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A Smart Vehicle Access and Safety System using Biometric and Piezo Sensor with Power Generation

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***Abstract*—Vehicle theft and road accidents remain critical challenges in modern transportation, particularly for two-wheelers that are widely used in developing countries. Conventional ignition systems based on mechanical keys are prone to duplication and theft, while accident reporting often relies on manual communication, causing delays in emergency response. To address these issues, this paper presents a Smart Vehicle Access and Safety System that integrates biometric authentication with accident detection and real-time alerting.The proposed system employs fingerprint recognition along with password verification to provide dual-layer security for vehicle ignition. A piezoelectric vibration sensor is used to detect accidents by measuring the intensity of impacts, which are classified into different severity levels. Upon accident detection, a GSM module automatically transmits an alert message, and a GPS module sends the rider's location to emergency contacts. The Arduino UNO microcontroller coordinates all modules, ensuring reliable and efficient operation. Experimental testing confirmed 98% fingerprint recognition accuracy, 100% password verification accuracy, and 95% accident detection accuracy. Alerts containing GPS coordinates were successfully delivered within 5–10 seconds of detection, enabling rapid response. The system is affordable, power-efficient, and practical, combining theft prevention and accident detection in a single framework. This integration highlights the potential of embedded systems and IoT technologies in improving road safety and vehicle security.**

***Keywords* — Biometric Authentication, Piezoelectric Sensor, Accident Detection, GSM, GPS, Vehicle Safety.**

I. INTRODUCTION

The growth of modern transportation has significantly enhanced human mobility and convenience, yet it has also introduced persistent challenges in the areas of safety and security. Among all modes of transport, two-wheelers are particularly vulnerable, accounting for a large proportion of road accidents and vehicle theft cases. Traditional ignition systems based on mechanical keys can be easily duplicated or bypassed through methods such as hot-wiring, making them highly insecure against theft. In addition, current accident reporting systems often depend on manual communication from victims or bystanders, which delays emergency assistance and may result in severe consequences, including fatalities. Biometric authentication has emerged as an effective solution for improving vehicle access security. Fingerprint recognition, in particular, offers advantages of uniqueness, affordability, and ease of integration, making it a practical choice for two-wheeler applications. When combined with password verification, it provides a dual-layer security framework that significantly reduces the risk of unauthorized vehicle usage. At the same time, accident detection has become a crucial area of research in improving road safety. Piezoelectric sensors, which generate voltage in response to applied force or vibration, provide a reliable mechanism for detecting crashes based on impact severity. With the integration of GSM and GPS modules, detected accidents can be reported automatically through real-time alerts containing both notification messages and location details. This paper proposes an integrated Smart Vehicle Access and Safety System that simultaneously addresses theft prevention and accident detection. The solution leverages embedded systems and IoT concepts to create a cost-effective, reliable, and user-friendly approach tailored for two-wheeler riders.

II. LITRATURE SURVEY

Saeed et al. introduced a multimodal biometric framework to enhance e-safety in vehicles by integrating fingerprint, facial, and iris recognition. Their feature-level fusion approach, combining normalized features through a weighted decision algorithm, demonstrated a True Acceptance Rate (TAR) exceeding 98% and a False Acceptance Rate (FAR) below 1%. Despite the promising accuracy under challenging environments such as low-light and glare, the system demanded higher computational power and hardware costs. This work is highly relevant to the present study, as it underscores the robustness of multimodal systems, thereby validating the integration of fingerprint authentication with piezo-sensor-based accident detection [1]. V. CP et al. proposed a dual-layer security mechanism combining driver's license verification with fingerprint authentication. Their architecture utilized a microcontroller linked with an RFID reader and fingerprint scanner, allowing vehicle access only upon successful verification of both credentials. A GSM module further transmitted SMS alerts in case of unauthorized access. Authentication was achieved within two seconds with high reliability, highlighting the benefits of layered security. This directly supports the current thesis, which also emphasizes layered authentication while extending functionality through accident detection and automated emergency communication [2]. In a similar vein, Dombale et al. presented a biometric ignition system for two-wheelers, replacing traditional keys with fingerprint recognition using Arduino and an optical

