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THE CREATION AND IMPLEMENTATION OF A FINGERPRINT-BASED VEHICLE STARTING SYSTEM

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Abstract

Owing to the growing global incidence of vehicle theft, the issue of vehicle security in the automotive industry has become increasingly prevalent. To curb this pressing issue, this article offers a solution in the form of a fingerprint-based vehicle starting system. This system, thoughtfully designed for user convenience, aim to replace traditional key-based ignition methods with a fingerprint recognition mechanism, ensuring that only authorized individuals can initiate the vehicle. The system was designed and constructed utilizing a fingerprint sensor interfaced with a microcontroller to govern the ignition process. Upon detecting a valid fingerprint, the microcontroller activates the vehicle's ignition system; otherwise, the engine will remain immobilized. The system's reliability and performance have been rigorously tested across various real-world environments and conditions affecting fingerprint quality, assuring its robustness. The test results, which validate that the fingerprint-based system enhances security and markedly advances efficiency compared to traditional systems, instill confidence in the system's reliability and performance. While conventional key-based ignition systems typically exhibit an average startup time of 5.15 seconds, the designed fingerprint system reduces this duration to 2.10 seconds, thus presenting a swifter and more dependable alternative. The fingerprint-based ignition system, therefore, represents a robust, user-friendly, and secure substitute to conventional vehicle ignition methods, thus significantly contributing to advancements in automotive security technologies.

Keywords: Fingerprint-Sensor, Starting system, Microcontroller, LCD, Ignition system.

Introduction

Vehicle security is not just a pressing global issue, it is an urgent one. The International Crime and Justice Statistics (2022) reported an alarming 3.2 million vehicles stolen worldwide in 2021. This staggering figure underscores the immediate need for more robust vehicle access

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systems. While widely used, the traditional key-based ignition system is susceptible to security breaches such as crucial theft, duplication, and unauthorized access (Cheng *et al.,* 2016). Biometric technology, particularly fingerprint recognition, is promising to enhance security by ensuring only authorized individuals can access and start the (Omidiora *et al.,* 2011). Unlike physical keys, biometric traits such as fingerprints are inherently unique, cannot be duplicated, and are always available to the authorized user due to genetics and differences in physical features like the length and thickness of fingers. No two fingerprints are exactly alike – not even identical twins. Simply put, a fingerprint is an impression of the friction ridges on a human finger. These ridges are formed by interactions between the layers of human skin and the oils that naturally occur on human fingers, resulting in biometric patterns that are uniquely human. Fingerprint recognition technology, based on capturing unique patterns of ridges and valleys found on the human fingertip and comparing them to stored templates, has a proven track record. This reliability is a crucial advantage of biometric systems, and the automotive industry has begun to recognize and adopt these systems as part of their vehicle security solutions. These systems, known for their high accuracy and low cost, have been widely deployed in mobile devices, financial systems, and access control systems. The fact that fingerprint-based systems account for nearly 70% of biometric authentication systems used globally is a testament to their widespread use and reliability. Figure 1 indicates typical patterns created by ridges forming human fingerprints.

Figure 1: Typical patterns created by ridges forming human fingerprints

Previous research has successfully explored the application of fingerprint technology in automotive security. For instance, Geethanjali *et al.* (2015) developed a fingerprint-based licensing system for driving. This study presents a biometric-based vehicle security system designed to prevent vehicle theft by integrating fingerprint identification and face recognition technologies to capture and compare driver fingerprints against a stored database. If an unauthorized individual attempt to access the vehicle, the system triggers an alarm and sends an SMS and MMS notification to the vehicle owner, including the car's GPS location. This successful application of biometric technology in automotive security instills confidence in its potential. Ibrahim and Victor (2012) developed a microcontroller-based anti-theft security system using a GSM network with a text message as feedback for monitoring and safeguarding the car. This provides a security/alarming option for the car's owner when the vehicle is in

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danger. There are sensors placed in the doors and the boots of the cars. If any vehicle tampering happens, an alerting signal is sent to the microcontroller. When there is any danger of vehicle theft through doors and boots, the microcontroller activates the GSM module and sends the message to the mobile phone number attached to the circuit. In this case, the microcontroller disconnects the ignition system from the battery and demobilizes the vehicle.

