User Participation-based Indoor Location Service

Chul-Hwan Yun, Joo-Yub Lee, Hyunjae Park, Jungmin So

Department of Computer Engineering, Hallym University, Chuncheon, Gangwon-do, 200-702, Korea
jso1@hallym.ac.kr

Abstract: Indoor location service is gaining significant interest due to the wide spread of smart phones and the potential for various location-based services. The Wi-Fi fingerprint-based method is the most widely used approach, but its major problem is the cost of radio map construction and management. In this paper, we present an indoor location service system where the radio map is automatically generated and updated by user participation. The initial input to the system is the names of reference locations. Users participate in building and updating signal fingerprints at locations. To promote user contribution, candidate locations are shown to the users so that users can easily give feedback to the server. The proposed system does not require manual site-surveying, and it does not rely on propagation models or dead reckoning for estimating location. Measurements in an office building show that user feedback can significantly improve the localization accuracy.

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1. Introduction

The recent widespread of smart phones has significantly changed our lifestyle. The users can connect to Internet "wherever they are", using their smart phones. It opens up a new category of services called the location-based services (LBS). A LBS is a service that is based on users' current location. For example, you can search for the nearest public restroom. When you enter a store, you can receive advertisement or coupons or event notifications for that particular store. You can set alarms on your phones so that when you go to Wal-Mart next time, you are reminded of what you need to buy. When you are in a museum, you can receive information on the painting that you are standing in front of. There are lots of services we can think of that are location-based. The key technology to enabling these services is accurately positioning users in indoors and outdoors.

Outdoor location service can be achieved using GPS in general. GPS provides approximately 10-30m location errors, but this is usually enough for outdoor services, such as finding a building or the nearest gas station. However, indoor location service is more difficult to achieve. First of all, GPS signals are not received indoors. Also, indoor location service typically needs higher accuracy compared to outdoor location service, although the required accuracy depends on the applications.

Due to lack of GPS, Wi-Fi based localization techniques have gained interest. Since nowadays most public buildings are equipped with Wi-Fi access points, using Wi-Fi does not require additional infrastructure cost. The location service using Wi-Fi is based on what is called Wi-Fi fingerprinting. Prior to service, reference points are selected in the building, and signal strengths from Wi-Fi access points are measured at the reference points. The RSSI vector associated with its location is called the fingerprint, and they are store in the data base called the radio map. Once the radio map is generated, the location service can begin. When an application wants to find out the user's current location, it scans the Wi-Fi signals and send them to the localization server, and the server finds a reference point that has the most similar fingerprint, using a nearest neighbor algorithm.

The benefit of the fingerprint-based method is that it does not use propagation models which are very unreliable at indoors. However, to use the fingerprint method, the radio map needs to be constructed. The reference points are usually 3-5 meters a part, and a large building will contain a few hundreds of reference points. Going through all the reference points and measuring signal strength is a cumbersome task. Also, the accuracy of the radio map degrades as time passes, due to changes in the environment such as displacement of furniture. Even a small change in the environment can cause significant errors in location estimation. Thus, radio map needs to be updated periodically, which adds to the initial deployment cost. Because of this, recent works on indoor localization try to get rid of manual radio map construction and management.

The floor plan takes a significant role in indoor location service. Without the floor plan, user position is just represented as virtual coordinates. The floor plan is needed to tell where the user is semantically, such as in an office, corridor, or an elevator. Sometimes the floor plan can be used as information when estimating user location, providing constraints such as user cannot walk through walls. However, there is standard format for floor plans and thus the process of mapping virtual coordinate to a floor plan is a challenge.

We propose an indoor location system in which manual site-survey is not necessary. The system does not require a floor plan as input, although it can be used optionally if available. The input to the system is a list of labeled reference points in the building, such as room #1313 and central lobby. Then, the system relies on user participation to build and update radio maps. The user contribution is done by pressing buttons, or choosing a location from the list. The advantage of user participation-based approach is that the server information can be kept up-to-date without having periodic manual site-surveying. Our experiments show that localization accuracy is much higher when user participation is used, compared to the case when only the initial radio map is used.

The rest of the paper is organized as follows. In section 2, we discuss related work on indoor location service. In section 3, we present the user participation-based indoor location system, and discuss challenges and solutions. In section 4, we show the results of experiments conducted in an office building. Finally, section 5 concludes the paper.

2. Related Work

Wi-Fi based indoor location system is first proposed by Bahl et al. (2000), which is called the RADAR system. Reference points are selected so that they cover the entire in-building area, and signals from Wi-Fi access points are measured at the reference points and stored with the (x, y) coordinates. Radio map of a building is the collection of Wi-Fi fingerprints: a Wi-Fi fingerprint is a location and its associated signal strength vector. The radio map is generated manually in the offline phase. At online phase, the signal strengths measured at the current user location is sent to the server, and the server returns the estimated user location by comparing the measured signal strengths with the radio map. For the distance metric between two signals strength vectors, the Euclidean or Manhattan distance was used. The server can find a single best location, or find k nearest locations and return their centroid as the estimated location.

