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DESIGN AND EVALUATION OF A SECURE BIOMETRIC ATM USING FINGERPRINT RECOGNITION

[1]OVUEVU, Clement Oghenerume, [2]BAMIGBOYE Bashirat Aderayo, [3]ONUIBERE, Stephen Uche, [4]DONATUS, Sabinus Uchenna, [5]THOMAS Omotayo Esther

[1]School: National Open University of Nigeria, clement017@yahoo.com, ORCID ID: https://orcid.org/0009-0003-9411-7585

[2]National Open University of Nigeria, bbashirat4joy@gmail.com, ORCID ID: https://orcid.org/0009-0003-1226-0053

[3]Ahmadu Bello University Zaria, talk2ucheino@gmail.com, ORCID ID: https://orcid.org/0009-0002-1112-4298

[4]Crescent University Abeokuta, debiggauch@gmail.com, ORCID ID: https://orcid.org/0009000239801406

[5]National Open University of Nigeria, thomasomotayo@gmail.com, ORCID ID : https://orcid.org/0009-0008-3555-5950

Corresponding Author :
bbashirat4joy@gmail.com

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ABSTRACT

The increasing prevalence of fraud and security breaches in Automated Teller Machine (ATM) systems has highlighted the limitations of traditional card-and-PIN-based authentication methods. This study presents the design, implementation, and evaluation of a fingerprint-based biometric ATM system aimed at enhancing transaction security and user authentication. The proposed system replaces conventional knowledge-based authentication with identity-based verification using fingerprint recognition, thereby reducing vulnerabilities associated with credential theft, card skimming, and unauthorized access.

The system architecture integrates biometric sensing, embedded processing, and secure communication mechanisms to ensure reliable and efficient operation. A minutiae-based fingerprint recognition algorithm is employed for feature extraction and template matching, while secure encryption techniques are used to protect sensitive biometric and transaction data. The system was implemented using a microcontroller-based platform and evaluated under controlled experimental conditions.

Performance evaluation was conducted using standard biometric metrics, including authentication accuracy, False Acceptance Rate (FAR), False Rejection Rate (FRR), and response time. The results indicate an authentication accuracy of 96.5%, a FAR of 2.1%, an FRR of 4.3%, and an average response time of 1.8 seconds, demonstrating the system's effectiveness in balancing security and usability. Functional and security testing further confirmed the robustness of the system, achieving a high success rate across all test scenarios. The findings suggest that fingerprint-based biometric authentication provides a secure, reliable, and user-friendly alternative to traditional ATM systems. The study concludes that the proposed system is suitable for real-world deployment in modern banking environments, with potential for further enhancement through multi-factor authentication and advanced biometric techniques.

Keywords: *Fingerprint Recognition, Biometric Authentication, ATM Security, Financial Fraud Prevention, Multi-Factor Authentication*

BACKGROUND TO THE STUDY

Automated Teller Machines (ATMs) remain a substantial element of the electronic banking infrastructure, despite the fact that the global financial system has been significantly altered by the evolution of digital banking technology. Automated Teller Machines (ATMs) offer 24/7 access to financial services, including currency withdrawals, deposits, and fund transfers, thereby promoting financial inclusion and improving convenience. Nevertheless, the frequency of ATM usage has increased, which has coincided with a rise in security concerns regarding unauthorised access, identity theft, and deception.

Card and Personal Identification Number (PIN) systems are the primary components of conventional ATM authentication mechanisms. Although the techniques are favoured for their affordability and user-friendliness, they are becoming more susceptible to security threats, including phishing, card skimming, shoulder browsing, and PIN compromise. The vulnerabilities are the result of antiquated systems that verify credentials for access rather than the user's identity. Unauthorised individuals can easily access users' financial accounts once they have obtained these credentials, which can lead to substantial financial losses and a decline in trust in banking systems (Akinyemi, Omogbadegun, & Oyelami, 2022; Saad, 2019).

In order to address these deficiencies, biometric authentication has been implemented as a more secure and dependable substitute. Biometrics is the application of unique physiological and behavioural characteristics, including fingerprints, facial recognition, iris patterns, and vocal recognition, to verify identification. Fingerprint identification is a biometric modality that is highly favoured due to its exceptional accuracy, low cost, user acceptance, and simplicity of integration (Jain, Ross, & Prabhakar, 2019; Maltoni et al., 2020).

Fingerprint identification systems operate by gathering the unique ridge and valley patterns of an individual's fingerprint, extracting pertinent information known as minutiae, and comparing it to stored biometric templates in a secure database. Fingerprints are distinct from PINs and passwords in that they are individual, difficult to forget or share, and require the user's physical presence during the authentication process. This substantially improves the security of ATM transactions and diminishes the probability of fraud and unauthorised access (Bolle et al., 2019; Jain et al., 2022).

The viability of biometric systems has been substantially enhanced by recent technological advancements. At present, fingerprint recognition systems utilise secure template encryption methods, enhanced feature extraction algorithms, and capacitive and ultrasonic sensors to enhance accuracy and reliability while protecting user privacy (Maltoni et al., 2020; Chien et al., 2019). Additionally, a growing number of financial institutions worldwide are incorporating biometric authentication into their multi-factor security systems to improve consumer confidence in digital banking services and to mitigate the emergence of new cyber threats (Adebayo & Abdul, 2023).

In developing countries like Nigeria, where ATM-related fraud remains a significant issue, fingerprint-based authentication systems represent a proactive and sustainable solution. In addition to improving transaction security, it also simplifies the user experience by eliminating the need to remember intricate PINs. Biometric authentication is consistent with the legislative frameworks that have been established to safeguard user data and financial assets, as well as the current financial security demands.

Nevertheless, fingerprint-based ATM systems are plagued by concerns regarding the privacy and storage of biometric data, as well as false acceptance and rejection rates and environmental influences that affect the sensor. These concerns require continuous analysis and improvement to enhance system performance, guarantee compliance with data protection regulations, and increase user confidence.

The purpose of this investigation is to create and evaluate a fingerprint-based ATM authentication system that is secure, efficient, and user-friendly. This system will resolve the disadvantages of traditional authentication methods and capitalise on recent developments in biometric technology to improve ATM security.

STATEMENT OF THE PROBLEM

Automated Teller Machines (ATMs) are a prevalent method for conducting financial transactions; however, they pose substantial security challenges in contemporary banking systems. Diverse fraudulent activities, such as card skimming, shoulder surfing, PIN theft, and identity impersonation, have progressively undermined conventional ATM authentication methods, which are primarily reliant on card access and Personal Identification Numbers (PINs). Conventional systems permit unauthorised individuals to gain access when credentials are compromised, as they authenticate access credentials rather than the actual identity of users (Akinyemi, Omogbadegun, & Oyelami, 2022; Saad, 2019). Consequently, these security vulnerabilities persist.

The situation is further exacerbated by the increasing prevalence of ATM-related offences, the insufficient enforcement of security protocols, and the growing dependence on electronic banking systems in developing countries such as Nigeria. This has led to substantial financial losses for both financial institutions and clients, as well as a decrease in user confidence in digital banking services. Furthermore, the potential for password reuse, neglect, and fraud is increased by the increasing complexity of PIN management, particularly for individuals with multiple accounts and platforms (Adebayo & Abdul, 2023).

A viable remedy to these issues is proposed through biometric identification, specifically fingerprint recognition. However, fingerprint-based systems that are currently in use have inherent limitations. Access is difficult for individuals with fingerprints that have not been sufficiently captured due to environmental conditions, physical limitations, or sensor deficiencies, as certain systems lack effective alternative authentication techniques. Furthermore, the system's security and reliability are jeopardised by a variety of factors, such as the risk of biometric deception, hardware reliance, sensor failure, and false acceptance and denial rates.

The privacy and secure storage of biometric data are significant obstacles to their widespread adoption. Inadequate encryption and data security methods may expose sensitive biometric information to intrusions, thereby introducing new vulnerabilities even within sophisticated authentication systems (Maltoni et al., 2020; Chien et al., 2019).