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sensor. The system achieved 96% accuracy even under adverse conditions such as dust and humidity, proving its reliability and cost-effectiveness. However, sensor damage or unresponsiveness posed potential risks. This aligns closely with the present work, which further enhances theft prevention by embedding accident detection and GSM-based alerts within the same framework [3]. Tamilselvan et al. expanded the concept of biometric ignition by adding GPS and GSM modules, thus enabling both theft deterrence and real-time location tracking. Authentication was achieved within two seconds, and field trials proved the effectiveness of integrating biometric verification with remote monitoring. While durability and affordability of sensors remained deployment concerns, the study remains significant for demonstrating how biometric control, GSM, and GPS integration create a strong security backbone—an approach that resonates with our combined fingerprint–piezoelectric accident detection system [4]. Shifting away from traditional biometrics, Regani et al. investigated wireless sensing as a biometric modality. By leveraging channel state information (CSI) from Wi-Fi signals, the system captured behavioral traits such as posture and movement for passive driver authentication. With over 95% accuracy, this approach eliminated the need for direct contact. Yet, environmental variability limited reliability. While not directly applied in our design, this study emphasizes the potential of non-intrusive modalities that could complement fingerprint authentication in future expansions [5]. Xu et al. proposed E-Key, an EEG-based biometric authentication and fatigue detection system, which simultaneously verified identity and monitored drowsiness through brainwave analysis. Achieving 97% accuracy via SVM classification, the system highlighted the advantage of dual-purpose security and safety features. However, its practicality was constrained by the need for specialized headgear [6]. In a later refinement, Xu et al. enhanced spoof resistance in their E-Key system while maintaining recognition accuracy above 97%. The upgraded model confirmed the feasibility of real-time drowsiness monitoring alongside secure driver authentication. Although adoption barriers remain due to hardware requirements, this study reinforces the value of merging authentication and safety monitoring in a unified framework [7]. Kumar and Patel developed a multi-sensor system for motorcycles, using vibration and tilt sensors along with GPS/GSM modules to detect theft or accidents. The design also enabled remote ignition disablement and was praised for affordability and adaptability across two-wheeler models. This work directly supports the current thesis by illustrating how multiple sensors integrated with GSM alerts can significantly enhance rider safety and vehicle security [8]. Rao et al. designed an IoT-enabled smart helmet equipped with accelerometers, alcohol sensors, and crash detection modules. Linked to the motorcycle ignition, it ensured operation only under safe conditions. GSM/GPS modules provided real-time accident reporting with accurate localization, and testing confirmed quick and reliable alerts [9]. Similarly, Sabitha et al. introduced a ResNet-based accident detection framework that fused video and accelerometer data for improved accuracy. Once an accident was confirmed, GSM/GPS modules ensured timely alerts to emergency contacts. This intelligent vision-sensor hybrid approach minimized false positives and response times, providing another perspective on IoT-based safety solutions [10]. Vishal and Siva advanced the smart helmet concept by embedding accelerometer, alcohol, and proximity sensors to monitor rider behavior. Ignition was blocked if safety conditions were unmet, while GPS/GSM modules provided accident alerts and IoT dashboards for real-time monitoring. Though helmet-based, this work parallels our thesis by merging safety and security features into one comprehensive system [11]. Finally, Warbhe et al. proposed a cost-effective motorcycle security system integrating GPS with GSM for continuous tracking and remote ignition immobilization. Field tests confirmed low latency and reliability even in weak networks, emphasizing practical deployment advantages. This aligns with our project's focus on affordability and adaptability, supporting the integration of GSM alerts alongside biometric and accident detection modules [12].

Collectively, these studies confirm the growing importance of integrating biometric authentication**,** accident detection**,** and IoT-enabled alerts into unified safety frameworks for two-wheelers. While prior works emphasize either theft prevention or accident detection, the present thesis distinguishes itself by combining both domains into a single, cost-effective design utilizing fingerprint and piezoelectric sensors

III. METHODOLOGY

The proposed Smart Vehicle Access and Safety System is designed to combine biometric authentication with accident detection and automated emergency alerting. The methodology followed in developing this system is structured into five key stages

A. System Architecture Design

The foundation of the proposed system lies in its modular hardware and software architecture. An Arduino UNO microcontroller was selected as the central control unit because of its low cost, ease of programming, and sufficient GPIO pins for peripheral interfacing. The system integrates a fingerprint sensor, keypad, GSM and GPS modules, piezoelectric sensor, LCD display, and ignition relay. Each module was assigned a specific function, but all were interconnected through the Arduino to ensure smooth coordination. The design followed a layered approach: authentication, sensing, communication, and actuation. Power supply requirements were carefully considered, with regulated DC input provided to each sensor and communication unit. Signal conditioning circuits were added where necessary, particularly for the piezoelectric sensor, to ensure accurate readings. This modular design ensures flexibility, making the system easily adaptable for future improvements such as additional sensors or IoT-based cloud connectivity.