The Horus (Youssef, 2008) system also uses Wi-Fi fingerprints and manual site-surveying, but uses a probabilistic approach when estimating user location. In order to do this, each location in the radio map must have multiple signal strength vectors, because the probability of the user being on the spot depends on the distribution of signal strengths. The COMPASS system (King, 2006) considers orientation of a user when estimating the current location. This is due to the fact that human body significantly attenuates Wi-Fi signal, and thus which way the user is facing impacts the signal strengths received at the location. To account for user orientation, the radio map of this system includes multiple signal strength vectors for the same location, but for different user orientations.

The common problem with the above systems is the need for manual site-surveying. The EZ system (Chintalapudi, 2010) was one of the efforts to remove this burden. The system assumes that a user can get location fixes using GPS locks inside a building from time to time. If this is possible, the user can estimate his location by measuring Wi-Fi signals, using constraints on wireless signal propagation. The problem with EZ system is that the GPS location estimation is not accurate inside a building, and relying on propagation characteristics also contributes to high localization error.

The Unloc system (Wang, 2012) uses movement tracking based on sensors embedded in smart phones to remove manual site-surveying. The location error for movement tracking increases with walking distance, but landmarks such as elevator or stairs can fix the user location occasionally, keeping the location error to a small distance. The Zee system (Rai, 2012) uses constraints from the floor plan to find the user location. Once the user starts walking, the system tracks user path. By observing the pattern of the path, the system can identify current location of the user. The LIFS system (Yang, 2012) is the first attempt to create a virtual floor plan by capturing user movement patterns. These systems rely on user movement tracking using embedded sensors on smart phones. However, estimating user location using movement tracking is very erratic, especially when the user is holding the smart phone in an unusual way (Lee, 2012).

There were efforts to use the physical layer information in location estimation. The spot localization (Sen, 2012) uses frequency response of a signal as additional information in finding user location. The CUPID system (Sen, 2013) uses antenna arrays to filter out NLOS (non-line-of-sight) signals, so that the error caused by signal variation due to fading is reduced.

Systems were proposed that use media other than Wi-Fi for localization. Chen et al. (2012) uses FM radio in addition to Wi-Fi, because FM radio signals are much more tolerant to walls than Wi-Fi signals. Tarzia et al. (2011) uses background acoustic signals to identify locations. Chung et al. (2011) uses magnetism for this purpose. These media can be used for identifying locations because they differ in space and are stable in time. However, the granularity of estimation for these media is coarse compared to Wi-Fi signals. They can be used as secondary information to remove ambiguity in Wi-Fi based location estimation.

Our proposed system does not rely on floor plans. The input to our system is the list of semantically labeled reference points. The system uses movement tracking, but not to an extent where its accuracy matters significantly. In the next section, we described the proposed system in detail.

3. The Proposed Indoor Location System

The goal of the proposed system is to enable indoor location service at buildings without any preparation, such as floor plans and manual site-surveying. The only input to the system is the list of locations in the building such as “room 101” or “east stairs”. Users many name the locations as they want to, but they are regarded as unofficial labels. Official location names can be managed by authorized personnel, such as building managers.

When a user enters a new building, since there is no information, the system tells the user that his location is “unknown”. If the official list of locations exists for the building, the user is shown the list so that he can select his location from the list. In addition, the user can register his current location as an unofficial reference location. The user interface is shown in Figure 1. The current estimated location is shown, and other candidate locations are shown as buttons and lists. Locations that are estimated to be closest to the user are shown on the buttons, and other locations are shown when the user selects the “Other Location” button.

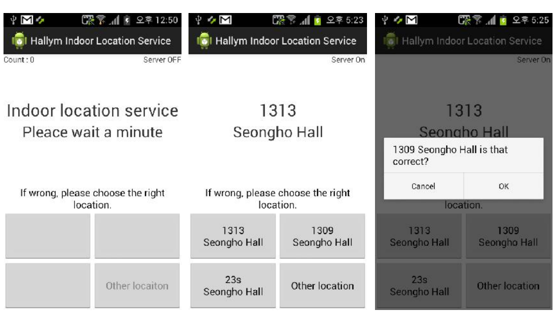

Figure 1. Client mobile application showing user interface for user-participated radio map updates

Initially, without any information, only the list of locations is shown to the user, and the user selects one from the list to mark his location. When the user selects a location, his selection and a measurement of Wi-Fi signals at the location is sent to the location server, and is included as a part of radio map at the server. As the feedbacks from users accumulate at the server, the radio map is incrementally constructed, and the accuracy of location estimation improves gradually.