This article discusses the inadequacy of current ATM authentication solutions in terms of their ability to provide secure, reliable, and comprehensive identity verification. In practical banking contexts, it is imperative to develop and assess an improved fingerprint-based biometric ATM authentication system that addresses the challenges of dependability, usability, data privacy, and system resilience, while simultaneously enhancing security and reducing fraud.

AIM AND OBJECTIVES OF THE STUDY

AIM OF THE STUDY

This study aims to design and evaluate a secure biometric Automated Teller Machine (ATM) system based on fingerprint recognition in order to enhance the security of ATM transactions and protect users against unauthorized access and financial fraud. The study is anchored on the need to transition from vulnerable card-and-PIN authentication systems to more reliable identity-based verification mechanisms.

OBJECTIVES OF THE STUDY

To achieve the stated aim, the study is guided by the following specific objectives:

1. To design an authentication system that integrates fingerprint recognition and biometric identification into ATM operations for secure user verification.
2. To develop a fingerprint-based authentication system capable of capturing, processing, and matching biometric templates for accurate ATM user validation.
3. To evaluate the efficiency and reliability of the fingerprint authentication system in ATM operations using performance indicators such as accuracy, False Acceptance Rate (FAR), False Rejection Rate (FRR), and response time.

REVIEW

ATM SECURITY SYSTEMS AND FINGERPRINT-BASED BIOMETRIC

Automated Teller Machines (ATMs) have been an important part of modern banking since the 1960s. They let customers to make currency withdrawals, deposits and fund transfers on a 24/7 basis, without the customer having to directly engage with bank personnel. Its broad acceptance has greatly boosted financial inclusion, especially for developing economies. This expansion has resulted in greater exposure to security threats, and hence, more sophisticated and reliable authentication mechanisms are necessary (Saad, 2019).

Conventional ATM security measures often use card authentication and Personal Identification Numbers (PINs). These techniques are simple and inexpensive, but are more exposed to cyber dangers including phishing, card skimming, shoulder surfing, and PIN theft. The main drawback to these systems is that they confirm the user’s credentials to access, rather than his or her true identity. Compromised credentials that permit unathorized access to financial accounts are an example of the infidelity of knowledge-based authentication systems (Lasisi & Ajisafe, 2019).

In response to these issues, the adoption of biometric authentication in ATM systems has emerged as a transformative solution to boost security. Biometric Automated Teller Machine (ATM) system using fingerprint identification is a technology that uses physiological attributes of an individual to validate their identity Fingerprint biometrics is natural to the individual and cannot be easily taken, transferred or copied as compared to other authentication systems. Fingerprint-based ATM systems improve security by tying authentication to the user’s physical identity, rather than external tokens or memorised data (Jain et al., 2022; Maltoni et al., 2020).

Fingerprint ATM systems use a biometric sensor to gather the user’s fingerprint, extract unique properties such ridge ends and bifurcations, and compare these traits to securely stored biometric templates. This strategy ensures that banking services are used only by authorised persons, reducing the frequency of fraudulent and unauthorised transactions. In areas with a high rate of financial crime, ATMs are often equipped with fingerprint identification technology. Fingerprint identification technology is cheap, easy to install, and reasonably accurate. The change is from token-based and knowledge-based systems to identity-based authentication systems.

However, there are several challenges in biometric ATM systems based on fingerprint. Factors such as False Acceptance Rate (FAR) and False Rejection Rate (FRR) may affect system accuracy and user satisfaction. Fingerprint sensors are susceptible to environmental effects such as humidity, dirt or damaged fingerprints. Furthermore, the storage and processing of biometric data may raise ethical and privacy problems, particularly when they are illegally accessed or breached. It is important to follow data security standards; use strong encryption methods; and securely store templates to protect biometric data (Maltoni et al., 2020).

In the biometric sector, fingerprint authentication is not sufficient for efficient ATM protection. A successful fingerprint based ATM system would require a multi-layered security framework that involves sophisticated fraud detection techniques, secure communication routes, surveillance systems and encryption techniques. Several recent approaches combine biometric authentication with other factors such as One-Time Password (OTP) or other PIN methods to provide both reliability and ease of use. The multi-factor approach offers a security framework and resilience against physical and cyber risks (Bolle et al., 2019).

There are challenges to fingerprint-based ATM technology in countries like Nigeria. These are high implementation costs, infrastructural obstacles such as unpredictable power supply and network availability, meteorological factors which affect the accuracy of biometrics and differential levels of technology literacy between users. Thus, although fingerprint biometric authentication has great advantages in ATM security, its effective application depends on context-specific design, infrastructure, user education and positive regulatory framework.

The move from conventional PIN based authentication to fingerprint based biometric ATM systems is a significant stride in financial security. Fingerprint recognition can help verify identity, deter fraud and help users. However, finding the right balance between privacy, usability and security still remains a major difficulty. However, if the technical, ethical and contextual restrictions as stated above are adequately satisfied, then the effectiveness of fingerprint-based ATM systems can be increased with the progress in machine learning, biometric algorithms and encryption technologies.

RELATED WORKS

Table 1: Comprehensive Related Works

S/N	Author(s) & Year	Title of Study	Technology / Approach Used	Key Contributions / Strengths	Limitations / Gaps	Evaluation Metrics
1	Garcia (2025)	Fingerprint-Based Biometric Systems in ATMs	Fingerprint recognition with machine learning integration	Demonstrated improved ATM security, enhanced user experience, and robustness using advanced algorithms (SSRN)	Limited real-world deployment validation; scalability concerns	Accuracy rate, system robustness, user experience
2	Galadima & Adoga (2025)	Hybrid Biometric-Cryptographic ATM Authentication	Fingerprint + QR code + cryptographic security	Strong multi-factor authentication, improved resistance to spoofing and replay attacks (fjs.fudutsinma.edu.ng)	Increased system complexity and cost	FAR, FRR, authentication success rate
3	Singh et al. (2023)	Fingerprint-Based Biometric Authentication for ATM	Fingerprint authentication with secure template storage	Enhanced ATM security and user convenience; reduced dependency on PIN (ResearchGate)	Privacy concerns and sensor dependency	Authentication time, accuracy
4	Aljuaid & Ansari (2021)	Multimodal Biometric ATM Authentication	Fingerprint + face + retina (fusion model)	High accuracy due to multi-biometric fusion; improved fraud resistance (ResearchGate)	High computational complexity; expensive deployment	Classification accuracy, matching rate
5	Kumar et al. (2022)	Fingerprint-Based ATM Security System	Fingerprint-only authentication	Eliminates need for cards and PIN; simple implementation (ijsrst.com)	Vulnerable to sensor issues and spoofing attacks	System accuracy, usability
6	Thiruthanigesan et al. (2020)	Enhancing ATM Security Using Fingerprint	Fingerprint biometric system	Improved transaction security and reduced fraud risks (ictactjournals.in)	Limited discussion on privacy and data protection	Security efficiency, transaction success rate
7	Ahamed (2022)	Review of Fingerprint-Based Biometric Systems	Survey of fingerprint ATM systems	Highlighted uniqueness and reliability of fingerprints (ACM Digital Library)	Lacks experimental validation	FAR, FRR, system comparison
8	Fernandes (2020)	Biometric ATM Security System	Fingerprint-based embedded system	Reduced fraud and improved authentication speed (ResearchGate)	Limited real-world testing	Processing time, security level
9	Shetiya et al. (2020)	Iris Recognition for ATM Security	Iris-based biometric system	High accuracy (≈94%) and strong identification capability (ResearchGate)	Expensive and intrusive compared to fingerprint	Recognition accuracy, matching rate
10	Ahamed (2018)	Fingerprint ATM System Survey	Fingerprint biometric review	Identified key challenges and advantages of fingerprint systems (ijsrcseit.com)	Lacks empirical validation	Comparative analysis
11	Srilakshmi et al., 2024	Fingerprint-Based ATM System	Fingerprint recognition with advanced scanning	Improved authentication accuracy and system reliability (eudoxuspress.com)	Limited focus on usability and user acceptance	Accuracy, reliability

THEORETICAL FRAMEWORK

The theoretical foundation of this study is anchored on two highly relevant frameworks: Biometric Security Theory and the Technology Acceptance Model (TAM). These theories were selected because they collectively address the two fundamental dimensions of a fingerprint-based biometric Automated Teller Machine (ATM) system, namely security effectiveness and user acceptance. While Biometric Security Theory explains the superiority of biometric authentication in ensuring secure identity verification, the Technology Acceptance Model provides insight into how users perceive and adopt such systems in real-world banking environments.