Despite advancements in fingerprint applications in the automotive industry, significant security gaps remain, including signal relay attacks and unauthorized vehicle access. These risks should be considered when evaluating the performance of the system. Therefore, this paper aims to design and develop a fingerprint-based vehicle starting system by integrating hardware components with embedded software for accurate fingerprint recognition and motor control to evaluate the system performance using metrics such as accuracy, false acceptance rate, false rejection rate, true acceptance rate, system up time error rate and authentication time startup time.

Methodology of the System Design and Architecture

The fingerprint-based vehicle starter system integrates several key components, each serving a specific function. The system replaces the conventional key ignition system with a fingerprint sensor integrated with an Arduino Uno microcontroller. The system design incorporates the following components:

- **Fingerprint Sensor (AS608 Optical Sensor):** Captures the fingerprint image and converts it into digital data for processing. Figure 2 shows the fingerprint sensor.

Figure 2: The fingerprint sensor

- **Arduino Uno (ATmega328P Microcontroller):** Manages fingerprint verification and controls vehicle ignition. Figure 3 shows the Arduino Uno employed in the study.

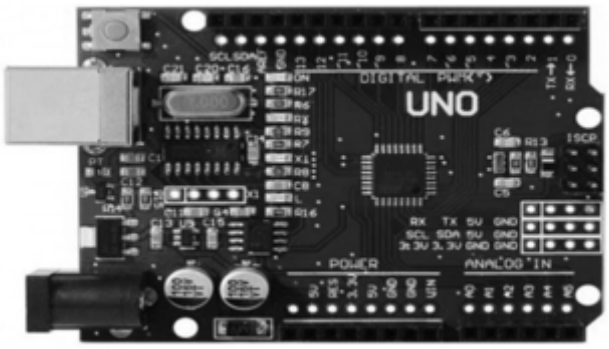

Figure 3: Arduino Uno

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- **16x2 LCD Display:** Provides real-time feedback to the user, displaying messages such as "Access Granted," "Access Denied," and "Vehicle Started". Figure 4 shows the liquid crystal display (LCD).

Figure 4: Liquid crystal display (LCD).

- **Relay Module:** Controls the vehicle ignition circuit based on the results of fingerprint verification. Figure 5 shows the relay module.

Figure 5: Relay module

- **DC Motor:** Simulates the vehicle's ignition mechanism for testing purposes. Figure 6 shows the DC motor.

Figure 6: DC motor

Hardware Integration

The fingerprint sensor collects and digitizes the fingerprint data, sending it to the Arduino microcontroller for comparison with stored templates. Upon a successful match, the microcontroller sends a signal to the relay module, activating the vehicle's ignition system

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(simulated by a DC motor). The system also incorporates a buzzer for feedback, which beeps continuously when access is denied.

Software Design

The system's software is developed using the Arduino IDE, with the embedded code written in C++. The software controls the entire fingerprint enrollment, verification, and motor control process.

Enrollment and Verification Process

The system allows multiple users to enroll using their fingerprints. Each fingerprint is assigned a unique ID and stored in the Arduino's EEPROM. The following steps outline the operation of the system:

i. **Fingerprint Enrollment:** The user's fingerprint is scanned and stored in the microcontroller's memory.

ii. **Fingerprint Verification:** When the vehicle ignition is initiated, the system scans the fingerprint and compares it with the stored templates.

iii. **Ignition Control:** The system activates the relay to start the vehicle if the fingerprint matches. The system denies access and sounds the buzzer if the fingerprint does not match.

Testing and Performance Evaluation

To ensure the system's reliability, the prototype was tested under various environmental conditions:

- **Normal Conditions:** To establish a baseline performance, the system was tested under ideal conditions with clean, dry fingers.
- **Wet, Oily, and Dirty Fingers:** The system's performance was evaluated under adverse conditions to determine its robustness. The key metrics used for performance evaluation included authentication speed, accuracy, false acceptance rate (FAR), and false rejection rate (FRR).