When running the application, the mobile application continuously scans for Wi-Fi access points, which drains the battery very quickly. In order to conserve energy, a simple optimization based on movement detection is applied. Suppose the user obtained his location from the server. The accelerometer can tell whether the user has moved or stayed at the same place. While user is moving, Wi-Fi scans were done at $Timer_{short}$ periods, for example 10 seconds. If the user does not move, it is not necessary to do Wi-Fi scans, since the location does not change. However, to account for errors in movement detection and errors in previous location estimation, the system still continues to do Wi-Fi scans but at a slower rate. An interval of $Timer_{long}$ is used for the case where the user is not moving. The flow diagram of the client mobile application is shown in Figure 2.

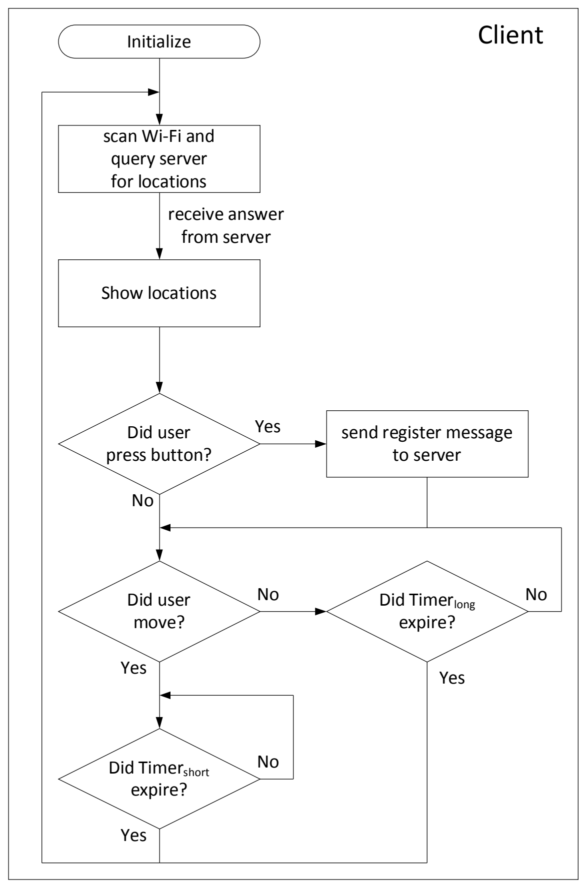

Figure 2. Flow diagram for the client mobile application

The location server, manages the radio map and replies queries from users. The client can send two types of messages: Request and Register. A Request message is used when user wants to find out his location. A Register message is sent when user indicates his location to the server. The format of messages sent from client to server is described in Figure 3. The "Type" field indicates whether this message is a Request or a Register. The "User token ID" is a temporary ID given to the user from the server. This is to track users anonymously, as described later. The "Location ID" field indicates which location the user is in. This field is empty if the message is a Register message. Note that each official reference location has a location ID, so that the message does not need to include character strings. The "unofficial name" field is an optional field, used when the user wants to register an unofficial location, such as "my office". Finally, the RSSI vector is the signal strength vector measured at the location.

Type	User token ID	Location ID	unofficial name
RSSI vector			

Figure 3. Message format for request and register messages

When the location server receives a Request message from the client, it processes the message and sends a Reply message back to the client. If the received message is a Register message, the server updates the radio map with the new information. The message format of a Reply message is similar to a Request message, except that the RSSI vector is not included. The flow diagram of the location server is shown in Figure 4.

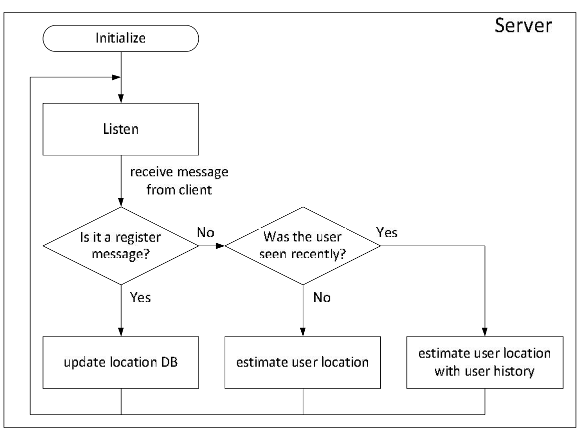

Figure 4. Flow diagram for the location server

The main role of the location server is to correctly estimate user location, using the radio map. The basic location estimation scheme follows the RADAR system (Bahl, 2000), which selects k reference points with minimum Euclidean distance in signal space. However, instead of averaging the k results, we apply a voting mechanism to decide the final estimated location. Since the radio map is generated and updated by user contribution, each reference point may have multiple RSSI vectors collected by different users. We exploit this fact in the estimation algorithm. Each reference point maintains exactly n RSSI vectors in the proposed system. If there are more than n RSSI vectors for the same location, the older ones are removed in order to keep the information up-to-date. The location estimation algorithm first finds k RSSI vectors with minimum distances. Then, the reference point with maximum RSSI vectors selected in the result is chosen as the final estimated location. If there is a tie, the reference point that has the minimum distance wins.