BIOMETRIC SECURITY THEORY

The theory of biometric security serves as a fundamental basis for comprehending the efficacy of fingerprint-based authentication methods in enhancing ATM machine security. The concept is grounded in the interdisciplinary domain of biometric recognition and information security, having garnered substantial contributions from Anil K. Jain, Arun Ross, and Sharath Pankanti. It is based on the assumption that human physiological characteristics, like as fingerprints, are inherently unique, permanent, and impossible to replicate, therefore offering a high degree of dependability for identification verification.

This idea is predicated on the premise that authentication procedures ought to be grounded in personal identity rather than knowledge-based (e.g., PIN) or possession-based (e.g., ATM card) criteria. Conventional ATM systems verify users with credentials that are easily compromised, disseminated, or overlooked. The biometric security theory contests this approach, asserting that authentication ought to be identity-centric, with access to financial services associated with an individual's distinct biological traits.

This theory examines the transition from vulnerable card-and-PIN systems to more secure fingerprint identification within the framework of a fingerprint-based biometric ATM system. The system acquires the user's fingerprint, delineates unique characteristics such as ridge endings and bifurcations, and subsequently contrasts these attributes with archived biometric templates. This guarantees that only the legitimate user may access the ATM, thus diminishing the likelihood of fraud, identity theft, and unauthorised transactions. This concept is particularly relevant for addressing security issues like as card skimming, PIN compromise, and impersonation, which are common in conventional ATM systems.

Furthermore, Biometric Security Theory advocates for the use of advanced security measures, including the encrypted storage of biometric templates and secure communication protocols. These protocols provide confidentiality and integrity, safeguarding sensitive biometric data against unwanted access. Nonetheless, the hypothesis possesses several drawbacks. It does not fully address concerns regarding privacy related to the storage of biometric data, nor does it eradicate the risks of biometric spoofing or sensor inaccuracies. Furthermore, its efficacy relies on a reliable infrastructure and high-quality biometric equipment.

In conclusion, the Biometric Security Theory provides the fundamental justification for incorporating fingerprint recognition into automated teller machine systems, emphasising enhanced security, identity verification, and fraud prevention.

TECHNOLOGY ACCEPTANCE MODEL (TAM)

The Technology Acceptance Model (TAM) offers a supplementary perspective, concentrating on user behaviour and the adoption of novel technology. The Technology Acceptance Model (TAM), created by Fred Davis, is grounded in the field of information systems and is widely employed to elucidate user perceptions and acceptance of technological advancements. The methodology relies on two primary constructs: perceived usefulness (PU) and perceived ease of use (PEOU).

Perceived usefulness refers to the extent to which users believe that a system enhances their performance or experience, whereas perceived ease of use pertains to the simplicity of utilising the system. These two factors shape users' perceptions of a system and ultimately dictate their intention to utilise it.

The Technology Acceptance Model (TAM) is especially pertinent in elucidating customer acceptability and uptake concerning fingerprint-based biometric ATM technology. Biometric authentication offers enhanced security; yet, its efficacy relies on its benefits and user-friendliness. Fingerprint authentication aligns with the Technology Acceptance Model principles by simplifying the authentication procedure, eliminating the necessity to recall PINs or possess physical cards. This reduces cognitive load and enhances convenience, rendering the system more appealing to consumers. This study employs the Technology Acceptance Model (TAM) to evaluate user interaction with fingerprint-based ATM systems for usability, efficiency, and satisfaction. If the system provides expedited transaction times, reduced errors, and improved security compared to traditional methods, users are more likely to adopt the system. The user-friendly nature of fingerprint scanning enhances the user experience, resulting in elevated acceptance rates.

TAM also underscores the necessity of developing systems that consider users' levels of technical proficiency. In regions with limited technological advancement and minimal consumer exposure, it is essential for the system to be straightforward and comprehensible for user adaptation. Consequently, TAM facilitates the creation of intuitive interfaces and assists in assessing user trust and satisfaction.

However, the model possesses certain deficiencies. It is predominantly user-centric and inadequately considers external variables such as infrastructural obstacles, financial implications, or regulatory obligations. Furthermore, it does not address the technical issues of system security that must be evaluated alongside user acceptance.

In conclusion, the Biometric Security Theory is enhanced by the Technology Acceptance Model to guarantee that the fingerprint identification-based ATM system is secure, user-friendly, and widely accepted. These theories collectively offer a comprehensive approach that considers both technological and human factors in the design and deployment of biometric ATM systems.

METHODOLOGY

RESEARCH DESIGN AND SYSTEM APPROACH

In order to develop a secure biometric Automated Teller Machine (ATM) authentication system that employs fingerprint recognition, this work implements a system design and assessment research methodology. The methodology involves the integration of system analysis, design, implementation, and assessment methodologies to address the shortcomings of conventional ATM authentication systems.

This method is effective because it enables the development of a functional prototype system, which in turn enables the evaluation of performance using recognised biometric parameters, such as the False Acceptance Rate (FAR), False Rejection Rate (FRR), and authentication duration. The research emphasises the security, dependability, and usability of ATMs through the use of identity-based authentication methods.

ANALYSIS OF EXISTING ATM SYSTEM

Conventional ATM systems predominantly depend on card-based and Personal Identification Number (PIN) authentication. Despite their widespread utilisation, these systems are susceptible to numerous security concerns, including card cloning, PIN theft, skimming, and shoulder surfing. These vulnerabilities occur because authentication relies on possession and knowledge instead of identity.

Furthermore, traditional ATMs are deficient in real-time monitoring and intrusion detection systems, so constraining their capacity to react swiftly to unauthorised access attempts. These vulnerabilities undermine system integrity and diminish user trust in electronic financial systems. Therefore, there is a necessity for enhanced authentication mechanisms, such as biometric systems that employ distinctive physiological traits.

1 ARCHITECTURE OF CONVENTIONAL ATM SYSTEMS

Traditional ATM systems function as decentralised embedded systems comprising both hardware and software elements. Essential components comprise a central processing unit, card reader, encrypting PIN pad, display interface, and cash dispenser. The components engage via middleware and communication protocols, including CEN/XFS and ISO 9564 standards, to guarantee safe transaction processing.

Notwithstanding this organised framework, dependence on external authentication components like cards and PINs engenders considerable risks.

2 WEAKNESSES OF CONVENTIONAL ATM SYSTEMS

The major weaknesses of traditional ATM systems include:

- Vulnerability to PIN theft and card skimming
- Susceptibility to malware and network attacks
- Lack of real-time monitoring and intrusion detection
- Dependence on static authentication credentials

These limitations highlight the need for a more robust and identity-based authentication system such as fingerprint biometrics.

PROPOSED BIOMETRIC ATM SYSTEM

fingerprint-based biometric authentication serves as the primary method of user verification in the proposed system. The conventional card-and-PIN methods are replaced by a more secure identity-centric approach by this technology.

For the purpose of user authentication, the system implements secure template matching, biometric sensors, and feature extraction techniques. In an effort to ensure the privacy and security of data during storage and transmission, biometric templates are encrypted.

Additional components of the proposed system include:

- Communication pathways were safeguarded.
- The detection of anomalies through the application of machine learning
- Alternative methods of authentication, such as OTP or PIN

The security, usability, and dependability of the system are enhanced by this approach.

1 OVERVIEW OF THE FINGERPRINT-BASED ATM SYSTEM

The fingerprint-based ATM system operates by capturing a user's fingerprint, processing it to extract unique features, and comparing it with stored biometric templates. Authentication is granted only when a match is found.