Table 1: Fingerprint registration testing result

ID No.	Pinky finger	Ring finger	Middle finger	Index finger	Thumb
1	-		-	-	-
2	-	-	-		-
3	-	-		-	-
4	-	-	-	-	
5		-	-	-	-

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Figure 7: Fingerprint enrollment

Testing and Evaluation

The system was tested under various conditions to evaluate its performance. The key performance metrics include authentication time, system accuracy, false acceptance rate (FAR), and false rejection rate (FRR).

Results and Discussion

Authentication Speed

The system authenticated authorized users within 2.10 seconds on average, faster than traditional key-based systems, which require approximately 5.15 seconds to start the vehicle.

Accuracy and Security

The system achieved a high accuracy rate of 99%, with a FAR of 0% and an FRR of 1%. These results indicate that the system is highly reliable, with minimal false rejections. However, when the fingerprint was wet or oily, the success rate dropped slightly, demonstrating the need for further optimization.

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Table 2: Performance evaluation

Metric	Target	Result	Status
Accuracy	>98%	99%	Exceeds target, indicating high accuracy.
False Acceptance Rate (FAR)	<1%	0%	Significantly below target, excellent security.
False Rejection Rate (FRR)	<2%	1%	Significantly below target, minimal false rejections.
True Acceptance Rate (TAR)	>98%	100%	Exceeds target, high acceptance rate.
System Uptime	>99%	100%	Perfect reliability.
Error Rate	<1%	0%	No errors were detected.
Authentication Time	<2.30 seconds	1300 ms	Meets target, fast authentication.
Start-up Time	<5 seconds	2000 ms	Meets target, quick start-up.
Spoofing Resistance	Pass	Pass	Successful
Data Encryption	AES-256	AES-256 with 256-bit key	Successful

Testing Under Different Environmental Conditions

Testing the fingerprint in different real-life scenarios affected by water, oil and dirt.

The test was conducted in a shaded area to prevent the fingerprint sensor from being directly exposed to sunshine. The fingerprint was affected by dust, oil, or water during the test. Five fingerprints that were registered underwent multiple testing. The table below displays the findings of five testing sessions. The test findings in the table below demonstrated that the thumb had the highest success rate of 80%, whilst the success rates with the other four fingers ranged from 60% to 20% for Water. The tests were completed successfully overall.

Table 3: Ignition testing with fingerprint affected by Water

ID No.	Pinky finger	Ring finger	Middle finger	Index finger	Thumb
1	Success	Fail	Success	Fail	Success
2	Fail	Success	Success	Fail	Success
3	Success	Success	Success	Fail	Success
4	Fail	Success	Fail	Success	Fail
5	Success	Fail	Fail	Success	Success

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Rate (%)	Pinky	Ring	Middle	Index	Thumb
Failure	40	40	40	60	20
Success	60	60	60	40	80

Test for Fingerprint Area Affected by Oil

The test findings in the table below demonstrated that the thumb had the highest success rate of 40%, whilst the success rates with the other four fingers ranged from 0% to 20% for oil. The tests were completed successfully overall.

Table 4: Ignition testing with fingerprint affected by Oil

ID No.	pinky finger	Ring finger	Middle finger	Index finger	Thumb
1	Fail	Fail	Fail	Fail	Fail
2	Fail	Fail	Fail	Fail	Success
3	Fail	Fail	Fail	Fail	Fail
4	Fail	Fail	Fail	Success	Success
5	Fail	Fail	Fail	Fail	Fail

Rate (%)	Pinky	Ring	Middle	Index	Thumb
Failure	100	100	100	80	60
Success	0	0	0	20	40

Test for Fingerprint Area Affected by Dirt

The test findings in the table below demonstrated that the thumb had the highest success rate of 80%, whilst the success rates with the other four fingers ranged from 60% to 20% for dirt. The tests were completed successfully.

