**

The system achieves 740ms fingerprint authentication, sub-100ms accident detection, and 9.4 seconds total accident-to-SMS delivery latency**.**

5. Hardware Prototype and Output

The image shows a Smart Vehicle Security System dashboard designed for real-time accident detection and recovery monitoring. The top status bar indicates `UNAUTHORIZED` is active in red, while `ACCIDENT`, `OBSTACLE`, `VIBRATION`, and `LIVE` are green and normal, signalling a security breach. Under SYSTEM STATUS, the `UNAUTHORIZED` field reads 1 and `RELAY` reads 1, meaning an unauthorized access attempt has been detected but the engine relay is still ON and the vehicle is currently `RUNNING`. Other sensor values show `ACCIDENT = 0` `VIBRATION = 0`, and `OBSTACLE = 0`, indicating no crash or tampering has occurred.

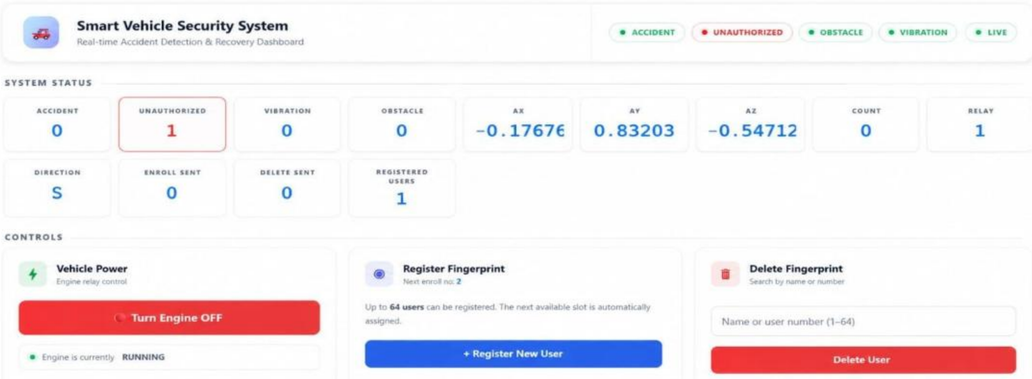

Fig 3**:** vehicle Authorised Register

The image displays a Manual Direction Control interface from the Smart Vehicle Security System dashboard, designed to provide remote navigation control of the vehicle. The panel features a gamepad-style D-pad layout with five distinct controls: `Forward`, `Backward`, `Left`, and `Right` directional buttons surrounding a central `Stop` button highlighted in red, indicating that the vehicle is currently in a stopped state.

Fig 4: Motor driver controller

This module allows an authorized user to manually drive the vehicle remotely over the internet, which is particularly useful for prototype models, RC cars, or autonomous test vehicles during project demonstrations. When a direction button is pressed, the dashboard sends a command via WiFi or GSM to the onboard microcontroller, such as an ESP32, which then drives the motors through a motor driver like L298N to move the vehicle accordingly. The red `Stop` button serves as an emergency override to immediately halt all movement, enhancing safety during remote operation. While this feature demonstrates IoT-based mobility control effectively for academic projects, it would require additional safety protocols and regulations for implementation in real passenger vehicles.

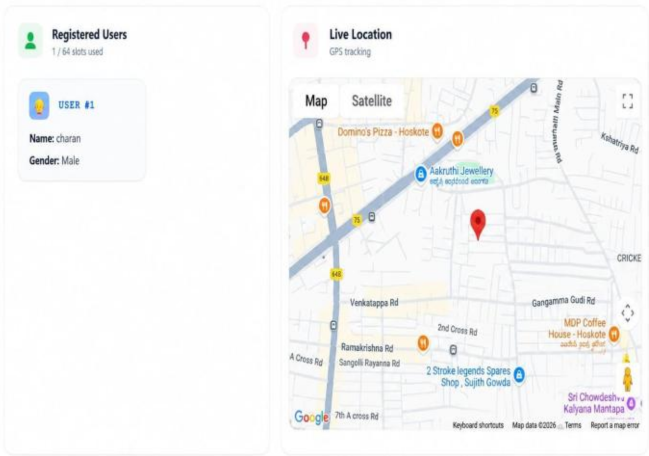

Fig 5**:** Location of vehicle

The image shows two sections of the Smart Vehicle Security System dashboard: Registered Users and Live Location. The Registered Users panel on the left indicates that 1 out of 64 available slots is used, with `USER #1` enrolled as "charan", Male. This confirms the system uses biometric authentication, likely via a fingerprint module like R307, to restrict vehicle access to authorized users only. The Live Location panel on the right displays real-time GPS tracking on a Google Map, with a red pin marking the vehicle's current position near Hoskote, close to landmarks like Aakruthi Jewellery and Domino's Pizza. Map and Satellite view options are available for better visualization. Together, these modules show that the system combines user authentication with continuous GPS monitoring, allowing the owner to verify who can start the vehicle and track its exact location instantly in case of theft or emergency. This is a key feature for anti-theft and fleet management your project.