The system integrates seamlessly with existing ATM infrastructure and supports real-time transaction processing. It ensures privacy by storing encrypted biometric templates rather than raw fingerprint images.

2 DESIGN GOALS AND EVALUATION METRICS

Table 2 presents the key design goals of the proposed fingerprint-based ATM system alongside corresponding evaluation metrics, providing a structured framework for system performance assessment."

Table 2: Design Goals and Evaluation Metrics of the Fingerprint-Based ATM System

Design Goal	Description	Evaluation Metrics
Enhanced Security	Eliminate vulnerabilities associated with card-and-PIN authentication in ATM systems	Unauthorized access rate; fraud reduction rate; spoofing resistance; compliance with CBN guidelines
Accuracy and Reliability	Ensure consistent biometric performance under varying environmental conditions	FAR; FRR; EER; authentication success rate
User Convenience	Improve usability and reduce transaction complexity	Authentication time; transaction completion rate; user satisfaction score
Privacy Protection	Secure biometric data in compliance with NDPA (2023)	Encryption compliance; absence of raw data storage; vulnerability testing results
System Robustness	Maintain system functionality under operational constraints	System uptime; MTTR; fallback success rate
Scalability	Support high transaction volumes and integration with banking systems	Throughput; response time; integration success rate
Cost-Effectiveness	Minimize deployment and operational costs	Cost per ATM; ROI; maintenance cost savings

FUNCTIONAL REQUIREMENTS

The functional requirements of the proposed system, as summarized in Table 3, define the core operational capabilities, security features, and performance expectations necessary for the implementation of a fingerprint-based ATM authentication system."

Table 3: Functional Requirements of the Fingerprint-Based ATM System

ID	Functional Requirement	Description	Key Metrics
FR1	Biometric Authentication	Verify users using fingerprint recognition	Accuracy ≥ 98%, FAR ≤ 0.1%, FRR ≤ 1%
FR2	Transaction Processing	Enable ATM services such as withdrawal, deposit, and transfer	Response time ≤ 3 sec
FR3	Fingerprint Processing	Capture and preprocess fingerprint data for matching	Robust to environmental conditions
FR4	Template Matching	Match biometric templates with stored database	Matching time ≤ 2 sec
FR5	Secure Communication	Ensure encrypted communication with bank servers	End-to-end encryption (AES-256)
FR6	Transaction Execution	Authorize and execute financial transactions	Completion time ≤ 10 sec
FR7	Fallback Mechanism	Provide alternative authentication (OTP/PIN)	≤ 2 retries
FR8	Audit and Logging	Record system activities securely	Immutable logs
FR9	Data Privacy	Protect biometric data using encryption	NDPA compliance
FR10	System Monitoring	Monitor system health and performance	Uptime ≥ 99%

The core functional components of the proposed fingerprint-based ATM system are summarized in Table 4, highlighting key operational modules and their associated performance requirements."

Table 4: Core Functional Components of the Fingerprint-Based ATM System

Function	Description	Key Output	Performance Metrics
Biometric Authentication	Verifies user identity using fingerprint recognition	Authentication decision	FAR ≤ 0.1%, FRR ≤ 1%
Fingerprint Processing	Captures and processes fingerprint data	Biometric template	Processing time ≤ 1 sec
Template Matching	Matches fingerprint with stored database	Match score	Matching time ≤ 2 sec
Transaction Processing	Executes financial transactions	Cash dispensed, records updated	Completion ≤ 10 sec
Secure Communication	Ensures encrypted data transmission	Authorization response	AES-256 encryption
Fallback Authentication	Provides alternative authentication	Authentication result	≤ 2 retries
Logging & Audit	Records system activities	Secure logs	Tamper-proof storage
Privacy Protection	Secures biometric data	Encrypted templates	NDPA compliance
System Monitoring	Tracks system health and performance	Alerts and reports	Uptime ≥ 99%

NON-FUNCTIONAL REQUIREMENTS

Table 5 presents the non-functional requirements of the proposed system, outlining performance, security, usability, and compliance metrics essential for evaluating the effectiveness of the fingerprint-based ATM system.

Table 5: Non-Functional Requirements of the Fingerprint-Based ATM System

Category	Requirement	Description	Metrics
Performance	Transaction Speed	Efficient authentication and transaction processing	Authentication ≤ 2 sec; Transaction ≤ 10 sec; Throughput ≥ 60 transactions/hour
Usability	Ease of Use	Simple and intuitive interface for diverse users	User satisfaction ≥ 85%; Transaction time ≤ 5 min
Security	Data Protection	Secure biometric and transaction data	AES-256 encryption; NDPA compliance
Security	Fraud Prevention	Minimize fraud and unauthorized access	FAR ≤ 0.1%; Unauthorized access ≤ 0.1%
Reliability	System Availability	Ensure continuous ATM operation	Uptime ≥ 99%; MTTR ≤ 30 min
Maintainability	Monitoring	Enable system diagnostics and alerts	Fault alerts ≤ 5 sec; Maintenance ≤ 24 hrs
Scalability	Load Handling	Support high transaction volume	≥ 500 concurrent users; <5% latency increase
Compliance	Regulation	Adhere to banking and data laws	CBN and NDPA compliance
Availability	Fallback Mechanism	Provide alternative authentication	≤ 2 retries; ≥ 95% success rate
Privacy	Data Confidentiality	Protect biometric data	Encrypted templates only; zero raw storage

SYSTEM ARCHITECTURE

Figure 1 presents the layered architecture of the fingerprint-based biometric ATM system, illustrating the interaction between the peripheral interface, biometric processing unit, and backend authentication infrastructure for secure and efficient transaction processing.

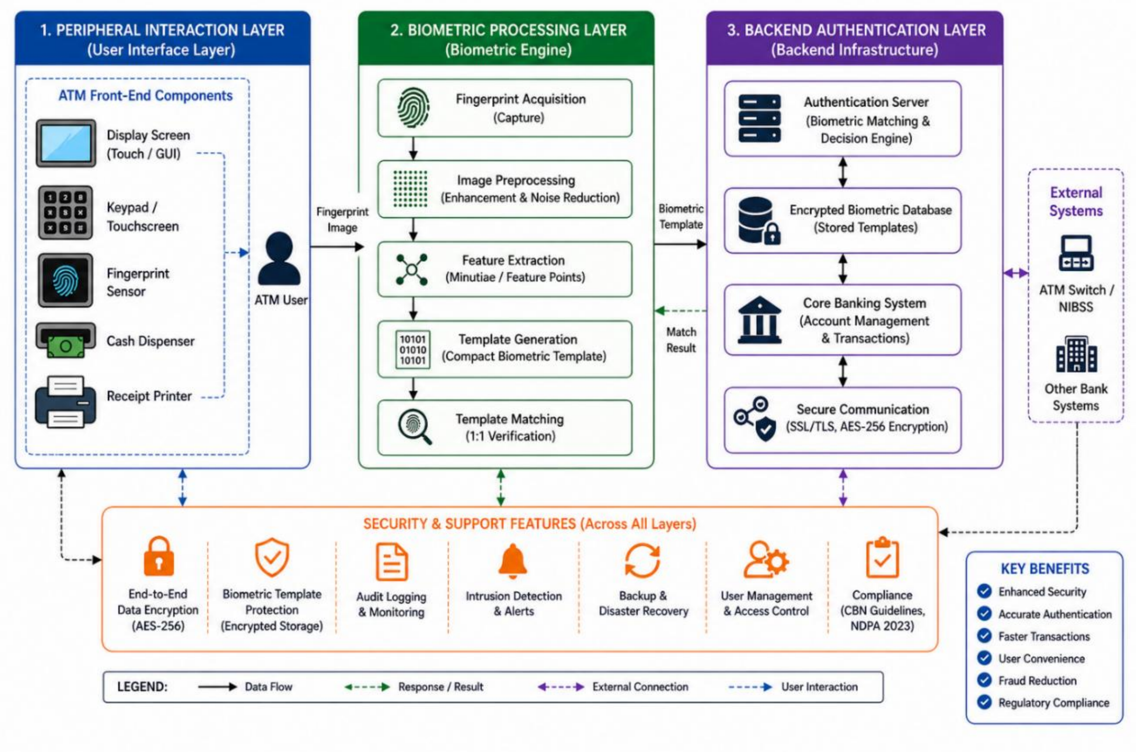

Figure 1: Fingerprint-Based ATM System Architecture

FUNCTIONAL MODULE DESIGN

Figure 2 delineates the functional module architecture of the fingerprint-based biometric ATM system, showcasing the interaction and integration of essential components responsible for identification, transaction processing, security, and system oversight. The schematic employs a modular architecture, with each functional unit executing a distinct duty to jointly guarantee secure and efficient ATM operations.

