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An Implicit Folksonomy Approach through Embedded Sensing Systems

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Abstract. With the emergence of Web 2.0, user-generated metadata facilitate management of digital content in the World Wide Web. Users create such metadata, or so-called folksonomies, for the purposes of individual uses and sharing throughout a community. In addition to explicit tags, relationship between academic works through citation is a kind of *implicit tags*. In this paper, we propose another form of *implicit folksonomy* through embedded sensing systems. Sensing information including geographical position, time, and walking patterns are recorded continuously. We develop a low-cost RFID-based localization system as a complement of Global Navigation Satellite System (GNSS) for tracking positions. Walking patterns are implicitly captured by sensor-enabled footwear. Behavior or actions of users in daily life can be automatically tagged by such sensing information. Sharing these implicit tags contributes to exciting opportunities, e.g., a user can search for persons who have the same interest through a social network of implicit folksonomy.

Keywords: Implicit folksonomy, implicit tags, embedded sensing, RFID-based localization, walking pattern recognition, sensor-enabled footwear.

1 Introduction

Folksonomy provides user-generated metadata or personalized tags as a tool for organize and share prevailing digital content in the World Wide Web [1]. Two well-known websites, namely Flickr and del.icio.us, allow users to explicitly tag photos and bookmarks with any keywords. In contrast, a concept of *implicit tags* is also available, e.g., relationship between academic works through citation and links between pages in the World Wide Web. However, we consider another form of *implicit folksonomy* through embedded sensing systems. Some kinds of metadata, especially geographically indexed information, can be implicitly tagged with the purposes of convenient usage, early-stage tagging, and time saving. For example, GPS-equipped mobile phones together with portable/wearable sensors would allow users to easily capture various kinds of location-relevant metadata. Such personalized metadata which are indirectly generated by users according to their everyday life are meaningful. Rekimoto [2] introduced the term *sensonomy* to describe a participatory process of capturing geographical position.

In this paper, we focus two kinds of metadata as significant tags according to user's daily life. First, we require both indoor and outdoor location information because geographical positions highly relate to everyday activities, i.e., we would like to know where the actions happen. However, Global Navigation Satellite System (GNSS) technologies such as Global Positioning System (GPS) do not work well in urban canyons as well as indoor and underground spaces. We developed a prototype of RFID-based localization system which alleviates the limitation of GNSS. The second metadata is walking related information such as walking, running, and so on. In addition, our pressure-aware slippers and sneakers can also capture walking habits and reveal characteristics of the surfaces on which users walk. Location together with walking information is implicitly recorded as folksonomic tags. Sharing these implicit tags contributes to exciting opportunities, e.g., a user is able to search for persons who have the same interest through a social network of implicit folksonomy. She can search for the persons who attended the same party last night, or the persons who have a meal at Thai restaurants frequently. A *place cloud* [3] can also be created to investigate the frequency of each visited place.

The remainder of the paper is organized as follows. Section 2 discusses decentralized localization infrastructure for urban-scale sensing, which can be developed by extending and integrating our RFID-based localization system [4]. Section 3 examines the data that were captured in a preliminary indoor experiment using pressure-aware slippers [5]. This informs the iterative design process of the WINFO+ system [6, 7] which allows city-wide sensing. We discuss and conclude our study in Section 4.

2 Urban-Scale Localization Infrastructure

GNSS technologies such as GPS do not work well in urban canyons, indoor and underground spaces, and so on. This can be problematic when people want to collect location-relevant sensor data in such areas. We propose to use RFID tags as location reference points for location detection, thereby complementing GNSS technologies. Upon installing RFID tags, location can be determined even if users are in a subway, meeting room, underground shopping area, etc. Mobile sensor devices can obtain unique IDs from the tags, and then retrieve corresponding 3D location information by querying a database. For folksonomic tagging purposes, more meaningful information such as floor- or room-level information would be possible to acquire from the tags.

An important issue here is the motivation and the deployment cost to physically install the tags, measure their positions, and update the database. WiFi-based localization [8, 9, 3] require little deployment cost only when WiFi stations are already deployed in the environment. In contrast, RFID-based localization uses inexpensive

RFID tags that can be easily deployed on demand at a wide variety of places, regardless of the availability of electric power.

