ubiTrack: Infrared-based User Tracking System for Indoor Environments*

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Abstract

Proximity method with IR (InfraRed) can robustly track users against electromagnetic noise. But coarse granularity has been considered to induce problem in tracking users accurately. We propose ubiTrack to track users by exploiting proximity method with IR sensors in indoor environments. Each IR sensor has its own ID and generates sensing area. The sensing area, considered as a circle in two dimensions, allows receivers to sense certain area. We divide the whole area into sub-areas, with overlapping sensing areas, to track users with fine granularity. Then the receiver can track its location after analyzing received IDs. Strictly speaking, a sub-area is represented by a packet of IDs. We exploit two methods to enhance tracking accuracy. First, we detect error IDs to increase accuracy of tracking. Second, we inspect the packet to find out whether it includes error IDs or not by a pre-defined rule. The experimental results show that ubiTrack can robustly track users with fine granularity even in a noisy environments.

Key words: LBS, proximity method, tracking

1. Introduction

In ubiquitous computing environments, location information of users is necessary to provide personalized service to the users anywhere at any time. It can be exploited not only for energy saving service, but also for medical treatment in silver town, guidance in emergency, and finding of lost objects. Commercial products, which use GPS (Global Positioning System) or CDMA (Code Division Multiple Access), are already available for outdoor environments. However, researches on indoor location tracking have not been sufficiently advanced.

For development of indoor location tracking system, appropriate methods with fine granularity are necessary. Generally, location tracking methods can be classified into three categories: triangulation, scene analysis and proximity [1]. The proximity method, which detects users who enter certain area, is considered to be a robust method to track users against electromagnetic noise, especially indoors. Also, this method enables us to track whole area at low cost. The followings are the previous researches related to the proximity method using IR sensors. Active Badge of AT&T uses active IR tags to find user's location [2]. CG & UI Lab. of University of Columbia attaches transmitters on walls to find location of the user who wears a helmet with eight receivers [3]. Vision & Media Computing Lab. of Nara institute uses an IR sensor, a RF tag and a pedometer to track users [4]. However, it is difficult for these systems to distinguish users in an area because they have coarse granularity.

We propose ubiTrack which uses overlapping sensing area for fine granularity based on IR sensors. ubiTrack consists of two main subsystems: acquisition module and utilization module. The acquisition module plays a key role in receiving IDs through IR communication. It consists of three components: IR transmitters, IR receivers and divider. Especially, the receiver creates a packet of IDs in a period. The packets are directly related to user’s location. The utilization module, called ubiTrack client, analyzes the packet to find location in real space. And it can send user’s location information to other applications. It operates on a host device such as PDA (Personal Digital Assistant). This architecture of ubiTrack can support robust user tracking with fine granularity.

UbiTrack uses three methods in order to improve both granularity and accuracy of tracking. First, overlapping sensing area supports fine granularity by dividing the whole area into sub-areas. Second, filtering removes error IDs, which especially occurs nearby in the edge of sensing area by intensity weakness. Finally, inspection of the packets enhances accuracy of tracking. According to our experimental results, the proposed methods guarantee fine granularity and high accuracy in tracking users. As a result, ubiTrack can be effectively applied to track users in various places such as in offices, department stores, museums, and libraries.

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This paper is organized as follows. In chapter 2, we describe architecture of ubiTrack. Proposed methods and experimental results are presented in chapter 3 and chapter 4, respectively. We conclude this paper in chapter 5.

2. Architecture of ubiTrack

UbiTrack uses proximity method, based on IR sensors, to track indoor users. Figure 1 shows architecture of ubiTrack. Transmitters are installed on the ceiling, 270 cm high, and have intervals (90 cm) among them. Each transmitter emits its own ID, which is determined by position of the transmitter. The transmitters are separated into four groups, i.e. A, B, C and D. The grouped transmitters are triggered by divider to divide whole area into sub-areas. The sensing areas, in a group, do not collide with each other. Then, ubiTrack client, with receiver, finds user's location in real space after mapping the obtained packets of IDs to real coordinates.

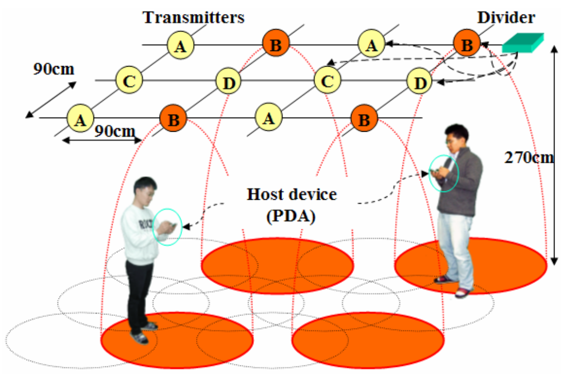
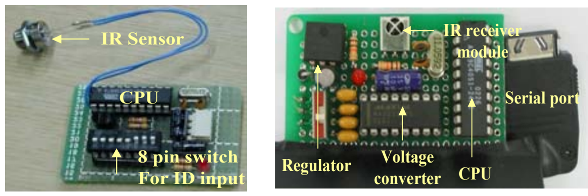


Fig. 1 Architecture of ubiTrack. User can know his/her location by proximity method using IR sensors. Obtained packets are mapped into location in order to track users in real space.