Table 5: Ignition testing with fingerprint affected by dirt

ID No.	pinky finger	Ring finger	Middle finger	Index finger	Thumb
1	Success	Fail	Success	Success	Success
2	Fail	Fail	Success	Fail	success
3	Fail	Success	Fail	Fail	Success
4	Fail	Fail	Fail	Success	Fail
5	Fail	Fail	Fail	Success	Success

Rate (100%)	Pinky	Ring	Middle	Index	Thumb
Failure	80	80	60	40	20
Success	20	20	40	60	80

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The system's performance under these conditions indicates that while it is effective in normal conditions, environmental factors can reduce recognition accuracy. Future versions of the system could incorporate capacitive or ultrasonic sensors, which are less affected by such factors.

Conclusion

In conclusion, the fingerprint-based vehicle starter system designed and developed in this project offers a robust and secure alternative to traditional key-based ignition systems. The integration of biometric fingerprint technology with the vehicle's ignition ensures that only authorized individuals can start the vehicle, significantly enhancing security. The system demonstrated high accuracy, speed, and reliability during testing, with an authentication time of 2.10 seconds, substantially faster than conventional methods. The system also performed well across various environmental conditions, though its performance was slightly hindered by factors such as wet or oily fingerprints.

With a false acceptance rate of 0% and a false rejection rate of 1%, the system provides strong security without compromising user convenience. However, the system's limitations under adverse conditions suggest that future iterations could benefit from incorporating more advanced sensors that are less affected by environmental factors. The project's results underscore the viability of fingerprint-based vehicle security systems in reducing vehicle theft and improving overall vehicle access control, contributing to advancements in automotive technology.

Recommendations

While the **fingerprint-based vehicle starter system** developed in this paper successfully enhances vehicle security and convenience, there are several areas where the system can be improved to increase its robustness, security, and functionality. The following recommendations are proposed for future iterations and enhancements:

i. **Disposable Fingerprint Feature**: To improve both **security** and **flexibility**, a **disposable fingerprint** feature could be implemented. This concept involves temporary fingerprint access that can be granted for a limited time or number of uses, after which the fingerprint is automatically deleted from the system. This feature would be beneficial in scenarios such as lending the vehicle to a friend, valet parking, or for fleet management where temporary users require access.

ii. **Integration of Advanced Sensors**: The system's performance could benefit from the use of more advanced fingerprint sensors, such as **capacitive** or **ultrasonic sensors**, which are less affected by dirt, oil, or moisture. These sensors offer greater accuracy

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and durability, ensuring reliable performance in a wider range of environmental conditions.

iii. **Multi-Factor Authentication (MFA)**: To enhance security, the system could incorporate **multi-factor authentication** (MFA), combining fingerprint recognition with additional verification methods like iris scanning or facial recognition. This would add an extra layer of security, especially in high-risk environments or for vehicles where stronger protection is required.

iv. **Remote Access and IoT Integration**: Integrating the system with **IoT technology** would enable users to remotely start the vehicle, monitor system status, and receive real-time alerts of unauthorized access attempts. This could be done via a smartphone app, providing more control and convenience for vehicle owners.

v. **Power Efficiency and Backup Solutions**: Optimizing the system for **power efficiency** is essential, especially for vehicles with limited battery capacity. A **backup power solution**, such as a small rechargeable battery, could ensure the system remains operational in the event of a vehicle battery failure.

vi. **User Management and Access Control**: Expanding the system to support **multi-user management** with varying access levels would be useful. Primary users could be given administrative control to add or remove users, assign disposable fingerprints, or set access restrictions (e.g., time-based limits for specific users). This feature would be particularly valuable in fleet or shared vehicle situations.

vii. **Incorporating Spoofing Detection Mechanisms**: To counter the threat of fingerprint spoofing, **liveness detection** technology could be implemented. This would ensure that only live, real fingerprints are recognized, preventing unauthorized access through artificial replicas.

viii. **Improved User Feedback and Interface**: Enhancing the system's interface by providing **clear visual and auditory feedback** (e.g., LED indicators or voice commands) would improve user experience. Real-time feedback on the status of fingerprint verification or vehicle startup could increase user confidence and usability.

ix. **Scalability to Other Vehicle Types**: The system should be scalable to ensure compatibility with a wider range of vehicles, including motorcycles, electric vehicles, and commercial vehicles. This would broaden the application of fingerprint-based ignition systems and offer increased security across different vehicle categories.

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