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SECURE BIOMETRIC ACCESS AND IDENTITY VERIFICATION IN LAST-MILE DELIVERY

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A B S T R A C T :

The growing reliance on e-commerce has intensified the need for secure and reliable last-mile delivery systems. Traditional delivery verification methods, such as PIN codes, QR scans or delivery photos, are vulnerable to theft, identity fraud and unauthorized access. This paper proposes a biometric-based authentication framework to secure last-mile deliveries by integrating facial recognition and fingerprint verification for recipient identification. The system ensures that only authorized individuals can receive parcels, thereby enhancing both security and customer trust. Experiments were conducted using a custom dataset with real-world delivery scenarios. The results show 96.3% verification accuracy with minimal false acceptance and rejection rates. The integration of biometric authentication represents a significant advancement in secure deliveries, reducing fraud and enabling contactless, privacy-aware transactions.

Keywords: Biometric authentication, last-mile delivery, identity verification, facial recognition, fingerprint scanning, delivery security, contactless delivery, deep learning, spoof detection, smart logistics.

Introduction

In today's rapidly evolving digital economy, the surge in e-commerce and doorstep delivery services has transformed the way goods are transported and received. As the volume of online transactions grows, the security and reliability of the **last-mile delivery** process—where parcels are handed over to end-users—has become increasingly important. Despite advancements in logistics and tracking technologies, the final step of delivery remains vulnerable to issues such as **package theft, identity fraud, unauthorized access, and false delivery claims**.

Traditional verification methods like PINs, QR codes, delivery confirmation photos, and handwritten signatures have proven to be insufficient in ensuring secure recipient authentication. These approaches are either easy to bypass or prone to human error, leading to a lack of accountability and customer dissatisfaction.

To address these challenges, **biometric authentication** has emerged as a powerful and reliable solution. By using unique physiological characteristics such as **facial features and fingerprints**, biometric systems offer a non-transferable, contactless, and secure method of verifying the identity of the intended recipient at the point of delivery. When integrated into last-mile delivery systems, biometric verification enhances the integrity of the process by ensuring that only the verified individual can receive the parcel.

This paper explores the development and implementation of a **secure biometric access and identity verification system** designed specifically for last-mile delivery scenarios. The proposed approach utilizes facial recognition and fingerprint scanning technologies to create a robust and fraud-resistant delivery authentication mechanism. Through experimental validation and real-world testing, the system demonstrates its potential to significantly reduce delivery-related fraud, improve user confidence, and streamline the delivery experience.

1.2 Literature Review

Integrating biometric systems into last-mile delivery processes is a relatively recent development in the broader field of secure authentication and smart logistics. Several studies have highlighted the limitations of traditional delivery verification methods and explored the potential of biometric technologies in enhancing delivery security.

Jain et al. (2011) provided a comprehensive overview of biometric authentication systems, outlining the effectiveness of fingerprints, facial recognition, iris scans, and other modalities in personal identification. Their work emphasized the reliability and accuracy of biometrics compared to traditional methods such as PINs or passwords, laying the groundwork for its application in real-world services such as delivery (Jain et al., 2011).

Kumar and Zhang (2016) investigated the use of multimodal biometrics – which incorporate more than one biometric attribute, such as face and fingerprint – to improve the robustness and accuracy of authentication systems. Their findings showed that multimodal systems significantly reduce false acceptance and rejection rates, which is crucial in high-security applications such as last-mile logistics (Kumar and Zhang, 2016). In the context of smart logistics, Chen et al. (2018) proposed a delivery framework using IoT and biometric authentication to secure package handovers. Their system demonstrated how facial recognition combined with smart lockers can be employed to prevent unauthorized package retrieval, enhance customer trust, and reduce theft (Chen et al., 2018). Sharma et al. (2020) focused on facial recognition systems implemented in mobile delivery apps. Their study showed that deep

learning-based face verification can be effectively embedded in mobile platforms, providing real-time user authentication in last-mile delivery scenarios with minimal processing overhead (Sharma et al., 2020). Alsaadi and Al-Ani (2021) explored spoofing attacks in biometric systems and highlighted the need for integrated liveness detection. Their findings are particularly relevant to secure delivery authentication, where fake fingerprints or printed photos can be used to impersonate recipients (Alsaadi and Al-Ani, 2021).

Finally, Gupta et al. (2022) introduced a blockchain-enhanced biometric delivery system that provides immutable logs of recipient verification, allowing auditability and non-repudiation in delivery disputes. Their approach addressed both the security and transparency of biometric verification in decentralized logistics networks (Gupta et al., 2022).

1.3 Objectives

The primary objectives of this research are:

- To develop a secure last-mile delivery framework using biometric authentication methods.
- To implement a dual-mode verification system based on facial recognition and fingerprint scanning.
- To evaluate the effectiveness of the system in preventing unauthorized access and delivery fraud.
- To analyze the user experience and feasibility of integrating biometrics into real-world delivery processes.
- To compare the biometric method with traditional delivery verification techniques in terms of accuracy, speed, and security.

1.4 Research Methodology

1.4.1 System Design Overview

The proposed biometric delivery system consists of:

- *Biometric Capture Module*: Installed on delivery terminals or handheld devices, this module includes a camera and a fingerprint scanner.
- *Verification Engine*: Powered by a deep learning model for face recognition (based on FaceNet) and fingerprint classification using CNN.
- *Database and Access Control*: A secure encrypted database stores pre-registered biometric templates linked to each delivery address.
- *Delivery Agent App*: Guides the delivery agent through biometric verification and logs outcomes in real time.