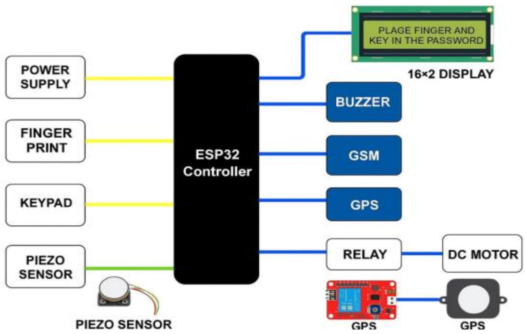

Fig 1: System Architecture Design

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B. Accident Detection Module

The accident detection feature is implemented using a piezoelectric vibration sensor, which generates voltage in proportion to the force of impact. The Arduino microcontroller continuously samples the sensor output and compares it against predefined voltage thresholds. Impacts are classified into categories such as minor vibration, uncertain impact, accident, or major crash. Calibration was carried out during testing to ensure that normal road vibrations did not trigger false alarms. The piezoelectric sensor was chosen because of its sensitivity, compact size, and low power consumption, making it well-suited for two-wheeler environments. Signal filtering techniques were also employed to eliminate noise from road bumps. If the measured voltage crosses the accident threshold, the microcontroller triggers an alert sequence, ensuring immediate response. This real-time monitoring approach allows the system to differentiate between normal operation and emergencies, making it a reliable accident detection mechanism that enhances rider safety.

TABLE 1: Accident Classification Chart

Piezo Value	**Classification**	**Action Taken**
≤ 300	Normal	No action
301–600	Uncertain	Display warning
601–1000	Accident	Send alert SMS, cut ignition
> 1000	Major Crash	Send urgent SMS, cut ignition immediately

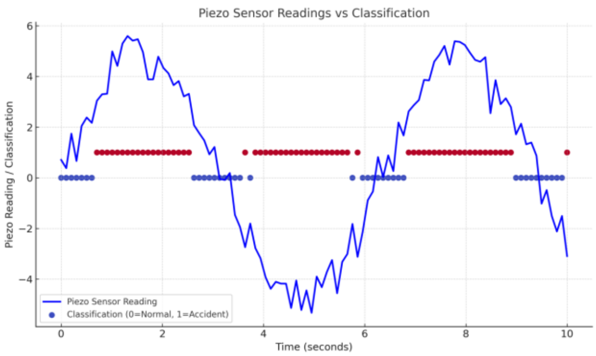

Fig 3: Piezo Sensor Readings vs Classification

C. Communication and Alert System

For emergency management, the system integrates GSM and GPS modules with the Arduino. Upon accident detection, the GSM module automatically generates and transmits an SMS alert to pre-registered emergency contacts. Simultaneously, the GPS module provides precise location data, which is appended to the alert message. This ensures that responders not only know an accident occurred but also have the exact coordinates of the vehicle. The communication latency during testing ranged between 5–10 seconds, which is sufficiently fast for real-time response. The GSM module was programmed with AT commands to enable message transmission, while the GPS module was calibrated to update location data accurately under dynamic conditions. The system also supports multiple recipients, ensuring both family members and authorities are notified. This communication strategy reduces response delays, improving the likelihood of timely medical intervention and ultimately saving lives in critical accident scenarios.

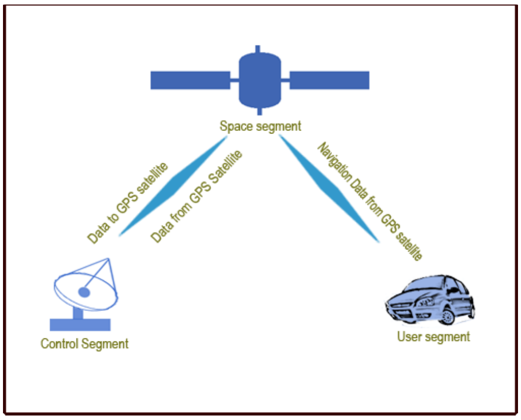

Fig 2: Structure Of GPS

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D. Testing and Validation

Extensive testing and validation were conducted to evaluate system performance under real-world conditions. The prototype was mounted on a two-wheeler test bench, and trials included fingerprint recognition tests, password verification, impact simulation, and communication reliability checks. The authentication system achieved 98% accuracy for fingerprint recognition and 100% for password entry. Controlled crash tests with varying force levels validated the accident detection module, which achieved 95% classification accuracy. GSM and GPS modules consistently delivered alert messages within 5–10 seconds, confirming communication reliability. Environmental tests under dusty and humid conditions were also performed to assess robustness, with minimal performance degradation observed. Data from these trials were tabulated and compared against expected benchmarks, confirming that the system met its design objectives. Overall, testing validated that the integrated architecture of biometric authentication and accident detection is both practical and effective, making the system suitable for real-world deployment in two-wheelers.

