A Privacy-aware User Tracking System Using Footprint Data Measured Across Multiple Pressure Sensor Sheets

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***Abstract*—In this paper, we propose a privacy-aware user tracking system which traces users by their footprints measured across multiple pressure sensor sheets. Use of footprints can reduce discomfort for privacy-sensitive users compared with that of faces captured by multiple cameras in existing tracking systems, since a footprint is weakly identifiable personal information which cannot directly identify a specific individual. In this context, the proposed system is said to be privacy-aware. In the proposed tracking system, the footprint data are collected from spatially disjoint pressure sensor sheets put on significant locations in a target area. The trajectory of a specific user is estimated by extracting locations of the sensor sheets that can observe the footprint of the user. The main task to be handled in the system is to recognize correspondence between footprints measured across multiple pressure sensor sheets. Moreover, we have conducted a basic evaluation to confirm the feasibility of the proposed system. The result shows that it can distinguish users by their footprints by 94%.**

Keywords—User Tracking; footprints; privacy-aware; pressure sensor sheets

I. INTRODUCTION

Understanding users' patterns of movement or behavior, in stations, airports, commercial facilities, etc., is one of important challenges in ubiquitous and mobile computing research fields. Use of the obtained trajectory data, such as designing evacuation routes and plans in disaster, strengthening strategic marketing efforts, and so on, would be vast improvement in social and economic infrastructure. This has motivated many studies on developing practical user tracking systems, e.g., camera-based, wireless positioning system-based, and GPS-based tracking systems.

The camera-based user tracking system has recently attracted considerable attention as one of promising user tracking systems. In the system, multiple non-overlapping cameras are distributed over a target area. The tracking is realized by recognizing users' faces captured by multiple camera, i.e., the trajectory of a specific user is estimated by extracting a sequence of cameras that can capture the face of the user. The major problem with the camera-based user tracking system is fluctuating appearances of faces across cameras due to lighting conditions, different viewpoints of cameras, varying users' poses, and so on. The additional problem with these systems is that they are invasive from a privacy point of view, i.e., monitoring users' faces in a public space is often refused by privacy sensitive users. Even when the face data are used and stored in a statistical form, not in a human understandable form, they are dislike being captured by cameras. As an alternative approach, the wireless positioning system-based approach has been proposed. However, these systems require users to equip additional devices, e.g., smartphones or wireless transmitters. In addition, unique address of such a smartphone would be linked with the personal identification.

In this paper, we propose a privacy-aware user tracking system. In the proposed system, we focus on footprints for distinguishing users. A footprint is weakly identifiable personal information, i.e., it cannot directly identify a specific individual, although it has the capability to distinguish an individual. Therefore, the use of footprints would alleviate the discomfort of tracking for privacy-sensitive users. In the proposed system, the footprint data are collected from spatially disjoint pressure sensor sheets put on significant locations in a target area. The trajectory of a specific user is estimated by extracting the locations of the sensor sheets that can observe the footprint of the specific user. The main task that has to be handled in realizing the proposed system is to recognize a single user across multiple pressure sensor sheets as an instance and different users as different instances, by using the footprint data. Therefore, in this paper, we propose a footprint matching method to match footprints measured by multiple pressure sensor sheets to the same user. Moreover, we conduct a basic evaluation to confirm the feasibility of the proposed system. The result shows that the proposed footprint matching method can distinguish users by 94% when they are standing at the upright position.

The rest of this paper is organized as follows. Section II presents related work and describes privacy issue. In Section III, we explain our proposed system, and evaluate its feasibility of the proposed tracking system in Section V. Finally, we conclude this paper in Section VI.

