

Exploring Cross-Environment Modeling and Robustness in Palm-based User Authentication using mmWave Testbed

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CCS Concepts

• **Security and privacy** → **Biometrics**; • **Hardware** → **Sensor applications and deployments**; • **Human-centered computing** → **Ubiquitous and mobile computing systems and tools**; • **Computing methodologies** → **Neural networks**.

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1 Introduction

Reliable and ubiquitous user authentication has become essential in smart cities, connected vehicles, and smart homes, where users interact with multiple devices in their daily lives. However, existing biometric approaches, such as fingerprint, facial, or voice recognition, often require expensive hardware, intrusive interaction, or raise privacy concerns, limiting their scalability in everyday settings [1–3]. To address these limitations, we explore a millimeter-wave (mmWave)

testbed that enables palm-based user authentication through fine-grained sensing of palm geometry, skin thickness, and surface texture. By leveraging the widespread integration of mmWave technology in WiGig and 5G, this approach provides a low-cost, contactless, and privacy-preserving alternative to conventional biometrics. This work presents how the mmWave testbed is utilized to investigate cross-environment modeling and robustness in palm-based user authentication. Our system, named *mmPalm*, captures the reflections of Frequency-Modulated Continuous Wave (FMCW) signals from a user’s palm to construct a distinctive palm profile that represents both structural and material characteristics of the hand. These reflections contain rich information about the three-dimensional geometry of the palm, sub-surface tissue variations, and fine surface textures, allowing unique identification without visual or physical contact. The mmWave testbed allows us to systematically collect palm data under varied distances, angles, and environments, providing a consistent platform for model development and evaluation.

2 Methodology

We identify and address three major challenges in developing mmPalm. First, commercial mmWave devices have a limited number of transmit and receive antennas, which constrains spatial resolution and makes it difficult to capture the complete palmprint structure. To overcome this, we synthesize multiple virtual antennas using a Time-Division Multiplexing Multiple-Input Multiple-Output (TDM-MIMO) scheme. This technique effectively expands the antenna aperture and improves spatial resolution, enabling the system to form a high-fidelity representation of palm features from



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multiple angles. Second, involuntary variations in palm orientation, rotation, and distance during authentication can lead to profile misalignment between enrollment and verification. We address this by developing a palm profile augmentation method. Specifically, we develop a systematic palm data collection procedure and a conditional Generative Adversarial Network (cGAN) that augments palm profiles across unseen poses and distances. This augmentation reduces enrollment effort and increases robustness, allowing the system to recognize users even when their hand position or orientation changes. Third, multipath reflections from nearby objects and body parts cause substantial environmental variations in signal propagation, reducing accuracy when the system is deployed in new locations. To mitigate this, we integrate an Adversarial Autoencoder (AAE) with Maximum Mean Discrepancy (MMD) regularization to extract environment-invariant latent features. This ensures that authentication performance remains stable across diverse settings without retraining from scratch.

3 Testbed Validation

3.1 Experimental Setup

mmPalm is implemented on a commercial mmWave device, TI AWR1642. It is equipped with 2 transmitter antennas and 4 receiver antennas. The testbed data were collected from 30 volunteers (aged 21–38) under IRB approval. Each subject contributed palm-reflected signals at distances of 15–60 cm and under controlled palm orientations. Evaluations were conducted in five environments (e.g., offices, lounges, and corridors) to test environmental robustness.

3.2 Evaluation Results

(1) **Overall Accuracy:** mmPalm achieves over 99.9% authentication accuracy when the palm is positioned 30 cm from the device, indicating that reflected mmWave signals contain sufficient discriminative palm information.

(2) **Distance and Orientation Robustness:** Without palm profile augmentation method, average accuracy under positional and angular discrepancies drops below 80%. Incorporating the palm profile augmentation method restores accuracy to above 97%.

(3) **Cross-Environment Adaptation:** In unseen environments, the cross-environment adaptation module improves average accuracy by more than 10% compared to models without adaptation, highlighting the importance of learning environment-invariant representations.

(4) **Attack Resilience:** Across random, impersonation, and counterfeit attacks, mmPalm achieves below 1% attack success rates, indicating high spoofing resistance of palm authentication enabled by mmWave signals.

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