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WiPS: Location and Motion Sensing Technique of IEEE 802.11 Devices

Teruaki Kitasuka
ISEE, Kyushu University,
Fukuoka 816-8580, Japan
kitasuka@f.csce.kyushu-u.ac.jp

Kenji Hisazumi
Japan Science and Technology Agency,
Japan
nel@f.csce.kyushu-u.ac.jp

Tsuneo Nakanishi
and Akira Fukuda
ISEE, Kyushu University,
Fukuoka 816-8580, Japan
{tun, fukuda}@f.csce.kyushu-u.ac.jp

Abstract

For increasing needs of positioning technology, easy and simple indoor positioning system is desired. Wireless LAN based positioning system is a major candidate of indoor positioning technology. Conventional WLAN based systems require high installation cost or long site calibration before use. In this paper, we describe the implementation of simple WLAN based indoor positioning system WiPS. WiPS uses RSSI between terminals to avoid site calibration. We perform an experiment called a flag game, in which the person raises and lowers the PDA held in each hand. WiPS determines each hand is up or down. As results of the experiment, WiPS detects the movement of PDA in 4.8 sec. on an average.

1 Introduction

Location sensing technology is very important for an infrastructure of an ubiquitous computing environment. There are several technologies for indoor location sensing, but they are not widely used currently. Wireless LAN (IEEE 802.11) based location sensing technologies are focused on, with an increase in WLAN ready laptop PC, PDA and WLAN VoIP phone. A few systems are already released commercially such as Ekahau Positioning Engine[1] and so on. Indoor location sensing technologies use ultrasonic[2], infrared, camera, GPS pseudolite, and so on[3]. These technologies including WLAN-based systems have to pay high installation cost and/or maintenance cost. We propose and implement low-cost and simple location sensing technology which used the WLAN infrastructure.

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This paper is organized as follows: Sec. 2 summarizes current positioning technologies using IEEE 802.11. In Sec. 3, an implementation and features of WiPS are described. In Sec. 4, simple experiment and its result are described. The content of the experiment is a flag game. We conclude this paper in Sec. 5.

2 Related Works

There are many location system using IEEE 802.11 standards in the research and commercially. IEEE 802.11 location system has a benefit of single device solution of both data communication and location sensing.

The first paper of IEEE 802.11-based user location and tracking system is RADAR[4]. RADAR measures RSSI at access points to determine the location of a mobile terminal. There are other RSSI-based systems such as Ekahau Positioning Engine[1], CMU-TMI[5], Place Lab[6] and so on. Except for WAF propagation model of RADAR, site calibration is required to activate location system. The process of site calibration is that calibrator handles a mobile terminal, and walks around the site to collect the relationship between RSSI and location. This process requires man-hour, e.g. 1 hour per 1,200 m^2 for Ekahau Positioning Engine.

Instead of RSSI, TDOA (Time difference of arrival) method is applied to IEEE 802.11-based positioning systems, such as AirLocation[7] and AeroScout[8]. TDOA-based systems are requires additional hardware to measure the time difference. Access points or receivers which support TDOA have to be installed. The clocks of these access points and receivers have to synchronize with each other precisely for TDOA.

3 Implementation of WiPS

In this section, an implementation of WiPS (Wireless LAN based indoor Positioning System) is described. Ba-

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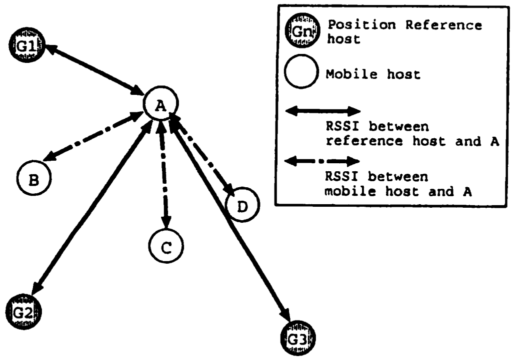

Figure 1. Basic mechanism of WiPS. To determine the position of A, WiPS uses not only RSSI of position reference G1, G2, and G3, but also RSSI of mobile terminals B, C, and D.