In Japan, the government has shown keen interest in RFID location reference points [4] and already embedded about a hundred "intelligent benchmarks," which are equipped with passive RFID tags, in the city of Kobe. We surely require much more RFID reference points to fully cover a city-wide area—perhaps, millions of them (e.g., 10*m* apart from each other).

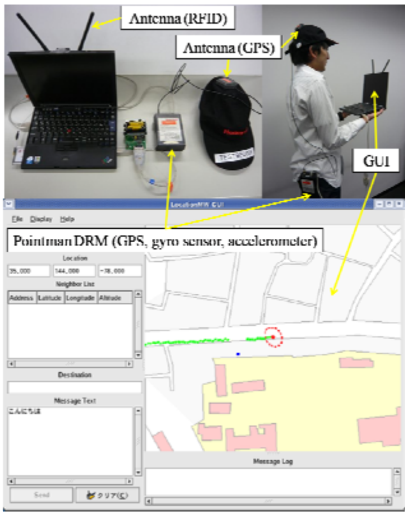


Fig. 1: P2P-based localization system.

Although government-initiated centralized deployment can be heavyweight and costly, they can hire professional land surveyors who have the skills to install high quality reference points in terms of physical robustness and information accuracy. An alternative approach is the citizen-initiated decentralized deployment that is more scalable in terms of the number of tags. We envision a hybrid, user-modifiable environment in which a small number of strategically allocated quality-assured tags, and a large number of end-user tags coexist. In such a user-modifiable environment, we can reduce the overall deployment cost by reducing (i) the number of tags that must be installed and (ii) the cost to install each tag.

To reduce the cost for installing each tag, we have developed a mechanism that automatically estimates the position of a newly installed tag by collecting location information from pedestrians who are in proximity to the tag [10]. Our system incrementally computes the estimated location of the tag as expressed in Equation (1).

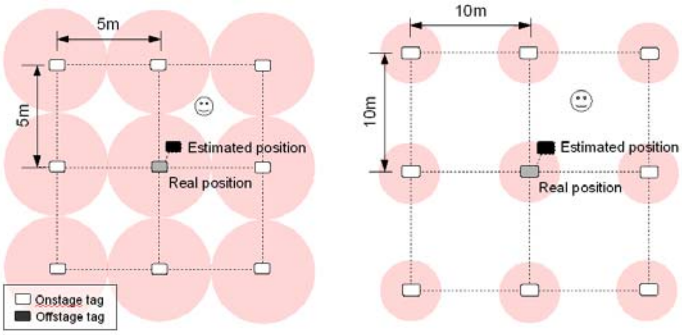
$$L_{i+1} = (iL_i + S_{i+1}) \div (i+1)\,. \tag{1}$$

It obtains a new location estimate L_{i+1} from pedestrian location S_{i+1} and previous location estimate L_i (where $i \geq 0$). This computational process can be triggered periodically, using the best pedestrian location S_{i+1} in each interval. Also, if there are multiple pedestrians nearby, S_{i+1} is a weighted sum of their location information. Our system currently uses Received Signal Strength Indicator (RSSI) to select the best S_{i+1} within each interval, and to assign a weight to each pedestrian. This mechanism allows people to simply install new tags without manually updating the database.

2.1 Implementation and Experiments

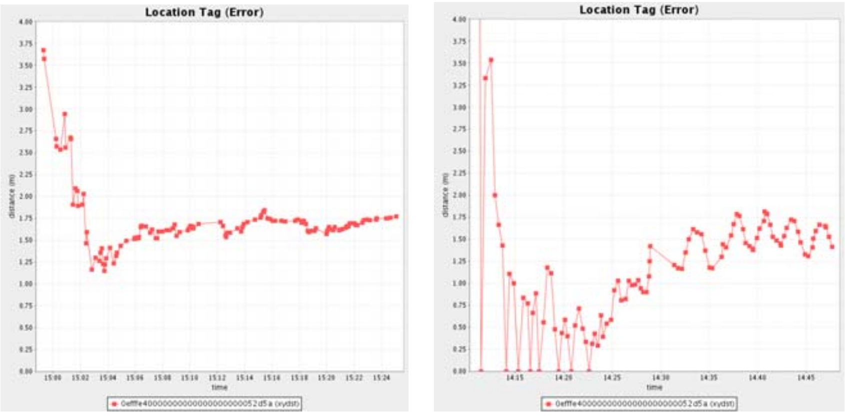
As shown in Fig. 1, we have developed a P2P-based localization system that reduces the number of required tags. The pedestrian device can estimate its position using