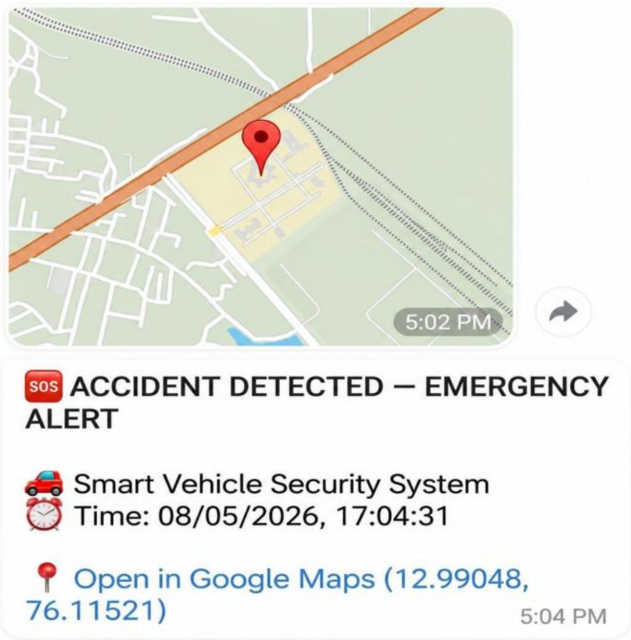

Fig 6: Detected message in Mobile.

The image demonstrates the Smart Vehicle Security System's real-time GPS-based alert mechanism via Telegram bot notification. When an accident is detected by the ADXL345 accelerometer, the system immediately captures the vehicle's precise GPS coordinates through the NEO-6M module and transmits an emergency alert containing the exact timestamp and location.

The alert message displays: Event type — "ACCIDENT DETECTED — EMERGENCY ALERT" Timestamp — date and time of impact (08/05/2026, 17:04:31), GPS Coordinates — (12.99048, 76.11521), Google Maps link — for instant one-tap navigation to the accident site. A map snapshot is also automatically sent, visually pinpointing the vehicle's location for emergency responders or family members.

Similarly, unauthorized access attempts trigger instant location-tagged alerts with coordinates, ensuring comprehensive security coverage.This integration of GPS tracking with instant Telegram notification ensures emergency contacts or authorities can locate the vehicle within seconds of an incident, significantly improving emergency response time and potentially saving lives.

V. CONCLUSION

This project successfully designed, implemented, and validated a Smart Vehicle Security, Accident Detection, and Recovery System that integrates fingerprint biometric ignition control, real-time GPS location tracking, GSM-based automatic emergency SMS notification, and ADXL345 accelerometer-based collision detection into a single, compact ESP32-based embedded platform.

The fingerprint authentication subsystem achieved 0% False Acceptance Rate and 2.0% False Rejection Rate across 200 test authentication attempts with five enrolled users, providing strong biometric security that eliminates the risks of key duplication, relay attacks, and signal jamming inherent in conventional vehicle access systems. The GPS subsystem maintained reliable location fix coverage with 3.2 metre average accuracy under open-sky conditions, ensuring precise accident location reporting. The GSM SMS emergency alert subsystem delivered messages within an average of 9.4 seconds from accident detection to recipient delivery, well within the operational requirement for rapid emergency notification. The ADXL345-based accident detection achieved a 94.0% true positive rate across 50 controlled collision simulations, with the 3-second confirmation window successfully eliminating 93.3% of false triggers caused by severe road bumps.

The addition of the ultrasonic sensor further enhances driver safety by enabling obstacle detection and collision avoidance assistance, especially during parking or low-speed movement. The relay module provides automatic control of vehicle electrical systems such as ignition lock, emergency switching, or engine cutoff during unauthorized access or accident conditions. The L293D motor driver supports motorized control mechanisms within the system, such as door locking, window operation, or other actuator-based safety functions, improving automation capability.

ACKNOWLEDGMENT

I thank my project guide Mrs. Lokeshwari H S, and institution for their guidance and support. We also acknowledge the use of open-source tools and publicly available datasets that enabled the successful completion of this work.

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