II. RELATED WORKS

The user tracking systems have been realized by using various device technologies, such as cameras, wireless

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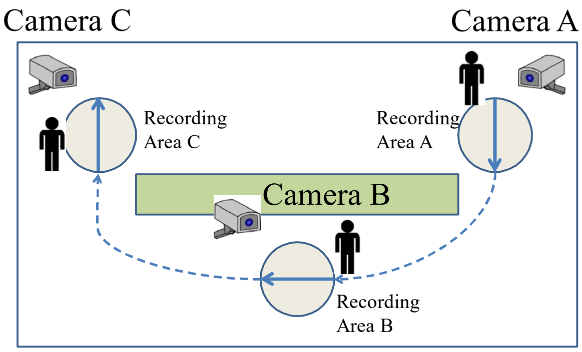

Fig. 1. Example of Camera-based User Tracking System.

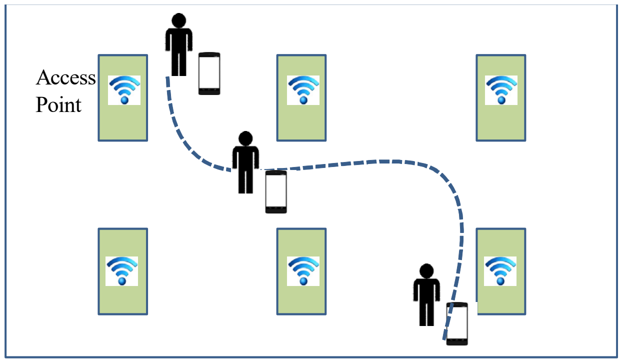

Fig. 2. Example of Wireless Positioning System-based User Tracking System.

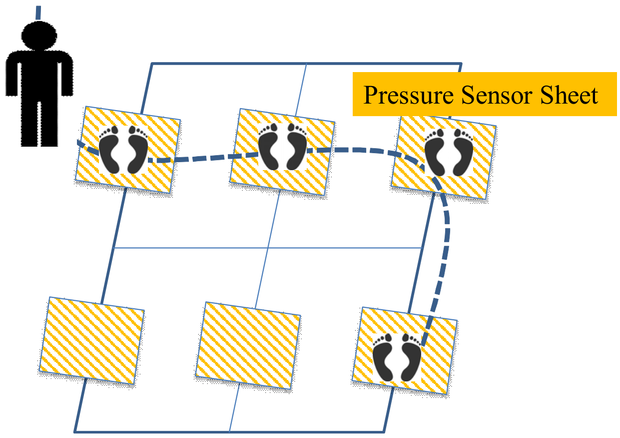

Fig. 3. Overview of Proposed User Tracking System.

positioning systems (e.g., Wi-Fi and Bluetooth), GPS, and so on. In this paper, as related works, we focus on camera-based[1][2] and wireless positioning system-based tracking systems[3][4], which are available on both indoor and outdoor environments, and introduce them. Next, we discuss a privacy issue on these tracking systems.

A. User Tracking with Cameras

The camera-based tracking system estimates the trajectories of users by recording their faces with cameras and analyzing the times and the locations of recording users' faces. The central task in the camera-based tracking system is to identify a specific user by its face in multiple movies. Fig.1 shows an example of estimating the trajectory of the user. In this figure, three cameras are put on the target area and the dotted line is the estimated trajectory. First, camera A records and recognizes the face of the user when the user passes on recording area A. Next, when the user reaches to recording area B, camera B records its face. The system tries to identify the face recorded in area B with that in area A. If they are the same user, the route from area A to area B is added to the trajectory of the user. Similarly, the procedure is applied to all faces recorded by all the cameras. At result, the final trajectory of the user is estimated.

B. User Tracking with Wireless Positioning System

In the user tracking system based on wireless positioning system, the trajectory is obtained by estimating the location of the user with a wireless positioning mechanism. The user is identified by the unique address of its smartphone (e.g., MAC address). Fig. 2 shows an example of the wireless-positioning system-based tracking system. In this figure, six wireless access points are distributed in the area. The location of a user equipped with a smartphone is determined from its distances from three or more wireless access points, i.e., it is located at the point of intersection of circles whose origins and radii are the positions of and distances from the access points, respectively. Thus, accurate distance measurement is essential in order to realize high localization accuracy. In RSSI (received signal strength indicator)-based methods, the distance can be measured from the observed RSSI values using the path loss model and the nature of the radio wave propagation. An RSSI value indicates the strength of a radio signal received by a receiver. Radio signals are attenuated as they propagate from transmitter to receiver. Therefore, an RSSI value is inversely proportional to the logarithm of the distance between them.