GPS, active[1] RFID (RF Code^{TM} Spider V) location reference points, dead reckoning modules (Honeywell GyroDRM^{TM}), and location information shared by co-located pedestrians. The system uses GPS if the satellite signals are available. Otherwise, the system operates without GPS by obtaining location information from a nearby RFID tag. Even if the user's device is far away from the RFID tags, it can estimate the position by using the dead reckoning modules. However, as pedestrians move and time passes by, the positioning error increases. In our positioning mechanism, co-located devices exchange their location estimation (along with relevant error estimation) with each other in order to cooperatively reduce the positioning error considering human mobility patterns [4].



(a) 5*m* grid configuration. (b) 10*m* grid configuration.

Fig. 2: Placement of RFID tags in the experiments. Lighter shades of red circles indicate the 2.5*m* range.



(a) 5*m* grid configuration. (b) 10*m* grid configuration.

Fig. 3: The error distance between the real and the estimated positions.

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[1] Passive RFID tags can be used in our system; however its disadvantage is shorter communication range in comparison with active RFID tags.

The maximum communication range of our RFID tags is approximately 12*m* in a corridor of our building, and 2.5*m* on outdoor athletic ground. Signal patterns vary as we place the tags near and far away from the ground surface, walls, and windows. We setup a small space (approximately 10*m* by 10*m*) on the rooftop of our building with 5 RFID tags, and carried out a number of preparatory experiments to improve the system iteratively. We then placed 9 tags on the athletic ground using the 5*m* and 10*m* grid configurations (Fig. 2), and measured the accuracy of our system's location estimation. Fig. 3 shows the results when a pedestrian walked for 26 minutes in the 5*m* grid, and 38 minutes in the 10*m* grid. In both cases, the difference between the real and the estimated positions of the tag quickly converges at an early stage and stays below 2*m* thereafter.

3 Sensor-Enabled Footwear

This section represents a study on rudimentary experiments from which experiences inspire us to design and implement durable and easy-to-use sensor-enabled footwear.

3.1 Preliminary Study and Experiments

To capture walking information and environmental context, we have embedded networked sensors in footwear. We began by analyzing the data from pressure sensor-enabled slippers [5] focusing on pressure distribution and its correlation with a person's walking patterns. The prototype integrates normal slippers, Crossbow® MICAz Motes, and three pressure sensors to wirelessly send pressure data to a server. The server then performs relevant signal processing. The three pressure sensors are embedded at the front, the center, and the back on the surface of the slippers (Fig. 4). We asked our subjects to walk with this prototype, and identified both simple and complicated signal patterns. We call the period during which a pedestrian's foot contacts the ground an *epoch*.

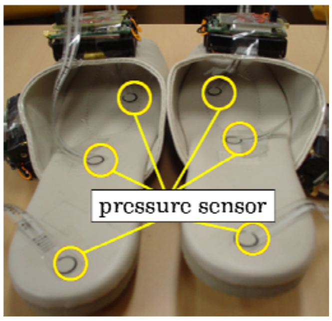


Fig. 4: Sensor-enabled slippers.

For *simple pattern* recognitions, it is straightforward to determine whether users walk, run, or stop from frequency and period of epochs. For example, high and moderate frequency of epochs mean running and walking activities, respectively. Long-lasting epoch means unmoved users, i.e., they may sit on a chair or stand straight for a while.

We identified the normal, shuffle, and forward-bending walking as *complicated patterns*. By extracting peak values from the front and rear sensors within an epoch, we can closely examine what goes on within each epoch and classify epochs into the following four groups:

Group A: The peak values from the front and rear sensors are high. This suggests smooth movement in normal walking.
Group B: The peak values from the front and rear sensors are low and high, respectively. This suggests shuffle walking.
Group C: The peak values from the front and rear sensors are high and low, respectively. This suggests forward-bending walking.
Group D: The peak values from the front and rear sensors are low.