UbiTrack extracts location information through two main subsystems: acquisition module and utilization module. The acquisition module plays a key role in acquiring IDs. It consists of IR transmitters, IR receivers and divider. Figure 2 shows the transmitter and the receiver. The transmitter, installed on ceiling in a grid form, emits its own ID. To send IDs at a distance, we use ASK (Amplitude-Shift Keying) method which modulates the IDs with 37.9 kHz carrier signal. Then, receivers filter out the carrier signal from the received ID signal using a band-pass filter. Unfortunately, the receiver can not know which ID is received at the first time in each period. For this reason, divider triggers all transmitters at the same time to emit special ID signals, 00h, in each period. Consequently, the receivers can correctly obtain a packet in every period. The packets are dispatched to the ubiTrack client through serial port for analysis.

The utilization module, called ubiTrack client, analyzes error of the packets by a pre-defined rule and matches the packets with location in real space. Then the client sends the obtained location information to other applications. The location can be used to know the direction of a moving object. UbiTrack client also provides an interface to communicate with other applications through WLAN (Wireless Local Area Network). To improve inter-operability among heterogeneous applications in ubiquitous computing environments, we need a standard format for communication. For this reason, we use ubi-UCAM (Unified Context-aware Application Model) which supports formatted context for heterogeneous services [5].



(a) (b)

Fig. 2 Components of ubiTrack. (a) The transmitter consists of an IR sensor, a CPU (89c2051), and an 8pin switch (Left side). (b) The receiver consists of a receiver module, a CPU, a voltage converter, a serial port, and a regulator (Right side).

3. Proposed Methods

Coarse granularity in IR-based proximity method has been considered to induce problem in tracking users accurately. To solve this problem, we propose a method which overlaps sensing area to obtain fine granularity. But it also induces latency to find user's location. In other words, the required time to determine user's location directly depends on the length of the packet. Thus, we propose two methods which assist ubiTrack tracks users with high accuracy.

To track users by exploiting the proximity method with fine granularity, we arrange the grouped transmitters so that their sensing areas overlap. Figure 3 shows sub-areas divided by sensing areas at a height of 120 cm in two dimensions. The small circles represent grouped transmitters. Since the shape of the sensing area is not a square or rectangle, it is difficult to obtain sub-area with a uniform size. Hence, we consider the intersection by four sensing areas as one sub-area, which is colored in Figure 3. As a consequence, the area covered by 12 sensing areas is divided into 35 sub-areas, which are represented as dots in Figure 3.

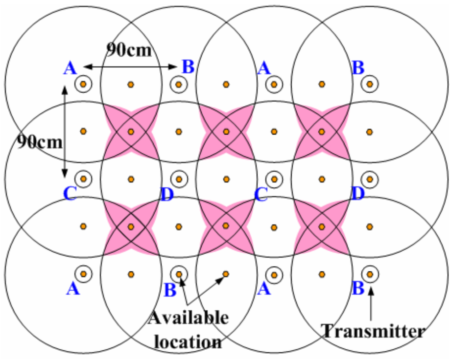


Fig. 3 Granularity of ubiTrack is increased by overlapping of sensing area. Whole area is divided into 35 sub-areas. Each colored portion is considered as one sub-area.

In general, IR communication of commercial remote controllers takes more than 100ms to get an ID signal. Hence, it is difficult to achieve real-time tracking. UbiTrack uses ID signals of which length is less than 25ms. The shorten ID signal is, inevitably, weak against noise in environments. Thus, we use data sampling and error filtering simultaneously to increase rate of acquiring correct ID. Figure 3 shows an ID signal obtained by the receiver. To filter error from the ID signal, we execute sampling twice at the 7th down edge in "ID Bits" (Figure 4). The reason is that 7th bit is the most sensitive position with respect to noise. However, inappropriate interval between samplings critically affects the number of correctly obtained IDs. Thus, we select proper interval through repeated experiments. As a consequence, we achieve the maximum number of correct IDs at the interval of 60ns.

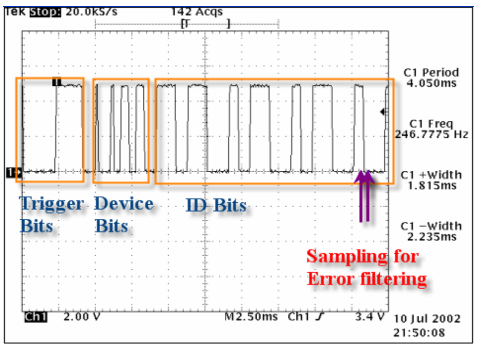


Fig. 4 ID signal consists of three components: Trigger, Device and ID. The receiver starts sampling by Trigger bits. The device bits are used to select different device type. So, it increases the number of distinguishable transmitter. ID bits carry the own ID of transmitter.

