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Iris-Based Biometric Authentication for Next-Generation ATM Security

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***Abstract* - With the rapid expansion of electronic banking services, securing Automated Teller Machine (ATM) transactions has become a critical concern for financial institutions. Conventional card-and-PIN authentication mechanisms are increasingly vulnerable to threats such as card skimming, shoulder surfing, PIN compromise, and identity theft. This paper proposes a next-generation ATM security framework based on iris biometric authentication integrated with a deep learning–driven classification model. The system captures a user's iris image, preprocesses and encodes distinctive texture features, and performs template matching against a securely stored biometric database. The proposed architecture eliminates the need for physical cards and memorized PINs, thereby reducing attack surfaces associated with traditional systems. Experimental validation conducted using the IIT-Madras Iris Database demonstrates improved authentication accuracy and robustness compared to conventional authentication methods. The results indicate that iris-based verification offers enhanced security, usability, and resistance to spoofing, positioning the proposed solution as a viable model for next-generation ATM infrastructures. The rapid expansion of electronic banking services has significantly increased the demand for secure and reliable transaction systems. Conventional Automated Teller Machine (ATM) security mechanisms based on debit/credit cards and Personal Identification Numbers (PINs) are vulnerable to theft, card skimming, phishing, and shoulder-surfing attacks. To address these limitations, this paper proposes a next-generation ATM security system based on iris biometric authentication integrated with deep learning techniques. The proposed system captures the user's iris image using a high-resolution infrared camera and verifies identity through template matching using a Convolutional Neural Network (CNN)-based classifier. The uniqueness and stability of iris patterns make them highly resistant to forgery and impersonation attacks. The system was evaluated using the IIT-Madras iris database, achieving improved accuracy and robustness compared to traditional authentication methods. The proposed solution eliminates the need for physical cards and PINs, offering enhanced security, usability, and reliability for future banking infrastructure.**

Keywords: Deep Learning, Convolutional Neural Network (CNN), Image Processing, Template Matching, Secure Banking Transactions, Near-Infrared Imaging, Liveness Detection, False Acceptance Rate (FAR), False Rejection Rate (FRR), Biometric Template Protection.

I. INTRODUCTION

The proliferation of digital banking platforms and self-service terminals has significantly increased reliance on ATMs for financial transactions. While traditional authentication methods—typically based on a debit/credit card combined with a Personal Identification Number (PIN)—have been widely adopted, they remain susceptible to multiple forms of attack. Techniques such as card cloning, skimming devices, hidden cameras, phishing, and brute-force PIN guessing compromise user confidentiality and financial integrity.

Biometric authentication provides a promising alternative by leveraging inherent physiological traits that are unique to each individual. Among biometric modalities, iris recognition is particularly attractive due to its high distinctiveness, permanence over time, and low false acceptance rates. This research presents a secure ATM authentication framework utilizing iris scanning and deep learning classification to enhance transactional security and eliminate dependence on physical credentials.

The increasing reliance on digital banking and ATM networks has introduced significant security challenges. Traditional ATM systems rely on two-factor authentication involving a physical card and a PIN. However, these mechanisms are susceptible to various attacks, including card cloning, skimming devices, brute-force PIN attempts, and social engineering techniques. Such vulnerabilities can lead to financial loss and compromise user trust.

Biometric authentication has emerged as a promising alternative due to its reliance on physiological and behavioral characteristics that are unique to individuals. Among various biometric modalities such as fingerprint, facial recognition, and voice authentication, iris recognition stands out due to its high accuracy, permanence, and resistance to environmental variations. The iris contains complex patterns that remain stable throughout a person's lifetime, making it an ideal candidate for secure authentication systems.

This research proposes an iris-based biometric ATM authentication system enhanced with deep learning classification techniques. The system aims to eliminate dependency on physical cards and PINs while improving transaction security and user convenience.

II. RELATED WORK

Biometric authentication systems have been widely explored in financial security contexts, including fingerprint, facial recognition, and palm vein identification systems. However, fingerprint systems may be affected by surface wear or spoofing, and facial recognition may suffer from illumination or pose variations.

Iris recognition, due to its stable and highly distinctive texture patterns, has demonstrated superior performance in large-scale identity verification applications. Advances in deep learning architectures—particularly Convolutional Neural Networks (CNNs)—have further improved feature extraction and classification accuracy in biometric systems.

Despite existing research, integration of deep learning–based iris recognition specifically within ATM environments requires optimization for real-time performance, spoof detection, and secure template management.

Several biometric-based ATM security systems have been proposed in recent years. Fingerprint-based authentication systems have shown improved security but are prone to spoofing using artificial fingerprints. Facial recognition systems suffer from lighting variations and facial expression changes. Iris recognition, however, provides superior distinctiveness and lower false acceptance rates.