Overall, our basic data analysis suggests that small inexpensive sensors, if integrated in footwear, can capture user activities (walking, running, etc.) easily. Interestingly, footwear devices can capture data without requiring a user to explicitly perform data capture operations. When integrating these results with location, we can assume more meaningful information. For example, if location is a stadium, running users are supposed to be sport players while unmoved users are assumed to be spectators.

3.2 WINFO+ System

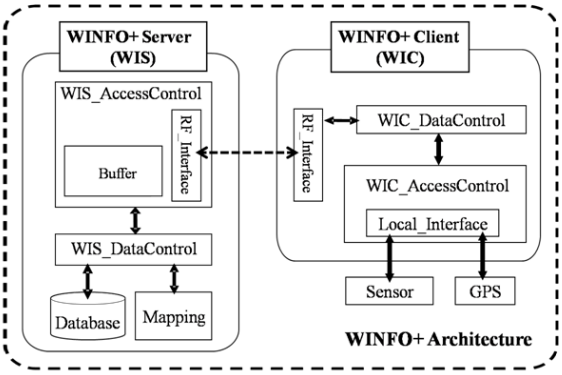


Fig. 5: WINFO+ architecture.

The idea of integrating shoes and sensors [12] is not new. However, a city-wide urban sensing requires a durable and easy-to-use device, scalable and adaptive system architecture, and reliable positioning infrastructure that works both indoors and outdoors. Based on the basic data analysis, we developed a footwear-based sensing system called WINFO+ [6]. As shown in Fig. 5, it is based on a client-server model and composed of WINFO+ Client (WIC) and WINFO+ Server (WIS).

A WIC is a wearable device that consists of a personal computer, "probe shoes," a GPS receiver (Sony VGP-BGU1), and a wireless interface (Fig. 6). The personal computer wirelessly obtains the pressure data from the shoes. The data are tagged with the GPS timestamp and compressed by using the four epoch types. WICs then transmit the data to a WIS, along with the latitude, longitude, epoch type, and timestamp information. In our prototype, WICs can communicate with a WIS virtually anywhere in a city by using the Personal Handy-phone System (PHS) technology.

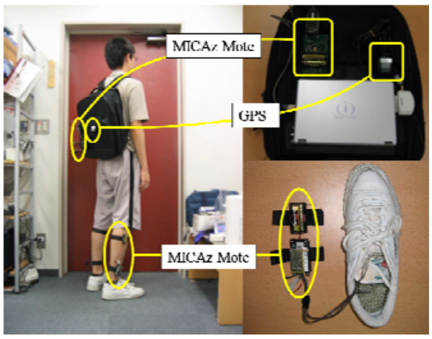
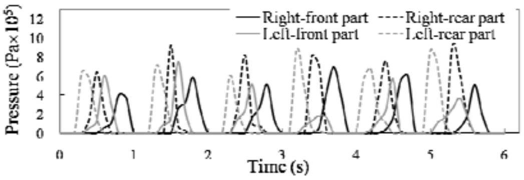
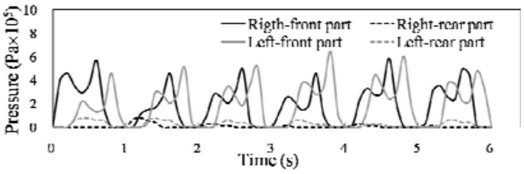


Fig. 6: Prototype of WINFO+ Client.

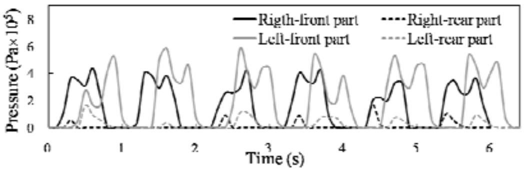
WINFO+ is designed for adaptive sensing in diverse device, information, and resource environments. WICs should acquire the right amount of information depending on their screen size and CPU power (i.e., *device adaptive sensing*). WINFO+ should respond to dynamic behavior of data (i.e., *information adaptive sensing*). For example, we might need finer-grained data when the data change substantially either in temporal or spatial axes. Moreover, the system should be able to determine the frequency of sensing and transmission depending on the amount of battery power left (i.e., *resource adaptive sensing*).