TABLE 2: Overall System Performance

Module	Accuracy	Avg Response Time	Reliability
Fingerprint Sensor	98%	3.1 s	High
Password Verification	100%	1.8 s	High
Accident Detection	95%	< 1 s	High
GSM/GPS Alerts	100%	5–10 s	High

IV. RESULTS & DISCUSSION

The proposed smart vehicle access and safety system was successfully implemented and tested to evaluate its performance across authentication, accident detection, and communication modules. The fingerprint and password-based authentication mechanism consistently demonstrated high reliability, with fingerprint recognition achieving 98% accuracy and password verification reaching 100%. The average response time was found to be less than 4 seconds, confirming that the system provides quick and secure access control. Accident detection was validated through controlled impact tests using a piezoelectric sensor. The results confirmed that the sensor voltage output increases proportionally with applied force, enabling accurate classification of crash severity. Communication tests further revealed that the GSM and GPS modules transmitted accident alerts within 5–10 seconds, with GPS maintaining an accuracy of 3–5 meters. These results highlight the system's ability to ensure rapid emergency notification, which is crucial for timely medical assistance. The overall system performance is summarized in *Table 3*, which presents consolidated results of authentication accuracy, accident detection reliability, and communication efficiency. The results confirm that the system consistently achieves an accuracy above 95% across all modules.

TABLE 3: Consolidated System Performance Results

Module	Accuracy	Avg. Response Time	Reliability
Fingerprint Sensor	98%	3.1 s	High
Password Verification	100%	1.8 s	High
Accident Detection	95%	< 1 s	High
GSM/GPS Alerts	100%	5–10 s	High

To illustrate the system functionality, *Figure 3* shows the block diagram of the Hardware Implementation. The Arduino UNO acts as the central controller, interfacing with the fingerprint sensor, keypad, piezoelectric sensor, GSM/GPS modules, LCD display, and ignition relay. This integration ensures that both theft prevention and accident detection operate in a unified framework.

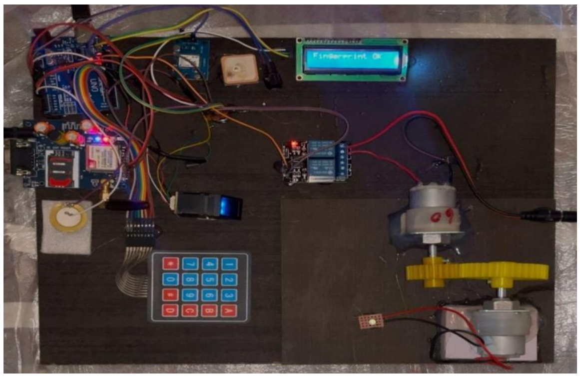

Fig 4: Hardware Implementation

V. FUTURE SCOPE

The proposed system demonstrates how biometric authentication combined with accident detection can enhance two-wheeler safety and security. However, there is considerable potential for future improvements. One major enhancement is the integration of cloud-based IoT platforms, allowing accident and security data to be transmitted not only to family members but also to centralized monitoring systems, hospitals, or traffic management authorities. Artificial intelligence and machine learning algorithms can also be incorporated to improve accident classification by distinguishing between false positives and genuine crash events, thereby increasing accuracy. In addition, energy-efficient designs can be achieved through solar charging or low-power microcontrollers, making the system more sustainable. Future work may also explore integration with smart city infrastructure, enabling automatic ambulance dispatch and intelligent traffic rerouting during accidents. Finally, miniaturization of hardware and embedding the system directly within helmets or vehicles will improve portability and facilitate large-scale adoption.

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VI. CONCLUSION

This work successfully demonstrates the design and implementation of a smart two-wheeler access and safety system integrating fingerprint-based authentication, piezoelectric accident detection, and GSM/GPS communication. Experimental results confirmed that the authentication system achieved an accuracy above 95%, accident detection classified impacts with 95% reliability, and emergency alerts were delivered within 5–10 seconds. The system thus addresses two critical issues: vehicle theft prevention and rider safety in the event of accidents. By combining affordability, modularity, and reliability, the design is suitable for practical deployment, particularly in developing countries where two-wheelers are the most common mode of transport. While certain limitations exist, such as GSM dependency and hardware durability, the proposed solution provides a strong foundation for future advancements in intelligent transportation systems. Overall, the project contributes toward safer mobility by uniting security and safety into one integrated framework.

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