1.4.2 Dataset and Sampling

A dataset was collected containing:

- *Facial images* of 500 users, with variations in lighting, expressions, and angles (5 images per user, 2500 total images).
- *Fingerprint scans* from the same users (500 samples), using capacitive fingerprint sensors.
- Simulated *delivery scenarios*, including authorized deliveries, impersonation attempts, and spoofing attacks using printed photos or silicone fingerprints.

1.4.3 Biometric Processing Techniques

- *Facial Recognition Pipeline*:
  - Face detection using MTCNN
  - Feature extraction using FaceNet embeddings
  - Matching using cosine similarity
- *Fingerprint Verification Pipeline*:
  - Minutiae extraction and CNN-based classification
  - Anti-spoof detection using texture analysis
- *Fusion Strategy*:
  - A score-level fusion technique was used to combine facial and fingerprint verification results for higher accuracy and fraud resistance.

1.4.4 Evaluation Metrics

- Accuracy
- False Acceptance Rate (FAR)
- False Rejection Rate (FRR)
- Average Verification Time
- User Acceptance Rate

1.5 Experimental Results

To evaluate the effectiveness of the proposed *Secure Biometric Access and Identity Verification System* in last-mile delivery, a series of experiments were conducted in both controlled and semi-realistic environments. The experiments focused on verifying the system's accuracy, robustness, resistance to spoofing, and user performance in real-world conditions. Two primary biometric modalities—*facial recognition* and *fingerprint scanning*—were tested individually and in combination using a *score-level fusion strategy*.

1.5.1 Dataset and Test Setup

- *Participants*: 500 users (age range: 18–60)
- *Biometric Samples*:
  - 2,500 facial images (5 per user, various lighting, angles, and expressions)
  - 1,000 fingerprint scans (2 per user, different finger positions)
- *Spoofing Attempts*: 200 printed photos and 100 silicone fingerprint replicas
- *Devices Used*: Smartphones with front cameras and capacitive fingerprint sensors
- *Testing Environment*: Indoor and outdoor (sunlight, shadows, low light)

1.5.2 Facial Recognition Results

Metric	Value
Accuracy	95.60%
False Acceptance Rate (FAR)	2.30%
False Rejection Rate (FRR)	3.10%
Average Verification Time	1.2 seconds

Explanation:
The facial recognition system was powered by a FaceNet-based embedding model. The system achieved high accuracy across varied lighting and facial expression conditions. However, performance slightly dropped in outdoor low-light conditions, which increased the false rejection rate. Most false acceptances were due to high similarity among family members or poor lighting. Spoof detection, enhanced by liveness cues and texture analysis, blocked 92% of photo-based attacks.

1.5.3 Fingerprint Verification Results

Metric	Value
Accuracy	96.90%
False Acceptance Rate (FAR)	1.50%
False Rejection Rate (FRR)	2.10%
Average Verification Time	0.9 seconds

Explanation:
Fingerprint scanning performed slightly better in controlled conditions. Most errors were due to partial prints or dry/dirty fingers. Anti-spoof detection using texture and ridge pattern irregularities successfully rejected 94% of silicone-based spoof attempts.

1.5.4 Fusion System Performance (Facial + Fingerprint)

Metric	Value
Combined Accuracy	**96.30%**
False Acceptance Rate (FAR)	0.90%
False Rejection Rate (FRR)	1.80%
Average Verification Time	2.3 seconds

Explanation:
The fusion of facial and fingerprint data led to more secure and accurate verification. The system leveraged the strengths of both modalities, significantly reducing vulnerability to spoofing. The score-level fusion model considered both match scores, enhancing accuracy in uncertain or poor-quality data scenarios. While it slightly increased processing time, it was still within acceptable real-time limits for delivery applications.

1.5.5 Spoof Detection Accuracy

Spoof Type	Detection Rate
Printed Face Photo	92%
Silicone Fingerprint	94%

Explanation:
Spoof detection mechanisms used texture irregularities, motion cues, and liveness features (e.g., blink detection and sweat pores). These mechanisms proved effective, but future work will enhance them using 3D face mapping and infrared-based detection.

1.5.6 User Experience Feedback

- *Ease of Use*: 91% users rated the system as intuitive.
- *Perceived Security*: 94% believed it provided better protection than OTP or delivery codes.
- *Acceptance Rate*: 92% indicated willingness to use the system regularly.

Explanation:
The system was perceived positively by users, with appreciation for its simplicity and the added sense of security. The contactless nature of facial recognition was preferred during pandemic and hygiene-sensitive scenarios.

1.6 Conclusion and Future Work

1.6.1 Conclusion

The experimental results clearly demonstrate that biometric verification significantly enhances last-mile delivery security. The dual-modality system ensures a high level of identity assurance, resists spoofing attempts, and operates efficiently in real-world environments. These findings support the feasibility of deploying biometric authentication as a standard in modern delivery services. This study demonstrates that biometric authentication, particularly through facial recognition and fingerprint verification, significantly enhances the security and reliability of last-mile deliveries. The proposed system achieved over 96% accuracy, effectively reducing fraud and ensuring that deliveries are made only to verified recipients. The dual-modality approach enhances resilience against spoofing and environmental anomalies, making it suitable for real-world deployment. Overall, biometric access control introduces a strong layer of identity assurance in logistics systems.

1.6.2 Future Work

Future research will focus on:

- Integrating **voice recognition and iris scanning** for multi-biometric authentication.
- Enhancing **spoof detection algorithms** using 3D face modeling and liveness detection.
- Developing **privacy-preserving biometric templates** using homomorphic encryption or federated learning.
- Deploying the system on **autonomous delivery platforms** such as smart lockers, drones, or delivery robots.
- Conducting large-scale pilot studies in collaboration with logistics providers to measure long-term performance and user behavior.

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