(a) Flat areas.



(b) Stairs (upward).



(c) Stairs (downward).

Fig. 7: Temporal change in pressure.

The WIC prototype is easy to wear and designed to look socially acceptable in most public spaces. Using the prototype, we carried out small-scale experiments in real urban spaces. Three male graduate students wore the prototype and walked in a central Tokyo area near Akihabara without drastically changing walking styles. They walked spontaneously along a street, crossed the street by using a pedestrian bridge, and stopped at a train station. Figs. 7 and 8 show sample data from one of the subjects. This experiment showed that footwear-based city-wide sensing can reveal characteristics of the surfaces on which pedestrians walk as well as wearers' walking habits. We also acknowledged the importance of location information in interpreting and using these sensed data. Unless the GPS signals are available, RFID-based localization system introduced in Sect. 2 can be applied.

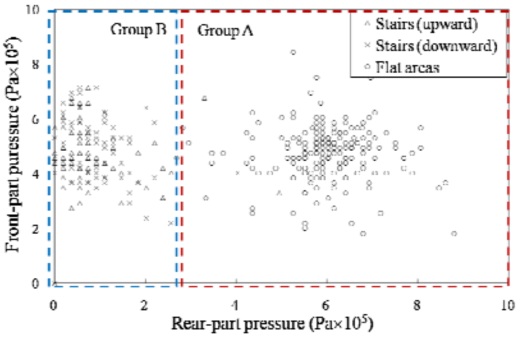


Fig. 8: Front-rear diagram.

4 Discussion and Conclusion

The combination of the RFID-based localization system and WINFO+ enables implicitly folksonomic tagging through city-wide sensing that can reveal geographical position, walking patterns and habits, as well as characteristics of ground surfaces. The system can also infer higher-level context from location and walking information. If timestamp is required, mobile phone clocks can provide a means to acquire accurate timestamp when GPS is not available. Other kinds of embedded or wearable sensors (e.g., camera, microphone, illumination, temperature, moisture) can also be used for the purpose of implicit folksonomy. Other RFID-based localization systems (e.g., [13]) can be used instead of ours. However, ours reduces installation cost by exploiting location information of pedestrians who pass by a newly installed tag to estimate the position of the new tag.

Allowing for implicit folksonomy contributes to exciting opportunities. A *place cloud* [3] can be created to investigate the frequency of each visited place. A user can also search for users who always visit the same places such as a baseball ground, library, museum, etc. When combining location with walking patterns, the user can narrow down the search by specifying more detailed conditions. For example, she can search for the persons who like to watch or play baseball (i.e., players or spectators). If a location is a Thai restaurant, a user can search for persons who are chefs or Thai-food lovers. Location is privacy data but it helps to increase intimacy if shared. Similar to data sharing in social networks (Facebook, MySpace, etc.), users are able to control other users with whom they share the data through privacy setting. Reno [14] is an example of social location disclosure service that facilitates both manual and automatic disclosure. We are currently exploring different approaches to address the privacy issue. In particular, we analyzed security and privacy issues of RFID location reference points [11]. We think it is very important to respect users' privacy boundaries and keep users in the loop in information disclosure processes. For example, implicitly sensed data from wearable devices should be securely stored in the user's personal device so that user can fully control the outgoing flows of the data.

In addition to the above-mentioned use cases, implicit folksonomy also leads to many benefits. First, users save time to create location-indexed tags by themselves. Second, implicit folksonomy is a convenient tool because sensing information is continuously collected in 24/7 manner without human intervention. Third, implicit folksonomy can be considered as an early-stage tagging or classification. Users can edit or add other tags later based on precedent classification.

We conclude here that embedded sensing systems provide a new concept of implicit folksonomy and data sharing in social networks. It is easy-to-tag, easy-to-share, and easy-to-modify environments which help to spread content in social communities. Our experiments with WINFO+ suggest that such footwear-based sensing can reveal interesting information provided that there is a pervasive location infrastructure that seamlessly covers a city. We believe that WINFO+ together with the localization infrastructure allows people to easily collect meaningful metadata in everyday life without any intervention.

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