A Footprint Matching Method for Walking Users in Privacy-aware User Tracking System Using Pressure Sensor Sheets

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***Abstract*— We have developed a privacy-aware user tracking system that can track users by using their footprint data measured across spatially disjoint pressure sensor sheets. The main task in the system is to recognize correspondence between footprints measured across pressure sensor sheets, i.e., it needs to recognize a single user walking across pressure sensor sheets as an instance and different users as different ones. In this paper, we propose a footprint matching method designed for walking users. It mainly consists of two steps: i.e., footprint averaging and similarity calculating, in order to handle footprint data recorded as a time series for a walking user. Moreover, we have conducted a basic evaluation to confirm the effectiveness of the proposed footprint matching method. The result shows that the matching performance can achieve 78%.**

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

I. INTRODUCTION

User tracking systems aim at understanding users' patterns of movement or behavior in a given area; e.g., station, airport, and commercial facility. The obtained trajectory data would create a vast improvement on designing evacuation routes and plans in disaster, strengthening strategic marketing efforts, and so on, which leads to support for developing and implementing efficient and effective social infrastructure. This has motivated many studies on developing practical user tracking systems.

Existing user tracking systems have been realized by using various device technologies, such as cameras, wireless positioning systems (e.g., Wi-Fi and Bluetooth), GPS, and so on. In this paper, 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. 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. Therefore, the central task in the camera-based tracking system is to identify a specific user by the user's face in multiple movies. 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.

As an alternative approach, the user tracking system based on wireless positioning system obtains the trajectory 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). 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.

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 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. The wireless positioning system-based approach also requires users to equip additional devices, e.g., smartphones or wireless transmitters. In addition, a unique address of the wireless device would be linked with the personal identification.

To address the issue of privacy protection, we have developed a privacy-aware user tracking system. In the proposed system, we focus on footprints to distinguish 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

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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 walking across multiple pressure sensor sheets as an instance and different users as different ones by using the footprint data. In this paper, we propose a matching method intended for walking users' footprints. It mainly consists of two steps: i.e., footprint averaging and similarity calculating, in order to handle the footprint data of a walking user recorded as a time series. Moreover, we have conducted a basic evaluation to confirm the effectiveness of the proposed matching method for walking users. The result shows that the proposed footprint matching method to distinguish users can achieve 78% when they are walking on the pressure sensor sheets.

The rest of this paper is organized as follows. In Section II, we explain our proposed tracking system, and evaluate the effectiveness of the proposed tracking system in Section IV. Finally, we conclude this paper in Section V.

II. PROPOSED TRACKING SYTEM

In this paper, we propose a tracking system using footprint data to address the privacy issue on existing 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.

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 feature, such as size, shape, center of gravity, and so on.
- Monitoring footprints can reduce discomfort for privacy-sensitive users compared with doing faces operated in existing camera-based tracking systems.

A. System Overview

As shown in Fig. 1, 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 walking 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 ones by using the footprint data. In this section, we will explain the system flow to operate the main

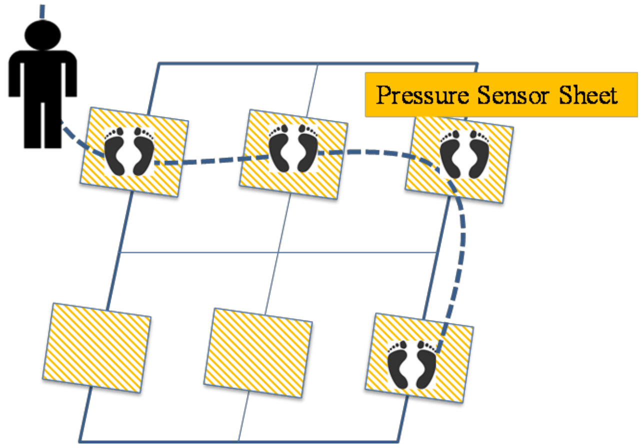

Fig. 1. Overview of Proposed User Tracking System.

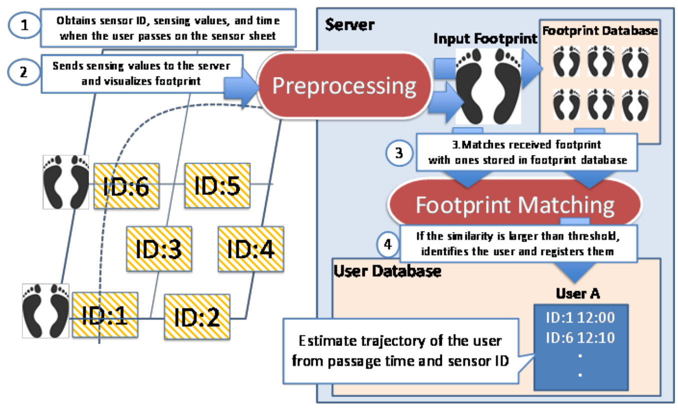

Fig. 2. System Flow of Proposed User Tracking System.