C. Privacy Issue

The major problems with the above user tacking systems are accuracy, robustness under a variety of environments, and scalability, in term of tracking performance. Additionally, we can find a problem from a different perspective. The problem is that they are invasive from a privacy point of view, i.e., monitoring users' faces in a public space is often refused by privacy sensitive users, because face images are strongly identifiable personal information which links with personal information and directly identify a specific individual. Even when the video data are used and stored in a statistical form, not in a human understandable form, they are dislike being recorded by cameras.

III. PROPOSED TRACKING METHOD

In this paper, we propose a tracking system using footprint data to address the privacy issue on the tracking systems, as was described in the previous section. The footprint data are collected from multiple pressure sensor sheets distributed over a target area. The trajectory of a user is obtained by extracting locations of the sensor sheets that can observe the user's footprint.

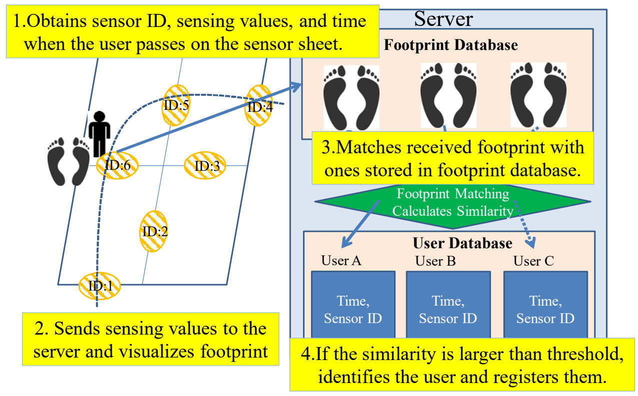

Fig. 4. System Flow of Proposed User Tracking System.

The reasons why we focus on footprints for tracking systems are as follows;

- The footprint data can be used to distinguish individual users, i.e., the footprint of each user has different features, such as size, shape, center of gravity, and so on.
- Monitoring footprints can reduce discomfort for privacy-sensitive users compared with monitoring faces operated in existing camera-based tracking systems.

A. System Overview

As shown in Fig. 3, we assume that multiple pressure sensor sheets are put on significant locations on the specific area, such as entrance, exit, passage, and so on. The system estimates the trajectory of a user by tracing the same footprint of the user across pressure sensor sheets.

B. System Flow

The main task that has to be handled in realizing the proposed system is to recognize a single user across spatially disjoint pressure sensor sheets as an instance and different users as different instances, by using the footprint data. In this section, we will explain the system flow to operate the main task, as shown in Fig. 4. In the system, each pressure sensor sheet is assigned a unique number (i.e., a sensor ID).

1. When a user passes on a sensor sheet, the sensor sheet records the sensing values and the time.
2. The sensor sheet sends the sensing values, the time, and its sensor ID to the server. The server visualizes the footprint from the received information.
3. The server matches the received footprint with ones stored in the footprint database. All footprints past measured in every sensor sheet are stored in the footprint database. For the footprint matching, the server calculates the similarities between the received footprint and ones stored in the footprint database.
4. If the similarity is larger than a threshold, the server selects the user with the footprint that matches the most with the received footprint among the footprints registered in the footprint database. And then the server registers the time and the sensor ID to the entry of the selected user in the user database.

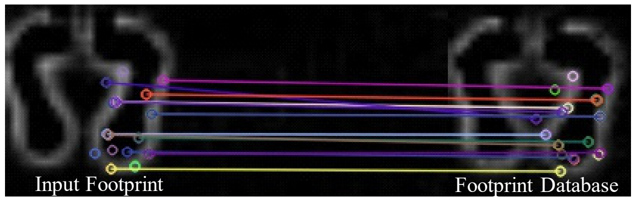

Fig. 5. Example of Footprint Matching.