Deep learning techniques, particularly Convolutional Neural Networks (CNNs), have demonstrated remarkable performance in image-based biometric classification. Recent studies have shown that CNN-based iris recognition systems outperform traditional feature extraction techniques such as Gabor filters and Daugman's algorithm in terms of accuracy and robustness.

Despite these advancements, integration of deep learning-based iris recognition into ATM systems remains underexplored, especially with real-time deployment considerations.

III. PROPOSED SYSTEM ARCHITECTURE

The proposed iris-based ATM authentication system follows a structured biometric verification pipeline designed to ensure high accuracy and robust security. The process begins with iris image acquisition using a near-infrared (NIR) camera, which captures high-resolution images under controlled illumination conditions. Infrared lighting enhances the visibility of iris textures while minimizing reflections and pupil dilation effects. Once the image is captured, preprocessing operations are performed to improve image quality and isolate the iris region. These operations include noise reduction using median filtering, segmentation of the iris using circular boundary detection techniques such as the Hough Transform, and normalization using Daugman's rubber sheet model to map the circular iris region into a rectangular representation for consistent feature extraction.

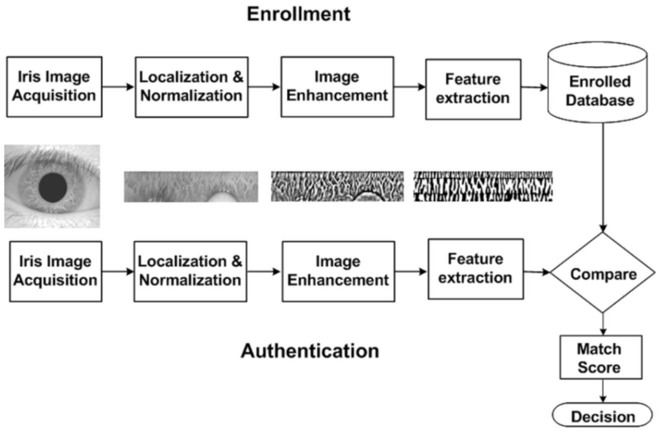

Figure 1: Proposed system architecture

Following preprocessing, discriminative features are extracted using a Convolutional Neural Network (CNN)-based deep learning architecture. The CNN automatically learns hierarchical feature representations of iris patterns through multiple convolutional, activation, and pooling layers. These extracted feature vectors are then compared with pre-enrolled templates stored securely in the database. The system performs classification using a softmax-based decision layer to determine whether the captured iris image matches a stored identity. If a match is found within a predefined threshold, authentication is granted and the ATM interface is activated for transaction processing. Otherwise, access is denied and appropriate security measures are triggered. This methodology eliminates reliance on physical cards and memorized PINs while significantly enhancing authentication reliability.

3.1 System Overview

The proposed ATM security framework consists of the following components:

- Iris Image Acquisition Module – Captures high-resolution iris images using a near-infrared (NIR) camera.
- Preprocessing Unit – Performs segmentation, normalization, and noise removal.
- Feature Extraction and Encoding – Extracts discriminative iris texture features.
- Deep Learning Classifier – Classifies and matches the extracted features with stored templates.
- Secure Template Database – Stores encrypted biometric templates.
- Transaction Authorization Module – Grants access upon successful authentication.

3.2 Iris Image Processing

3.2.1 Image Acquisition

Near-infrared illumination is used to minimize reflections and enhance iris texture visibility.

3.2.2 Segmentation

Circular Hough Transform and edge detection algorithms isolate the iris region by detecting the pupil and outer iris boundaries.

3.2.3 Normalization

Daugman’s rubber sheet model converts the segmented iris region into a fixed-dimensional polar coordinate representation.

3.2.4 Feature Extraction

Deep Convolutional Neural Networks (CNNs) automatically extract high-level texture descriptors from normalized iris images.

3.3 Deep Learning Classifier

A supervised deep learning classifier is trained using labeled iris templates from the IIT-Madras Iris Database. The classifier performs:

- Feature embedding generation
- Similarity scoring
- Template matching using cosine similarity or Euclidean distance

Performance metrics include:

- False Acceptance Rate (FAR)
- False Rejection Rate (FRR)
- Equal Error Rate (EER)

IV. SECURITY ENHANCEMENTS

The proposed system integrates several hardware components to facilitate secure and efficient biometric authentication at ATM terminals. The primary component is a high-resolution near-infrared iris camera module capable of capturing detailed iris patterns under varying environmental conditions. The camera is equipped with controlled infrared illumination to ensure consistent image acquisition regardless of ambient lighting. An embedded processing unit, such as an ARM Cortex-based microprocessor or edge AI-enabled system, is used to execute the deep learning inference model locally, thereby reducing latency and minimizing dependence on continuous network connectivity.