task, as shown in Fig. 2. 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 sensing values as a time series. A sensing value is defined as a pressure value with x and y coordinates on the sensor sheet, i.e. a footprint per one frame can be represented as an image with x and y coordinates.
2. The sensor sheet performs the footprint averaging, which will be detailed in next section, i.e., the footprint averaging is the simple average of a footprint image over a number of time periods. And then the sensor sheet sends the footprint data after the footprint averaging, 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

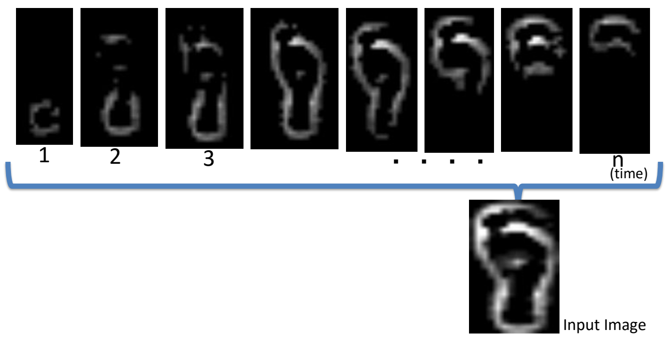

Fig. 3. Example of Footprint Averaging.

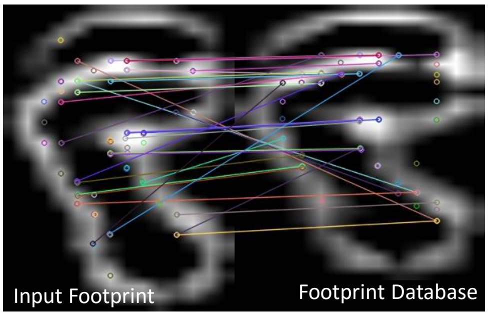

Fig. 4. Example of Footprint Matching.

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.

III. Footprint Matching

We propose the footprint matching to recognize correspondence between input footprint and one stored in the footprint database. In this paper, we propose a footprint matching method intended for walking users' footprints. It mainly consists of two steps: i.e., footprint averaging and similarity calculating, in order to handle the footprint data of a walking user recorded as a time series.

A. Footprint Averaging

The footprint averaging is the simple average of a footprint image over a number of time periods. More specifically, it averages the footprint images over n frames from the beginning to the end on recording as shown in Fig. 3. The value $I\ (x,\ y)$ with x and y coordinates of averaged footprint image is defined as follows:

$$I(x,y) = \frac{\sum_{t=1}^{n} p_t(x,y)}{n},$$

where $P\_t\ (x,y)$ represents an value with x and y coordinates of footprint image in time t.

B. Similarity Calculating

In the footprint matching, the server calculates the similarities between input footprint image 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. 4 shows an example of the footprint matching. In this figure, the circles are the feature points and the lines represent 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 II 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 experiments.

In this experiment, we used barefoot footprints obtained by averaging the sensing values at user's walking pattern for four users. More concretely, we measured five footprints for each user. One of these footprints were used to create the footprint database, and four footprints of the remaining footprints are used for estimation. Using these sets of footprints, we conducted the estimations at four times.

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 Open CV. The threshold as described in Section III C is set to 0.9.

TABLE I. RESULTS OF FOOTPRINT MATHING.

User	Left Right	Estimated User (4 trials)				Success ratio
		1	2	3	4	
A	L	○	○	×	○	75%
	R	○	×	○	○	75%
B	L	○	○	○	○	100%
	R	×	○	○	×	50%
C	L	○	○	○	○	100%
	R	○	○	○	○	100%
D	L	○	×	○	×	50%
	R	×	○	○	○	75%

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 78%. From the result, we observe that the proposed matching method achieves 100% in success ratio for User B (Left) and User C (Both). On the other hand, the performances for User B (Right) and User D (Left) are the worst among all users. More concretely, the success ratio for User B (Right) and User D (Left) is 50%. This is mainly due to an unclear images for the footprint of User B and D used in the footprint database.

V. CONCLUSION AND REMARKS

We have developed a privacy-aware user tracking system using footprints. In the proposed system, footprint data are used to distinguish instances. The footprint data are 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 have conducted a basic evaluation to confirm the effectiveness of the proposed matching method. The result shows that the matching performance in proposed footprint matching method can achieve 78% when they are walking on the pressure sensor sheets.

In the future, we will focus on the following:

- An important task is to use center of gravity. We will develop the extraction method to extract center of gravity of footprint data for walking users.
- Another outstanding task is to investigate the feature points of footprints to effectively match 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 by using footprint data.

ACKNOWLEDGMENT

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