C. Footprint Matching

In the footprint matching, the server calculates the similarities between input footprint and ones stored in the footprint database. The similarity between two footprints is calculated as follows;

1. Feature points are extracted from an image of a footprint with x and y coordinates. A feature vector $\vec{f}$ of a footprint is defined as follows:

$$\vec{f} = \{(x_1, y_1), (x_2, y_2), \cdots (x_n, y_n)\},$$

where (x_i, y_i) represents x and y coordinates of i-th feature point.

2. The feature vector $\vec{q}$ and $\vec{r}$ correspond to the input footprint and the one stored in the footprint database. The similarity function S between feature vectors q and r of two footprints is defined as follows:

$$S(\vec{q}, \vec{r}) = \frac{\vec{q} \cdot \vec{r}}{|\vec{q}||\vec{r}|}$$

Fig. 5 shows an example of the footprint matching. In this figure, the circles are the feature points and the lines represents links between the feature points and the corresponding ones.

IV. Evaluation

We have evaluated the effectiveness of the proposed footprint matching method using experiments. The objective of this evaluation is to analyze the matching errors for footprints in a realistic environment, and to confirm the feasibility of the proposed user tracking system and the similarity in the footprint data of the user. As mentioned in Section III B, the feasibility of the proposed system strongly depends on the performance of the footprint matching. We will judge the effectiveness of the proposed approach with these experiments.

In this experiment, we used barefoot footprints for five users standing at the upright position. More concretely, we measured 11 footprints for each user. One of these footprints were used to create the footprint database, and 10 footprints of the remaining footprints are used for estimation. Using these sets of footprints, we conducted the estimations 10 times.

TABLE I. RESULTS OF FOOTPRINT MATHING.

User	Estimated User (10 trials)										Success ratio
	1	2	3	4	5	6	7	8	9	10	
A	A	A	A	A	A	A	A	A	A	A	100%
B	A	B	A	B	B	B	B	B	B	B	80%
C	C	C	C	C	C	C	C	C	C	C	100%
D	D	D	D	D	D	D	D	D	D	D	100%
E	E	E	E	E	E	E	B	E	E	E	90%

In addition, we used LL pressure sensor sheets produced by Xiroku Inc., which uses the principle of electromagnetic induction. The extraction of feature points is used by the AKAZE algorithm and implemented in OpenCV. The threshold as described in Section III C is set to 0.99.

The result is shown in TABLE I. Overall, we find sufficient estimation performance for the footprint matching. The total success ratio for footprint matching is 94%. From the result, we observe that the proposed matching method achieves 100% success ratio for Users A, C and D. On the other hand, the performance for User B is the worst among all users. More concretely, the success ratio for User B is 80%. This is mainly due to an unclear image for the footprint of User B used in the footprint database.

V. Conclusion and Remarks

In this paper, we propose a privacy-aware user tracking system. In the proposed system, footprint data is used to distinguish instances. The footprint data is collected from multiple pressure sensor sheets put on significant locations in a target area. The trajectory of a specific user is estimated by extracting locations of the sensor sheets that can observe the user's footprint.

The main task that has to be handled in realizing the proposed system is to recognize an individual in different locations across spatially disjoint pressure sensor sheets. Therefore, in this paper, we propose a footprint matching method to identify a user across pressure sensor sheets. Moreover, we conduct a basic evaluation to confirm the feasibility of the proposed system. The result shows that the proposed footprint matching method can recognize individual users standing at the upright position by 94%.

In the future, we will focus on the following:

- An important problem with the proposed mechanism is the evaluation of the footprint matching of the use of walking users. We will develop the extraction method of feature points for footprint data of walking users.
- Another outstanding task is to investigate the feature points of footprints for effectively matching footprints. The meaningless feature points for footprint matching is removed to improve the matching performance.
- Furthermore, we would like to establish a method which can distinguish user's profile information such as gender, age, and so on from footprint data.

Acknowledgment

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