Palm-based User Authentication through mmWave

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***Abstract*—Biometric authentication systems are increasingly needed across a broad range of applications including in smart city environments (e.g., entering hotels, high-rise buildings, train stations, hospitals, and personalizing vehicles settings), and in smart home environments (e.g., controlling smart devices, enhancing VR/AR experience). Traditional methods, such as face-based and fingerprint-based authentication, usually incur high cost to be installed in all this kind of environments, making them hard to become a ubiquitous authentication approach. In this paper, we develop a ubiquitous low-effort user authentication approach based on palm recognition using millimeter wave (mmWave) signals. Extensive experiments demonstrate that our system achieves 99% authentication accuracy.**

I. Motivation

Biometric authentication methods have gained immense popularity due to their enhanced security features and user-friendliness. Existing biometric authentication methods typically utilize fingerprints or faces to differentiate users [4]. While these systems are generally accurate, their high costs can hinder widespread implementation, particularly in smart cities (e.g., accessing high-rise apartments, hotels, hospitals, and customizing vehicle functions) and in smart homes (e.g., managing smart devices and enhancing AR/VR experiences). Consequently, there is a pressing need for a cost-effective, ubiquitous user authentication method to provide secure and convenient access in these scenarios. Millimeter wave (mmWave) technology, as a high-bandwidth communication technology, has been integrated into current and next-generation wireless protocols, such as WiGig (IEEE 802.11ad and 802.11ay) and 5G, demonstrating its wide availability in our daily life. This has inspired us to develop a novel user authentication method that employs palm recognition through mmWave signals. Toward this end, we focus on two crucial elements: 1) the distinctive characteristics of human palms for user authentication, and 2) the low-cost mmWave sensing technology to accurately capture these fine-grained features of the palm.

II. Related Work

Research in biomedical fields has confirmed that the features of human palms, such as geometry, thickness, and skin distribution, differ significantly across individuals [3]. Moreover, the texture of each person's palm, including principal lines, wrinkles, minutiae, and delta points, is uniquely identifiable [2]. Initial research has utilized cameras to capture palm biometric information for purchase verification in the retail payment system [1]. Recently, researchers have shown that when users hold their smart devices, the palm biometric information can be captured by active emitted acoustic signals for user authentication [5]. In this work, we propose to extract these palm characteristics from mmWave signals reflected by human palms to form distinctive palmprints, including palm geometry, skin thickness, and texture, for user authentication. Different from existing palm biometric-based approaches, our approach uses mmWave, which is low-cost, low-effort, and can be ubiquitously deployed in many smart applications, as depicted in Figure 1. For instance, a low-cost mmWave-enabled WiFi device can be installed in a high-rise apartment building entrance, where a user just needs to raise a palm to verify his/her identity and get through the secured entrance. In the automotive domain, mmWave radars are frequently integrated to provide assisted driving and collision avoidance mechanisms. These devices can be leveraged for palm biometric-based user authentication, automatically enabling personalized vehicle settings and driving modes.

Fig. 1. Application scenarios of palm-based user authentication via mmWave.

III. Methodology

In this paper, we propose a system, which utilizes a commercial mmWave device to capture distinctive palmprint embedded in the reflected signals from human palms for user authentication. Particularly, our system emits Frequency-Modulated Continuous Waves (FMCW) that vary in frequency over time and capture the reflection of these signals from a user's palm. We find that the differences between the transmitted and reflected signals, resulting from their interaction with the palm, directly correlate with the user's palmprint, including palm geometry, skin thickness, and palm texture. *(1)* The palm geometry (e.g., contour and size) can influence the interaction