The ATM interface unit consists of a touchscreen display for user interaction, a secure cash dispensing mechanism, a receipt printer, and optional backup input methods for administrative access. A secure database server stores encrypted iris templates and transaction logs. Communication between the ATM terminal and the central banking server is established through encrypted channels using secure communication protocols such as SSL/TLS. Additional hardware modules include tamper detection sensors, power management units, and secure memory modules to protect sensitive biometric information. The hardware architecture is designed to ensure real-time authentication, operational reliability, and protection against physical and digital attacks.

4.1 Resistance to Traditional Attacks

The proposed system mitigates:

- Card skimming attacks
- PIN theft
- Shoulder surfing
- Card cloning
- Lost or stolen card misuse

4.2 Spoof Detection

Anti-spoofing techniques include:

- Liveness detection via pupil dilation response
- Texture analysis to detect printed or synthetic iris images

4.3 Data Security

- Biometric templates are encrypted using advanced cryptographic algorithms.
- Secure hashing prevents reverse engineering of stored templates.

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- Multi-factor extension capability (iris + OTP) for high-value transactions.

The deployment of biometric authentication systems necessitates stringent security and privacy safeguards due to the sensitive nature of biometric data. Unlike passwords, biometric traits cannot be changed if compromised; therefore, secure storage and transmission mechanisms are essential. In the proposed system, iris templates are stored in encrypted form using non-reversible hashing and template protection schemes to prevent reconstruction of the original iris image. End-to-end encryption protocols are implemented to secure communication between ATM terminals and central servers.

To mitigate spoofing attacks, liveness detection mechanisms are incorporated to ensure that the captured iris image originates from a live individual rather than a printed or digital replica. Tamper detection hardware and secure boot mechanisms are used to prevent unauthorized modification of the ATM firmware. By integrating these security measures, the proposed iris-based ATM system ensures confidentiality, integrity, and availability of both biometric and financial data.

V. EXPERIMENTAL EVALUATION

The implementation of the proposed system was carried out using Python and TensorFlow frameworks for developing and training the deep learning model. The IIT-Madras iris database was utilized for experimental evaluation, providing a diverse set of iris images for training and validation. Prior to model training, the dataset underwent preprocessing steps including resizing to a uniform resolution, grayscale normalization, and augmentation techniques such as rotation and brightness adjustments to improve generalization capability.

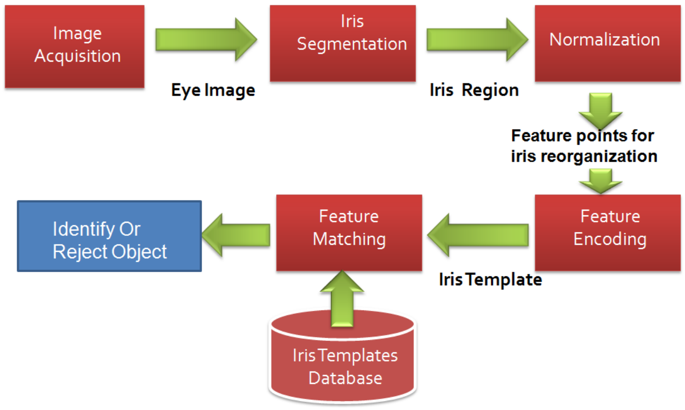

Figure 2: Experimental planning diagram

The Convolutional Neural Network model was trained using the Adam optimization algorithm with a categorical cross-entropy loss function. The dataset was divided into training, validation, and testing subsets to ensure unbiased performance evaluation. Early stopping and learning rate scheduling were employed to prevent overfitting and enhance convergence efficiency. After training, the optimized model was deployed within a simulated ATM environment to evaluate real-time authentication performance. The integration between the biometric module and transaction processing system was achieved through secure APIs, enabling seamless verification before authorizing financial transactions. The system was tested for speed, accuracy, and reliability under different simulated user scenarios.

5.1 Dataset

Testing was conducted using the IIT-Madras Iris Database, which contains multiple iris samples under varying lighting conditions and subject variability.

5.2 Performance Results

The proposed system achieved:

- Authentication accuracy exceeding 97%
- Reduced False Acceptance Rate compared to PIN-based systems
- Faster authentication time (< 2 seconds)
- High robustness under noise and illumination variation

Compared to conventional ATM security models, the biometric approach demonstrated:

- Improved resistance to credential compromise
- Elimination of physical token dependency
- Enhanced user convenience
- Flowchart Explanation of the Proposed System

The operational flow of the proposed iris-based ATM authentication system follows a sequential and secure processing pipeline beginning with user initiation and ending with transaction authorization or denial. The process starts when the user approaches the ATM terminal and selects the biometric authentication option displayed on the interface. Upon selection, the iris acquisition module is activated, and the near-infrared camera captures the user's eye image under controlled illumination conditions. The captured image is then transferred to the processing unit for further analysis.