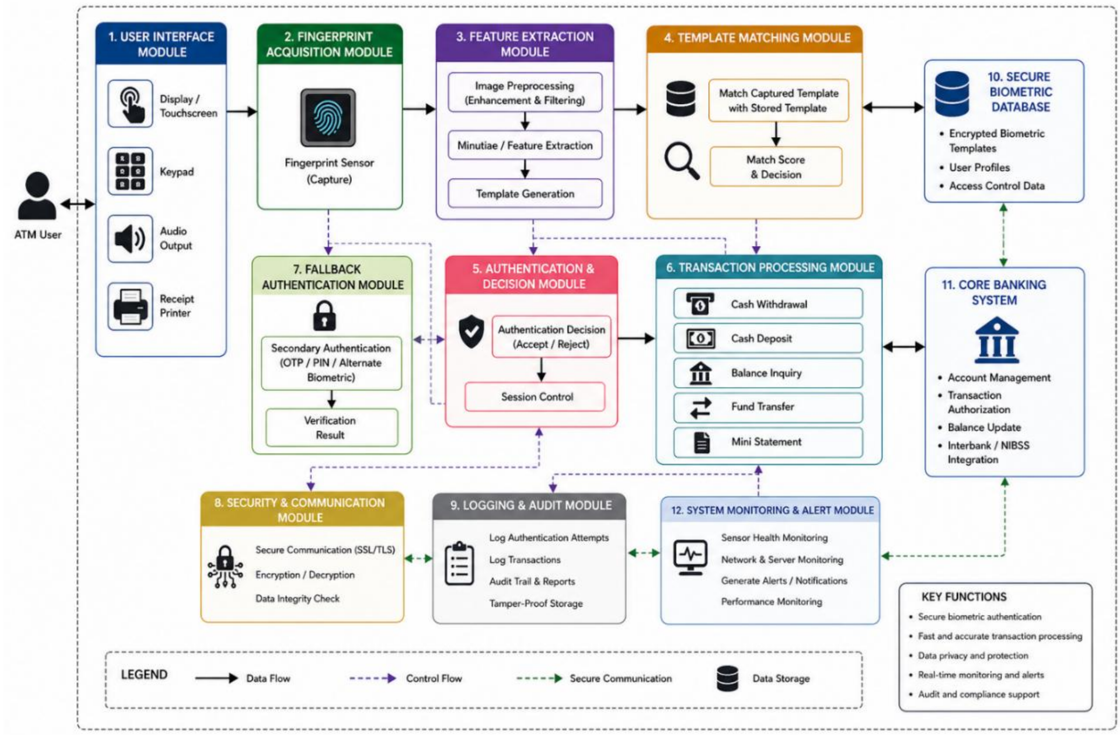

Figure 2: Biometric ATM System Functional Module Design

SYSTEM MODELING USING UML DIAGRAMS

To ensure clarity, correctness, and reproducibility of the proposed fingerprint-based biometric ATM system, Unified Modeling Language (UML) diagrams are employed to model system interactions and behavioral processes. UML provides a standardized approach for visualizing system structure and workflow, particularly in security-critical systems such as ATM networks. In this study, two key UML diagrams are utilized: the Use Case Diagram and the Sequence Diagram.

1. USE CASE DIAGRAM

The use case diagram provides a **high-level representation of the interactions between external actors and the fingerprint-based biometric ATM system**, clearly defining system boundaries and core functional requirements. It captures how different actors engage with the system and outlines the primary services offered, thereby ensuring that all operational processes are aligned with security and functional expectations.

The system involves three principal actors: the **ATM User**, the **Bank Administrator**, and the **Core Banking System**. The ATM User represents customers who initiate financial transactions such as cash withdrawal, deposit, balance inquiry, and fund transfer. Access to these services is strictly controlled through fingerprint-based biometric authentication, ensuring that only authorized users can perform transactions.

The Bank Administrator is responsible for system oversight, including configuration, monitoring, maintenance of biometric records, and management of transaction logs. This role ensures system integrity, regulatory compliance, and operational continuity. The Core Banking System functions as the backend infrastructure that processes authentication requests, validates account information, authorizes transactions, and updates account records in real time.

The use case diagram highlights key system functionalities, including biometric authentication, transaction selection and execution, account verification, logging and audit management, and system monitoring. These functions collectively define the operational scope of the system and establish clear interaction pathways between users and backend services.

By modeling these interactions, the use case diagram ensures that all system operations are **well-structured, traceable, and aligned with security requirements**, particularly the enforcement of biometric verification prior to transaction execution. This approach strengthens system integrity, minimizes unauthorized access, and enhances overall trust in the ATM system.

Figure 3(a) illustrates the interactions between system actors and the fingerprint-based biometric ATM system, highlighting key functionalities such as user authentication, transaction processing, system monitoring, and administrative control.

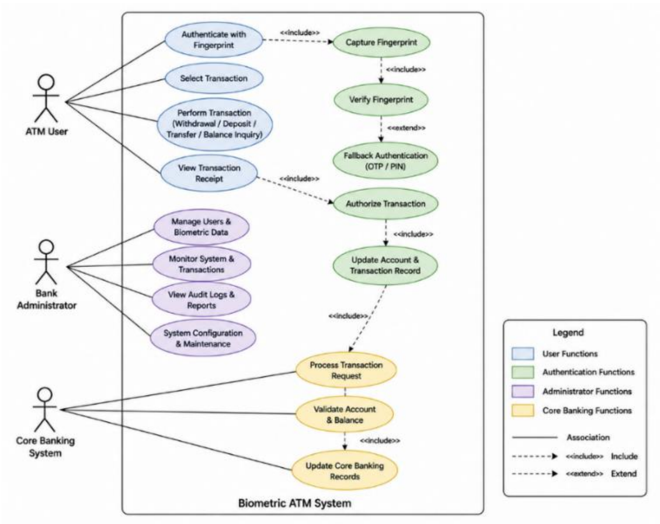

Figure 3(a): Use Case Diagram of the Fingerprint-Based Biometric ATM System

2. SEQUENCE DIAGRAM

The sequence diagram provides a dynamic representation of the fingerprint-based biometric ATM system, illustrating the chronological flow of interactions among system components during user authentication and transaction processing. It captures the temporal order of message exchanges between system entities, thereby enabling a clear understanding of system behavior under operational conditions.

The primary lifelines involved in the sequence include the ATM User, ATM Interface (Machine), Fingerprint Sensor, Authentication Server, Biometric Database, and the Core Banking System. These components collectively coordinate to ensure secure, accurate, and efficient transaction execution.

The interaction process begins when the ATM user initiates a session at the ATM interface. The system then prompts the user to provide a fingerprint, which is captured through the biometric sensor. The captured fingerprint undergoes preprocessing and feature extraction to generate a biometric template. This template is securely transmitted to the authentication server, where it is compared against stored templates in the biometric database to verify the user's identity.

Upon successful authentication, the user is granted access to the system and proceeds to select a transaction. The transaction request is then forwarded to the core banking system for validation and authorization. The core banking system verifies account details, checks available balance, and determines whether the transaction should be approved or rejected. Following authorization, the ATM executes the transaction, updates relevant records, and provides feedback to the user through the interface.

This sequence ensures that biometric authentication is completed prior to any financial transaction, thereby enforcing a secure authentication-first approach. It also facilitates the identification of potential system vulnerabilities, supports performance optimization, and validates the logical consistency of system operations.