Since the radio map information is filled in by users, there must be a way to filter out false feedbacks. Users may intentionally or unintentionally register wrong locations, which may degrade the system performance. To prevent this, two features are implemented in the server. First, users are tracked for a limited amount of time. The system does not exchange MAC address of users for security and privacy purposes. Instead, when a new user queries the location server, the user is given a random number as his token ID. The same token ID is used for a certain duration of time, and is refreshed to a new ID. Second, geographical relations between locations are identified and maintained at the server. The geographical relation is basically the neighbor relation between locations: if a user appears in location A and moves to location B in 10 seconds, A and B are marked as geographically close. Using this geographical relation, the server can limit the space where the user can actually be, based on the history. If the user tries to register a location that is outside the space, this is detected as false information and removed. The geographical relation can also be used in estimating the user location, since the candidate locations can be limited by previous user locations.

4. Experiments

We have implemented the proposed system and tested in a university office building with offices and classrooms. Figure 4 shows the environment where measurements took place. The black dots in the corridor indicate reference points. The reference points were placed 3-5 meters apart. Also, each room has a single reference point.

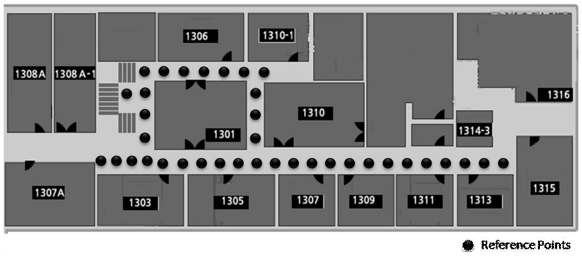

Figure 4. Floor plan of the service area where experiments were conducted.

All the reference points were given labels such as "room 1305" or "corridor near room 1313". We have compared two schemes: one with user participation and one without user participation. For both schemes, the initial radio map was generated by measuring signal strength of Wi-Fi access points at each reference point. For the user participation scheme, we had users go around the building using the developed system, possibly giving feedback information to the server. For the scheme without user participation, the radio map did not change after the initial set up. After one week, we conducted measurements to obtain the error distance of each scheme. The result is shown in Figure 5.

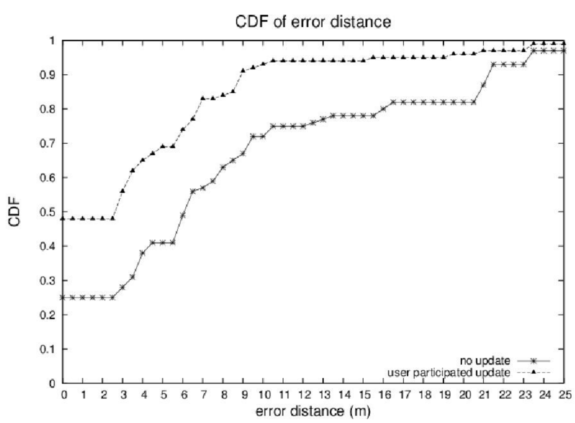

Figure 5. CDF of error distance with and without user participation

Without user participation, 25% of the location estimations were correct, and the average error distance was 8.3 meters. When user feedback is applied, the percentage of correct answers increased to 48%, and the average error distance was reduced to 3.9 meters. This improvement is due to the fact that the data at the server are more up-to-date, and larger number of location data improves accuracy of the voting algorithm used for location estimation.

5. Conclusion and Future Work

Wi-Fi fingerprinting is the most widely used technique in indoor localization, but the cost of manual site-surveying hinders its practicality. Previous works that try to automate the site-surveying rely on accurate movement tracking or floor plans. In this paper we propose a system that does not require floor plan or movement tracking, but relies on user participation to automatically create and manage radio maps. Techniques were proposed to make use of large amount of information, and filter out false feedbacks from the users. Experiments in an office building show that user participation-based radio map management can substantially improve the localization accuracy.

In the future, our goal is to automatically generate a floor plan that maps the labeled reference points, using user participation. In order to achieve the goal, we would need to develop techniques such as estimating distance and relative orientation between locations. The ultimate goal is to be able to immediately start the indoor location service at new building with only the names of semantic locations given as inputs, which we think are the least amount of information for a meaningful indoor location service.

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Corresponding Author:
Dr. Jungmin So
Department of Computer Engineering
Hallym University
Chuncheon, Gangwon-do 200-702, Korea
E-mail: jso1@hallym.ac.kr

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