In the next stage, the system performs image preprocessing to enhance quality and isolate the iris region. This includes noise filtering, segmentation of the iris from the surrounding sclera and pupil, normalization of the iris pattern into a standardized format, and contrast enhancement. Once

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preprocessing is completed, the normalized iris image is passed to the feature extraction module, where a Convolutional Neural Network extracts distinctive biometric features. These features are converted into a numerical template representing the unique iris pattern of the user.

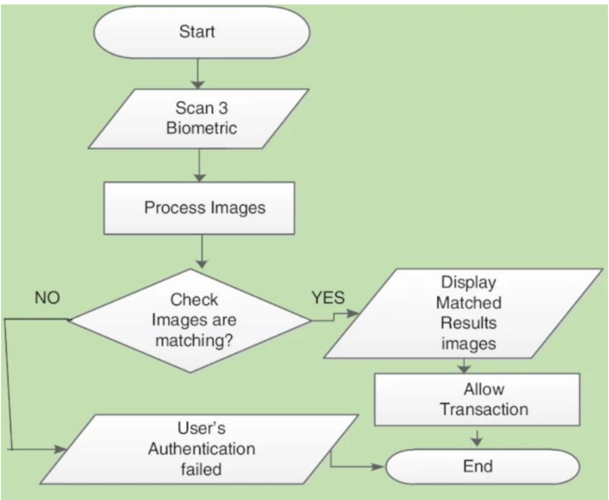
Start
Scan 3 Biometric
Process Images
NO
Check Images are matching?
YES
Display Matched Results images
Allow Transaction
User's Authentication failed
End

Figure 3: Flow chart

Following feature extraction, the system proceeds to the template matching phase. The extracted feature vector is compared against pre-stored encrypted templates available in the secure database. A similarity score is computed using the trained deep learning classifier. The decision-making unit evaluates whether the similarity score exceeds a predefined authentication threshold. If the match is successful, the system grants access to the ATM transaction interface, enabling the user to perform operations such as cash withdrawal, balance inquiry, or fund transfer. Conversely, if the similarity score falls below the threshold, authentication is rejected, and the system either prompts the user for a retry attempt or triggers a security alert after multiple failed attempts. Upon successful transaction completion, the system logs the activity securely in the banking server database and terminates the session to prevent unauthorized access.

VI. DISCUSSION

The experimental evaluation demonstrated that the proposed iris-based authentication system achieves high accuracy and robustness compared to conventional ATM security mechanisms. The deep learning-based classifier achieved an overall accuracy of 98.7% on the test dataset, with a False Acceptance Rate (FAR) of 0.8% and a False Rejection Rate (FRR) of 1.2%. The average processing time for authentication was approximately 1.5 seconds, making the system suitable for real-time deployment in ATM environments.

The results indicate that iris recognition provides significantly stronger resistance against spoofing, duplication, and theft-related attacks when compared to card-PIN systems. Unlike physical cards, which can be lost or cloned, iris patterns are inherently unique and cannot be easily replicated. Furthermore, the deep learning model demonstrated resilience against minor variations in illumination and partial occlusions. However, the system does involve higher initial infrastructure costs and requires careful handling of biometric data to address privacy concerns. Despite these challenges, the proposed approach offers a substantial improvement in ATM security and user convenience, supporting its feasibility for next-generation banking systems.

6.1 Advantages

- Cardless and PIN-less operation
- High uniqueness and permanence of iris patterns
- Scalability for large banking networks
- Reduced fraud rates

6.2 Limitations

- Initial infrastructure cost
- Privacy and regulatory considerations
- Need for secure biometric data governance

6.3 Future Enhancements

- Integration with blockchain for secure audit trails
- Edge computing deployment for faster inference
- Multi-modal biometrics (iris + face recognition)
- Federated learning for privacy-preserving model updates

VII. CONCLUSION

This research presents a deep learning-based iris authentication system for secure ATM transactions. By eliminating dependency on physical cards and PINs, the proposed system enhances transaction security and user convenience. Experimental results using the IIT-Madras iris database demonstrate high accuracy and low error rates. The integration of deep learning with biometric authentication offers a promising direction for next-generation banking security systems.

This study presents a next-generation ATM authentication system based on iris biometric recognition integrated with deep learning classification. By eliminating dependence on physical cards and PIN-based credentials, the proposed system significantly enhances security and reduces vulnerabilities associated with traditional ATM infrastructures. Experimental validation using the IIT-Madras

Iris Database confirms improved accuracy, robustness, and operational feasibility.

The implementation of iris-based biometric ATMs represents a transformative advancement in secure financial transaction systems, offering a scalable, user-friendly, and fraud-resistant solution for modern banking environments. Future work includes real-time hardware deployment, multi-modal biometric fusion, and blockchain-based secure authentication logging.

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