Finally, the inspection method can detect error IDs by a pre-defined rule in the packets. The size of one packet is 5 bytes, and each byte is filled with IDs. The special ID, 00h, is placed at the first byte to define each period. And the last bytes are filled with the grouped IDs. We allocate IDs according to alphabetical order of a group. The IDs are unique within a group. In other words, IDs of any transmitters in group A can not be bigger than that of any transmitter in group B, C or D. This rule is also applied to the last part of the packets. Hence, we can remove the packets, which have ID errors. It can be inferred that this method enhances accuracy of detecting user's presence.

4. Experimental Results

We have done experiments on the method of filtering error IDs, and the inspection method to know the robustness of proposed methods.

In the first experiment, we set up a transmitter and a receiver at a distance of 150 cm. Then, we moved the receiver from edge to center of the sensing area, moving 1 cm in each step. We repeated experiments after removing the filtering method. Figure 5 shows the experimental results. We observed that the number of error IDs increase at edge of sensing area. However, we found that the error interval of the sensing area decreased by using the method of filtering error IDs. Numerically, the value of cumulative error and the interval of occurring error are reduced by 43.55 % and 3 cm, respectively. It can be inferred that the stability of tracking increases as the edge of sensing area becomes sharp. As a result, we can more accurately track users.

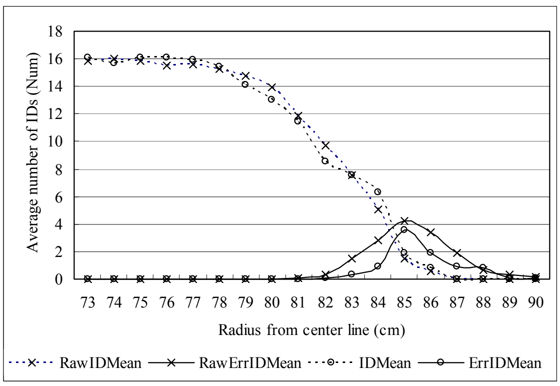


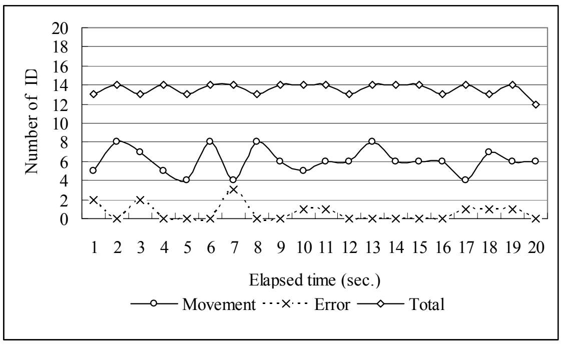
Fig. 5 Experimental results of the filtering method. The error occurs at the edge of sensing area. And the size of error occurring is reduced by the filtering method.

Second, we measured the selectivity of error packets by the inspection method exploiting ER1 robot to get ideal results [6]. ER1 can smoothly move better than that of human subject. Figure 6 shows ER1 moving around in the testbed at a speed of 50 cm/sec. We attached a receiver to ER1 at a height of 120 cm, and operated ER1 in the testbed. However, the maximum speed of ER1 is slower than that of walking speed of human. Hence, we took another experiment with a human subject as a real situation.

Fig. 6 ER1 robot in the testbed. IR receiver is attached at a height of 120 cm.

The number of received packets was counted at every two seconds in both cases. Figure 7 shows experimental results. "Movement" represents the number of the packets when the object moves to another sub-area. "Error" represents the number of received the packets considered to be error by the pre-defined rule. "Total" is summation of "Movement", "Error" and the number of repeated packets which is not represented on Figure 7.

(a)



(b)

Fig. 7 Experimental results (a) Performed on ER1 as an ideal case. (b) Performed on a human subject as a real case.

In the ideal case, the average value of "Movement" and "Error" are 3.75 and 0.05, respectively. In real situation, the average values are 6.05 and 0.6. It means walking speed of human is faster than that of ER1, but stability is reduced in a real situation. However, the inspection method can detect and remove the error packets. Consequently, it can reduce rate of occurring the error packets by 0.37 % and 4.4 %, respectively. From the experiment on ER1, we can additionally know that ubiTrack detects 35 sub-areas well. It means granularity is increased 3.89 times as compared to non-overlapped case, where the area can be covered by 9 transmitters. Eventually, we can confirm that the methods, proposed in ubiTrack improve accuracy and granularity of tracking.

5. Conclusions and Future Works

We proposed ubiTrack which uses three methods to improve granularity and accuracy of tracking: overlapping sensing area, filtering ID errors and inspection of the error packets. We confirmed improvement of reliability by doing several experiments. UbiTrack can be practically used in museums, theaters, shopping malls, exhibitions, and even home to provide indoor location-based services. The analysis of the sub-areas using probability method remains as a matter to be discussed further.

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