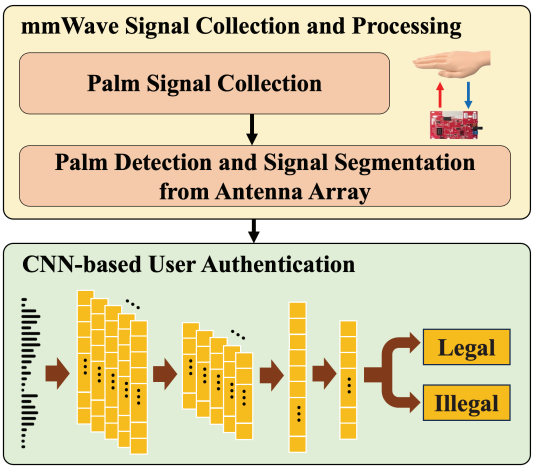

Fig. 2. System overview.

surface area and angle with the mmWave signals, altering their reflection and refraction. *(2)* Skin thickness modulates the mmWave energy absorption or reflection, and variations of the skin layers can cause non-uniformities in local electromagnetic fields within the skin, impacting the intensity and phase of the signals. *(3)* The palm texture, characterized by unique patterns of ridges and valleys, exhibits variations in density and dielectric properties, which influence the reflection and absorption characteristics of the mmWave signals. These palmprint features are unique to individuals, enabling our system to effectively authenticate users by analyzing the reflected mmWave signals.

We develop our system with three main components, as shown in Figure 2. *(1)* We develop a palm signal collection method for efficiently collecting palm data with designated positions and orientations. In particular, inspired by Apple's FaceID on capturing different angles of users' faces, we instruct the users to slightly move their palms to build a comprehensive palm profile for each user. Through collecting users' palm-reflected signals from different angles and distances, more palm data are efficiently collected for each individual user, which simulates the authentication scenarios with uncertain palm placements. *(2)* To capture comprehensive palmprint features from a commercial mmWave device, our system exploits multiple virtual antennas to gather reflected mmWave signals from various angles, allowing for a collection of more complete and detailed palmprint data. We also design palm detection and segmentation algorithms to determine mmWave signals predominately from palm reflections, ensuring effective extraction of fine-grained palm biometrics. *(3)* We develop a CNN-based user classifier to authenticate each individual. For each registered user, a classifier is created. During the authentication phase, the probability that the palm data belongs to each user is then computed and used to make an authentication decision.

IV. Performance Evaluation

Evaluation Methodology. We implement our system using a commercial mmWave device, i.e., TI AWR1642BOOST with a DCA1000EVM data capture and streaming card. When conducting experiments, we position the mmWave device on a table with the antennas pointing towards the ceiling. We recruit 30 volunteers including 23 males and 7 females. During the data collection phase, participants are encouraged to naturally place their palms to simulate the practical enrollment and authentication scenarios. In the enrollment stage, each participant places their palms directly above the mmWave device with a practical distances (i.e., $30cm$). Then, the palm data is collected by using the palm signal collection method. To evaluate the effectiveness and robustness of our system, we utilize *Authentication Accuracy (ACC).* This metric represents the percentage that user i is correctly identified as user i among all users.

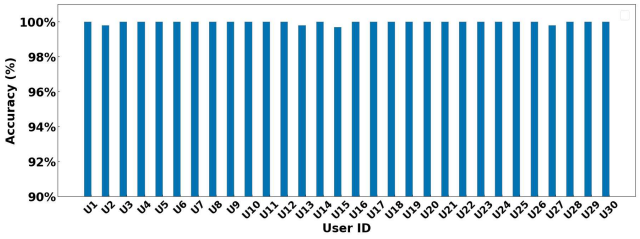

Fig. 3. Overall user authentication performance.

User Authentication Performance. We evaluate our system's overall performance in distinguishing multiple users based on their unique palmprints. The ACC for each of the 30 participants (denoted as U1, U2, ..., U30) is detailed in Figure 3. Notably, our system achieves ACCs of 100.00% for most participants and an average ACC of over 99.97%. The high level of authentication accuracy demonstrates that our system can precisely authenticate legitimate users through palm-reflected mmWave signals and effectively distinguish them from unauthorized individuals.

V. Acknowledgment

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