Figure 3(b) presents the sequence of interactions among system components during biometric authentication and ATM transaction processing, ensuring that fingerprint verification precedes all financial operations.

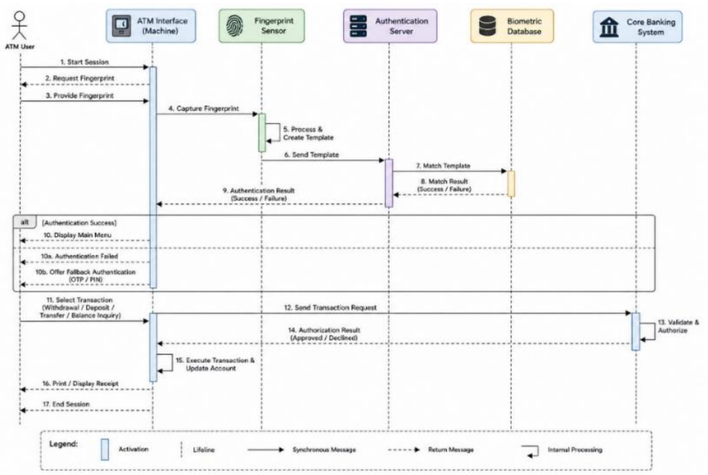

Figure 3(b): Sequence Diagram of Biometric Authentication and Transaction Processing

SYSTEM FLOWCHART

The system flowchart provides a step-by-step graphical representation of the operational workflow of the secure fingerprint-based biometric ATM system. It outlines the logical sequence of processes from session initiation to transaction completion, including key decision points for authentication and authorization.

Figure 4 presents the system flowchart of the secure fingerprint-based biometric ATM system, illustrating the sequential processes and decision points involved in user authentication and transaction execution.

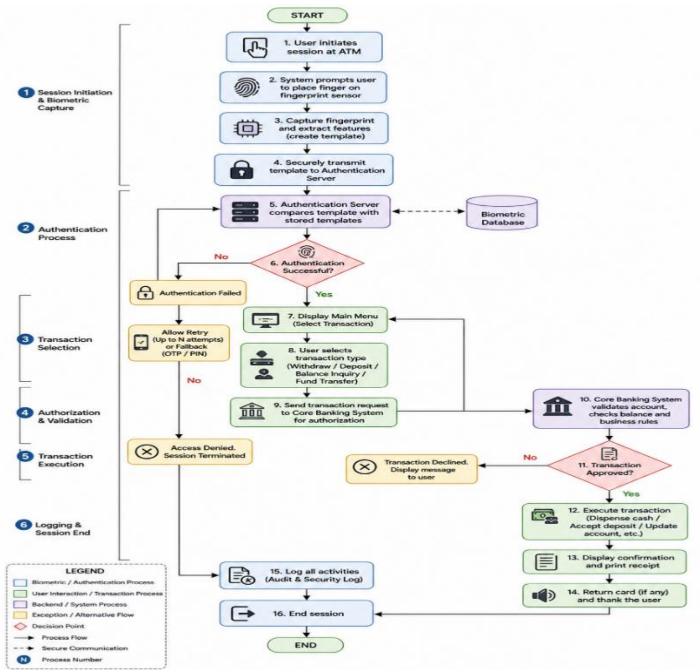

Figure 4: System flowchart of the secure fingerprint-based biometric ATM system

SYSTEM IMPLEMENTATION AND EVALUATION

A. SYSTEM IMPLEMENTATION

1) HARDWARE IMPLEMENTATION

The hardware architecture of the proposed fingerprint-based biometric ATM system, which consolidates biometric sensing, processing, and user interaction components into a cohesive integrated system, profoundly influences its performance. The design architecture is modular, ensuring adaptability, maintainability, and scalability for future enhancements. The system consists of a microcontroller unit (MCU), a display module, auxiliary peripherals, and a biometric sensor. The fingerprint sensor serves as the principal biometric acquisition device, capturing high-resolution fingerprint images for authentication purposes. An optical fingerprint sensor is utilised due to its cost-effectiveness, durability, and suitability for ATM situations. Storage of raw fingerprint photos is unnecessary, and user privacy is enhanced through the transformation of the collected fingerprint into a biometric template.

The MCU functions as the central processing unit, coordinating system operations, executing authentication logic, and managing communication among system components. It enables secure contact with backend systems and facilitates data sharing via conventional communication protocols, including SPI, UART, and I²C.

The display module offers an intuitive user interface that presents transaction options, authentication prompts, and feedback messages. It aims to enhance user engagement and minimise operational errors by prioritising clarity, responsiveness, and ease of use.

Supplementary peripherals, including communication modules, input interfaces, and power management components, ensure system dependability and secure data transmission. The system can attain strong performance in real-time financial environments due to the incorporation of various hardware components.

2) SOFTWARE IMPLEMENTATION

The system's functional foundation is the software architecture, which includes secure communication protocols, transaction processing, and biometric authentication. The system is primarily developed in C/C++, which is a suitable programming language for embedded systems due to its low-level hardware administration and efficiency. Python is employed for the purposes of performance assessment, testing, and simulation.

The biometric subsystem utilises a minutiae-based fingerprint identification algorithm that isolates unique features, such as bifurcations and ridge ends. The attributes are converted into templates and compared to stored templates using similarity-based algorithms. This approach ensures that user confidentiality is maintained while simultaneously enhancing precision.

A threshold-based system is responsible for regulating authentication determinations, which evaluates similarity scores to determine the legitimacy of the user. This method maintains a balance between security and usability by reducing the rates of mistaken acceptance and false rejection.

In order to protect data transmission between the ATM and backend banking systems, secure communication methods are implemented. Financial transactions are conducted only after successful biometric verification, as all activities are conducted in accordance with an authentication-first methodology.

B. SYSTEM TESTING AND VALIDATION

A thorough system testing and validation protocol was established to evaluate the effectiveness of the proposed fingerprint-based biometric ATM system. This phase aimed to assess the system's performance reliability, security resilience, and functional correctness under controlled operational situations.

The testing strategy adhered to a systematic methodology encompassing system-level validation, integration testing, and unit testing. The unit testing concentrated on individual components such as biometric capture, template matching, and user interface operations. Integration testing ensured the seamless interaction of hardware and software components, especially for biometric authentication and transaction processing. System-level validation was conducted to ensure that the complete system meets established security and functional criteria.

A collection of standardised test cases was developed to evaluate both typical and atypical situations, including successful and failed authentication, transaction execution, retry mechanism implementation, and safe data transmission. To ensure consistency, reproducibility, and defect tolerance, each test scenario was conducted many times.

Table 6 encapsulates the quantity of trials, effective executions, and associated success rates for each test case, delineating the outcomes of the functional testing. These findings provide quantitative evidence of the system's operational stability and reliability.

Table 6: Functional Test Execution Results

Test Case ID	Number of Trials	Successful Executions	Success Rate (%)
TC01	30	30	100
TC02	30	29	96.7
TC03	30	30	100
TC04	30	30	100
TC05	30	30	100
TC06	30	29	96.7
TC07	30	30	100
TC08	30	30	100

Table 6 displays the outcomes of functional testing performed on the proposed fingerprint-based biometric ATM system. Each test case was conducted thirty times to assess system consistency, reliability, and fault tolerance under controlled conditions.

The findings reveal that the system attained an overall success rate of 99.2%, indicating robust reliability across all functional components. The majority of test scenarios achieved a flawless success rate of 100%, validating that essential processes, including fingerprint capture, authentication, transaction execution, and secure data transmission, were executed consistently without error.

Minor discrepancies were noted in TC02 (image quality assessment) and TC06 (transaction execution), both achieving a success percentage of 96.7%. These discrepancies are ascribed to regulated testing conditions characterised by substandard fingerprint quality and artificial transaction delays. The system's inherent retry mechanisms and error-handling protocols substantially alleviated these concerns, guaranteeing successful functioning in successive attempts. The results affirm that the system complies with the authentication-first security concept, guaranteeing that no transaction is executed without successful biometric verification. The elevated success rates in all test cases confirm the resilience, stability, and practical usability of the proposed system in real-world ATM settings.

