

CapMat: A Smart Foot Mat for User Authentication

Denys J.C. Matthies, Don Samitha Elvitigala, Sachith Muthukumarana, Jochen Huber, and Suranga Nanayakkara
Augmented Human Lab, Auckland Bioengineering Institute, The University of Auckland, NZ, {firstname}@ahlab.org
Synaptics, Zug, Switzerland, jochen.huber@synaptics.com

ABSTRACT

We present CapMat, a smart foot mat that enables user identification, supporting applications such as multi-layer authentication. CapMat leverages a large form factor capacitive sensor to capture shoe sole images. These images vary based on shoe form factors, the individual wear, and the user's weight. In a preliminary evaluation, we distinguished 15 users with an accuracy of up to 100%.

CCS CONCEPTS

• Security and privacy; • Human-centered computing
→ Ubiquitous and mobile computing systems and tools;

KEYWORDS

Floor mat, Capacitive Sensing, User Identification, Implicit Authentication, Smart Home

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1 INTRODUCTION

User authentication in smart environments enables personalized services. Common approaches leverage biometric data for user identification such as fingerprints, voice printing, face and iris scanners. These typically require explicit interactions, which are tedious and time consuming to perform.

In this paper, we propose a smart foot mat that can identify and authenticate users implicitly, e.g. when approaching a door or walking inside a smart home. It leverages capacitive sensing (CS) and can sense a volume of up to 4cm above the sensor for additional features, even through stiff surfaces. Results from a preliminary evaluation demonstrate that CapMat is able to identify users with an accuracy of up to 100%.

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Figure 1: Functional CapMat Prototype. Right photo shows the underlying Synaptics capacitive sensor matrix.

We utilized a machine learning approach to understand the data, such as the specific properties of shoes (e.g. size, profile and wear), as well as user individual factors (e.g. weight and weight distribution). Future work will investigate an automatic feature extraction using deep learning to increase the stability of our system. We envision multi-factor authentication for smart environments to be a suitable application.

2 RELATED WORK

There is a large body of work on implicit user authentication. Holz et al. [3] developed a watch prototype that senses bioimpedance as a biometric feature while users operate a touchscreen using capacitive touch, which achieved 95% accuracy with 10 users. Implementing sensors into a foot mat to identify users was already explored in 2000. Nakajima et al. [6] developed a pressure sensitive mat based on resistive sensing. Using an euclidean distance calculation, they were able to distinguish 10 users with an accuracy of 85%. Smart sensing mats are also used to identify objects as demonstrated in Project Zanzibar [7], which is based on NFC and CS. CapFloor [1], a CS carpet, enables indoor localization and fall detection. Platypus [2] demonstrates user identification based on the individuals' body electric potential. The authors achieved an accuracy of 83.6% to identify 8 people walking in an indoor facility. An implicit user identification with capacitive insoles was demonstrated with CapSoles [4]. Thirteen users were distinguished with an accuracy of 100% after 8.5s of walking.

In summary, pressure sensing mats have been deployed throughout the past decades. These mats usually require squishy surface materials and therefore do not work underneath stiff surfaces. Another drawback of previous research was a low accuracy. High accuracy rates were achieved by utilizing a variety of biometric data sensed by wearables. However, this requires augmenting the user, which may not

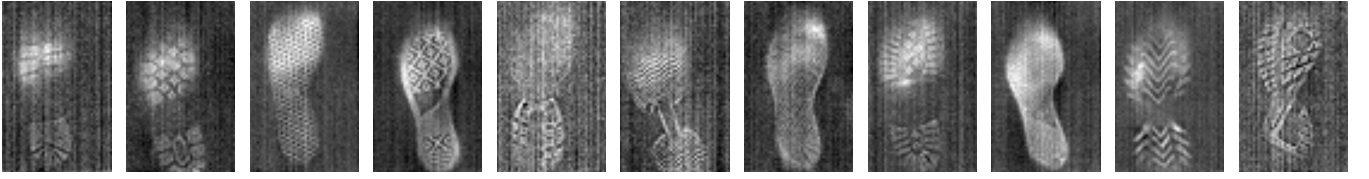


Figure 2: Demonstrating collected sensor raw data samples from 11 of 15 participants.

be preferred. In contrast, CapMat instruments a smart environment, while achieving high accuracy and exposing unique sensing capabilities through stiff surfaces, as well as basic interaction capabilities. Moreover, this type of biometric authentication may contribute to a greater user comfort [5].

3 PROTOTYPE

We implemented a proof-of-concept prototype as a research vehicle to investigate CapMat’s accuracy and limitations.

Implementation

CapMat leverages a 15.3" capacitive sensor prototyping hardware by Synaptics that is integrated into a rubber mat (see Figure 1). Its resolution is 72 (horizontal) * 46 (vertical) = 3312 data points with a 4mm pitch and a 1mm plastic cover lens.

Preliminary Evaluation

We assessed the accuracy of our implementation in a preliminary evaluation with 15 different users. The method was as follows: first, we asked participants to enroll their footprints by stepping on CapMat five times while varying the foot orientation. We used the collected snapshots to build a model of the user’s individual foot print using machine learning algorithms (see Table 1). After the module was computed, we asked the user to use CapMat to authenticate themselves, i.e. to step on the foot mat again, choosing any random foot orientation. To gain an impression on the robustness of our system over time, we asked the users to return the following day and authenticate themselves by stepping on the mat once more. We then computed the accuracy of different classifiers.

Table 1: Classifier Performance for $n=15$ participants

Classifier	RF		BN		SVM	
Day	1	2	1	2	1	2
Accuracy	98.7%	80%	100%	90.6%	100%	96%

Rather than treading the data with filters or using descriptive features, we utilized the raw data to train three different classifiers. We tested a statistical classifier: a Bayes Net (BN), a tree classifier: a Random Forest (RF), and a discriminative classifier: a Support Vector Machine. All classifiers enabled an unambiguous differentiation between all users (see Table 1) of the first day. The performance on day two slightly dropped because the data was recorded at a different place, where a different capacitive ground coupling occurred. To further increase consistency, a stable power source, as well

as a shielding electrode below the mat is required. Due to the high dimensional input data of 3312 data points, the RF performed the lowest. A feature engineering is suggested to increase the performance with this type of classifier. Other classifiers, such as the SVM, are designed to handle high dimensional data and thus are more suitable for our use case.

4 CONCLUSION & FUTURE WORK

In this paper, we presented a smart foot mat that enables user identification based on capacitive images of user-worn shoes. CapMat improves over prior work by an increased sensing range of up to 4cm in height as well as by a sensing through stiff surfaces. A preliminary evaluation for the application of user identification demonstrates both, feasibility and high accuracy of up to 100% for 15 users. Due to the prototypical implementation, the accuracy slightly dropped at day two.

In future, the hardware prototype should be improved (e.g. to account for capacitive ground coupling) as further features should be investigated more thoroughly (e.g. wear and tear of shoes, intra-shoe comparison for individual users). Although CapMat’s current implementation does not feature any form of foot-based interactivity, we envision this to be interesting to explore in future work. Applications beyond smart home should be explored, e.g. in mobile settings where multi-factor authentication is desirable.

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