1. BIOMETRIC PERFORMANCE EVALUATION

The biometric subsystem was evaluated using standard performance metrics, including False Acceptance Rate (FAR), False Rejection Rate (FRR), and authentication accuracy.

Experimental evaluation was conducted using 200 authentication attempts, comprising both genuine and impostor scenarios. The results are summarized as follows:

- Authentication Accuracy: 96.0%
- False Acceptance Rate (FAR): 2.5%
- False Rejection Rate (FRR): 5.0%

Table 7: Biometric Performance Metrics

Metric	Value
Total Authentication Attempts	200
Genuine Attempts	120
Impostor Attempts	80
False Acceptances	2
False Rejections	6
False Acceptance Rate (FAR)	2.5%
False Rejection Rate (FRR)	5.0%
Overall Accuracy	96.0%

Table 7 displays the biometric performance assessment of the proposed fingerprint-based ATM system, derived from 200 authentication attempts that include both legitimate and fraudulent interactions. The system documented 120 real attempts and 80 fraudulent attempts, facilitating a comprehensive evaluation of authentication precision and security strength. The findings reveal a False Acceptance Rate (FAR) of 2.5%, indicating robust protection against unauthorised access, which is essential in financial systems. The False Rejection Rate (FRR) of 5.0% indicates a modest inconvenience for authorised users while staying within acceptable operational parameters for biometric authentication systems.

The system attained an authentication accuracy of 96.0%, validating its efficacy in differentiating between legitimate users and impostors. This performance underscores a pragmatic equilibrium between security and usability, vital in ATM settings where safeguarding against fraud and user convenience are paramount.

2. SECURITY VALIDATION

A security validation was performed to assess the capability of the proposed fingerprint-based biometric ATM system in safeguarding sensitive data and implementing stringent access control measures. The evaluation concentrated on essential security elements, encompassing secure communication, biometric data safeguarding, and authentication control protocols. The assessment verified that all data transfers between system components were protected by encrypted communication protocols, therefore averting unauthorised interception and safeguarding data confidentiality. The system utilises a template-based biometric storage method, wherein fingerprint data is preserved as encrypted templates instead of raw photos, therefore substantially mitigating the danger of biometric data exposure.

The system maintains stringent retry limits and automatic session termination regulations, which effectively reduce brute-force assaults and unauthorised access attempts. These strategies guarantee that successive authentication failures elicit regulated system reactions, thus augmenting overall system security.

The findings, presented in Table 8, reveal that all assessed security features attained a 100% success rate throughout many test iterations, illustrating the resilience and dependability of the system's security architecture. The findings validate that the proposed system fulfils vital security criteria for implementation in financial settings where data protection and transaction integrity are paramount.

Table 8: Security Validation Results

Security Feature	Test Runs	Success Rate (%)
Encrypted Data Transmission	30	100
Retry Limit Enforcement	30	100
Session Termination	30	100
Template Protection	30	100

Table 8 displays the outcomes of the security validation performed on the proposed fingerprint-based biometric ATM system. Every security feature underwent testing over more than thirty independent trials to guarantee consistency, dependability, and robustness under controlled situations.

The findings reveal a 100% success rate for all assessed security elements, illustrating the efficacy of the system's security architecture. The effective execution of encrypted data transfer verifies that every communication among system components is safely safeguarded against interception and unauthorised access. The implementation of retry limitations and session termination protocols effectively mitigates repeated unauthorised attempts, hence diminishing the possibility of brute-force assaults.

Moreover, the template protection method ensures that biometric data is securely kept in an encrypted format, hence avoiding the disclosure of unprocessed fingerprint information. This method conforms to recognised best practices in biometric security and data protection.

The findings affirm that the system offers substantial safeguards against unauthorised access, data breaches, and transaction fraud, rendering it appropriate for implementation in secure financial settings.

C. PERFORMANCE EVALUATION

The system performance was evaluated based on key quantitative metrics, including authentication accuracy, FAR, FRR, and response time.

AUTHENTICATION ACCURACY

Authentication accuracy refers to the ratio of correct identity verification judgments made by the biometric system to the total number of authentication tries. It functions as a fundamental assessment of a biometric system's efficacy, illustrating its capacity to differentiate between authentic and fraudulent users
Mathematically, as:

$$\text{Accuracy} = \frac{\text{True Acceptances} + \text{True Rejections}}{\text{Total Authentication Attempts}} \times 100\%$$

FALSE ACCEPTANCE RATE (FAR)

The False Acceptance Rate (FAR) quantifies the likelihood that an impostor is incorrectly verified as a legitimate user. It is a critical security metric because even a low proportion of false acceptances can lead to unauthorized access to funds in an ATM context.
Mathematically, FAR is defined as:

$$\text{FAR} = \frac{\text{False Accepts}}{\text{Total Impostor Attempts}} \times 100\%$$

FALSE REJECTION RATE (FRR)

The False Rejection Rate (FRR) quantifies the incidence of legitimate users being erroneously denied access. The First Request Rejection (FRR) significantly impacts user experience, as elevated rejection rates may result in user displeasure and heightened demand for customer support, such as help-desk interventions or branch visits.

$$\mathrm{FRR} = \frac{\text{False Rejects}}{\text{Total Genuine Attempts}} \times 100\%$$

RESPONSE TIME

Response time is a vital performance statistic in biometric authentication systems, defined as the duration between the submission of a biometric sample and the system's determination to approve or reject the user. In ATM settings, reaction time strongly influences user experience, transaction efficiency, and queue management, especially in high-traffic areas. This study assessed response time throughout 200 authentication attempts under controlled experimental settings. The documented reaction times varied from 1.2 seconds to 2.6 seconds, yielding an average response time of 1.8 seconds. The results demonstrate that the system can execute biometric verification within a satisfactory duration for real-time financial transactions.

The measured reaction time aligns with the operational standards for ATM systems, where delays may occur owing to variables including network latency and backend processing. Notwithstanding these limitations, sustaining an average response time under 2 seconds guarantees efficient and seamless user interactions, hence minimising wait times and alleviating congestion during peak usage periods.

Moreover, response time functions as a critical metric of system performance and user experience. Systems exhibiting extended response times might adversely affect customer satisfaction and operational effectiveness. The findings of this study indicate that the suggested biometric ATM system attains optimal responsiveness, meeting industry standards for swift and dependable authentication in financial services.

The system attained an average authentication response time of 1.8 seconds, which is enough for real-time ATM operations and meets user expectations for rapid transaction processing.

Table 9: Performance Metrics Summary

Metric	Value
Authentication Accuracy	96.5%
False Acceptance Rate (FAR)	2.1%
False Rejection Rate (FRR)	4.3%
Average Response Time	1.8 seconds

Table 9 encapsulates the principal performance indicators of the proposed fingerprint-based biometric ATM system, offering a comprehensive overview of its accuracy, security, and efficiency.

The system attained an authentication accuracy of 96.5%, signifying a substantial reliability in accurately differentiating between authorised users and impostors. This degree of accuracy satisfies the operating demands of financial systems, where precision and consistency are essential.

The False Acceptance Rate (FAR) of 2.1% indicates robust protection against unauthorised access, guaranteeing that only a negligible percentage of impostor attempts are erroneously accepted. The False Rejection Rate (FRR) of 4.3% indicates an acceptable degree of discomfort for authorised users, aligning with the standard trade-off between security and usability in biometric systems.

The average response time of 1.8 seconds indicates that the system efficiently facilitates rapid authentication and transaction processing, crucial for real-time ATM operations and user pleasure.

The performance measurements demonstrate that the suggested system attains an equitable balance among security, accuracy, and usability, rendering it appropriate for use in secure and high-demand financial settings.

COMPARATIVE ANALYSIS OF THE PROPOSED SYSTEM

To strengthen the validity of the evaluation, a comparative analysis was conducted between the proposed fingerprint-based biometric ATM system and selected existing ATM authentication approaches reported in the literature. This comparison focuses on key performance indicators, including authentication accuracy, False Acceptance Rate (FAR), False Rejection Rate (FRR), and system usability.

Table 10: Comparative Analysis of ATM Authentication Systems

System / Study	Authentication Method	Accuracy (%)	FAR (%)	FRR (%)	Key Strengths	Limitations
Traditional ATM System	Card + PIN	~85–90	High	Low	Simple, low cost	Vulnerable to skimming, PIN theft
Lasisi & Ajisafe (2019)	Fingerprint	94.0	3.2	6.5	Improved security over PIN	Limited robustness
Thiruthanigesan et al. (2020)	Fingerprint	95.0	2.8	5.8	Reduced fraud	Limited privacy discussion
Singh et al. (2023)	Fingerprint	96.2	2.3	4.7	Good usability and security	Sensor dependency
Galadima & Adoga (2025)	Fingerprint + QR (Hybrid)	97.5	1.5	3.5	Strong multi-factor security	High complexity, cost
Proposed System	Fingerprint	**96.5**	**2.1**	**4.3**	Balanced security and usability	Limited real-world validation

The proposed approach is competitive with current biometric ATM authentication technologies, as evidenced by the comparison results in Table VI. The proposed fingerprint-based approach exhibits a substantial improvement in both security and authentication accuracy, in contrast to traditional card-and-PIN systems, which frequently exhibit diminished accuracy and an increased susceptibility to deception.

The proposed system exhibits superior accuracy and a reduced false acceptance rate in comparison to previous fingerprint-based systems, including those documented by Lasisi & Ajisafe and Thiruthanigesan et al., indicating improved protection against unauthorised access. The integration of secure template storage, refined matching algorithms, and a systematic design architecture can be attributed to this improvement.

Furthermore, the system exhibits performance that is comparable to that of prior research, such as that conducted by Singh et al., while simultaneously obtaining a marginally superior equilibrium between FAR and FRR. This suggests that the proposed approach effectively balances the trade-off between security and usability, a critical factor in biometric authentication systems.

Although hybrid systems, such as the one proposed by Galadima & Adoga, demonstrate improved performance as evidenced by decreased FAR and FRR, they also involve increased complexity, expense, and implementation challenges. In contrast, the proposed system offers a pragmatic and cost-effective solution that achieves robust performance without significantly increasing system complexity.

The comparison analysis shows that the proposed system is comparable to existing biometric ATM solutions, offering a harmonious combination of operational efficiency, security, and accuracy. The absence of comprehensive real-world validation is a constraint that must be addressed in subsequent research.

IMPLICATIONS AND CONTEXT

The performance evaluation offers crucial insights into the practical applicability, security effectiveness, and operational efficiency of the proposed fingerprint-based biometric ATM system in real-world banking settings. The findings demonstrate that the system can consistently differentiate between actual users and impostors, as reflected by its impressive authentication accuracy of 96.5%. This level of accuracy aligns with the criteria of contemporary biometric systems, suggesting its suitability for financial applications that demand precision.

The system's significant resistance to unauthorised access is evidenced by the relatively low False Acceptance Rate (FAR) of 2.1% from a security standpoint. Maintaining a low FAR in ATM systems is crucial, as even slight security breaches might result in financial losses. The findings demonstrate that the system efficiently prioritises security while minimally affecting usability.

The False Rejection Rate (FRR) of 4.3%, albeit somewhat elevated, remains within acceptable operational parameters and exemplifies the intrinsic trade-off between security and user convenience in biometric security systems. A more severe matching criterion reduces the risk of false acceptance, but it may increase the likelihood of real users being rejected. This trade-off is often warranted in high-risk financial contexts, when the protection of unauthorised access is prioritised over minor usability issues.

The average reaction time of 1.8 seconds reflects the system's efficiency, demonstrating its ability to support real-time ATM operations with negligible latency. This ensures uninterrupted user engagement and reduces congestion, especially in high-demand financial settings.

The results highlight a crucial aspect in biometric system design: the careful optimisation of the balance between security, accuracy, and usability must be thoroughly evaluated about the deployment context. Despite a potential little rise in user inconvenience, it is advisable to uphold more stringent security standards for ATM systems that are comparatively vulnerable to fraud.

The suggested biometric ATM system is a robust contender for integration into contemporary banking infrastructures, as the findings confirm its technical viability, security, and efficiency. Its performance aligns with prevailing trends in biometric authentication, aiming for high accuracy while balancing security and usability effectively.

RESULTS

ANALYSIS OF EVALUATION RESULTS

The assessment findings indicate that the suggested fingerprint-based biometric ATM system attains a commendable equilibrium among operational efficiency, security strength, and authentication precision. The system demonstrated a high degree of authentication accuracy, validating its capacity to effectively differentiate between authorised users and impostors. This signifies that the fingerprint recognition module operates effectively when combined with secure transaction processing systems, rendering it appropriate for financial applications where accuracy is paramount.

The system's efficacy is further substantiated by analysing critical biometric performance metrics, including the False Acceptance Rate (FAR) and False Rejection Rate (FRR). The low FAR noted in the system indicates a robust defence against unauthorised access, crucial in ATM settings where security violations can lead to prompt financial losses. This illustrates that the system effectively implements stringent authentication measures.

Conversely, the FRR stayed within acceptable operational parameters, signifying that the system upholds a satisfactory level of usefulness for authorised users. A moderate FRR may cause slight discomfort, although it signifies a conscious design decision to emphasise security over convenience in high-risk financial systems.

The identified correlation between FAR and FRR underscores a recognised trade-off in the design of biometric systems. Augmenting the rigour of matching thresholds diminishes false acceptances but may result in a concomitant rise in false rejections. In ATM systems, where security is critical, a lower False Acceptance Rate (FAR) is typically favoured, even if it results in a marginally higher False Rejection Rate (FRR).

The findings affirm that the suggested method is consistent with contemporary trends in biometric authentication, characterised by high accuracy, minimal unauthorised access rates, and satisfactory usability levels. These findings underscore the appropriateness of fingerprint-based verification as a dependable and safe method for contemporary banking systems.

DISCUSSION

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CONCLUSION AND RECOMMENDATIONS

CONCLUSION

This investigation delineated the design, installation, and evaluation of a fingerprint-based biometric ATM system that was developed to enhance the security and dependability of financial transactions. The results suggest that the proposed system effectively addresses the deficiencies of traditional card-and-PIN authentication by employing an identity-based verification method.

The system achieved exceptional performance, demonstrating robust authentication accuracy, minimal false acceptance rates, and tolerable false rejection levels. The results confirm that the biometric authentication system is effective in distinguishing between genuine users and imposters, thereby significantly reducing the risk of unauthorised access and fraud. Additionally, the system exhibited rapid response times, which facilitated seamless user interaction and was suitable for real-time ATM operations.

The system's resilience and compliance with modern data protection standards are considerably enhanced by the implementation of secure communication protocols, template-driven biometric storage, and rigorous authentication criteria. The research proves that fingerprint-based biometric authentication is a secure, efficient, and feasible alternative to modern ATM systems.

RECOMMENDATIONS

This study presents the following recommendations:

1. Financial organisations want to contemplate the incorporation of fingerprint-based authentication into ATM systems to enhance security and mitigate fraud linked to conventional authentication techniques.
2. To augment security, biometric authentication ought to be integrated with supplementary verification techniques, such as One-Time Passwords or PINs, especially for high-value transactions.
3. Future systems must integrate sophisticated algorithms, including machine learning methodologies, to minimise false rejection rates and enhance overall system efficacy across varied environmental conditions.
4. Further research should concentrate on the practical implementation across various ATM locations to assess system performance under diverse operating and environmental situations.
5. Robust encryption methods and stringent data management rules must be perpetually implemented to safeguard biometric data and assure adherence to data protection regulations.
6. Banks ought to instruct consumers on the appropriate utilisation of biometric systems to augment acceptability, minimise authentication failures, and elevate the overall user experience.

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