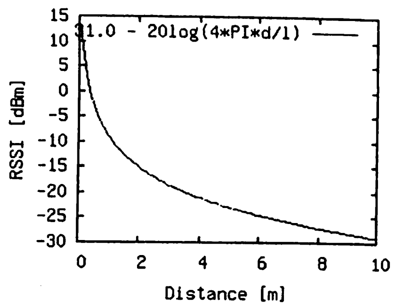

Figure 2. Relation between RSSI and distance on the free space propagation model

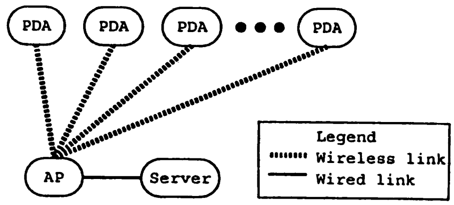

Figure 3. Configuration of WiPS experimental system. PDAs are both targets and references of positioning, and a server calculate PDAs position using RSSI.

sic concept of WiPS was proposed in [9, 10]. WiPS determines the location of wireless terminals. A major difference from conventional WLAN based system is that no additional hardware and a short calibration process are required. On each wireless terminal, WiPS client obtains RSSI (received signal strength indicator) value of each packet sent by other mobile terminal. WiPS server aggregates all RSSI values obtained by clients, to determine terminals location all together.

Conventional WLAN based positioning systems, which use RSSI, use only RSSI between access point and mobile terminal, and then determine location of each terminal separately. In contrast, WiPS also uses RSSI between mobile terminals. Fig. 1 shows the difference. For this difference, WiPS can determine more precise relative position between mobile terminals. Therefore applications which require relative location are suitable for WiPS. We pick up a flag game as a kind of these applications.

WiPS is planed to reduce site calibration process by RSSI measurement between mobile terminals. Another calibration which is called terminal antenna calibration is still needed in WiPS.

To estimate the distance from RSSI, WiPS currently uses the free space propagation model, which assumes the ideal propagation condition that there is only a line-of-sight path between transmitter and receiver. In indoor space, the free space model is not precise, but still appropriate to determine distance between mobile terminals, if terminals are closer enough. Since WiPS utilizes RSSI between mobile terminals, distance between sender and receiver is shorter than conventional RSSI-based positioning. Shorter distance implies less influence of obstacles to RSSI in our experiment.

In the free space model, relation between RSSI and distance is described as

$$P_r(d) \quad = \quad P_0 - 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) \text{[dBm]},$$

where $P_0 = 31.0[dBm]$(empirical constant), $\lambda = \frac{c}{f} = \frac{3\times10^8[\text{m/s}]}{2.4[\text{GHz}]}$. The graph of $P_r(d)$ is shown in Fig. 2.

Fig. 3 shows the configuration of current implementation. PDAs in Fig. 3 are used as mobile terminals. All of IEEE 802.11 devices in PDAs are the same. A server communicates with PDAs and calculates PDAs' location. AP (access point) provides only network connectivity between PDA and the server. AP does not act as a positioning reference currently. The specifications of PDAs are:

- CPU & OS: Intel XScale (PXA250 400MHz), Embedix based on linux-2.4.18-rmk7-pxa3
- WLAN device & driver: IEEE802.11b CF Type II (PrismII chip set), wlan-ng ver. 0.1.12 (modified)

Fig. 4 shows the software organization. Each PDA runs WLAN device on a infrastructure mode to communicate with a WiPS server through AP. WLAN of each PDA is set into a promiscuous mode to measure RSSI of other PDAs'

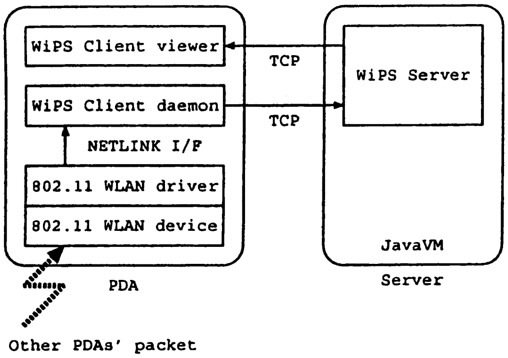

Figure 4. Software organization of WiPS experimental system.

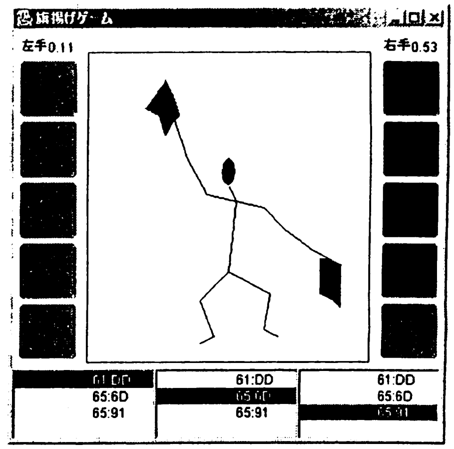

Figure 5. Screenshot of the flag game

packets. In promiscuous mode, a WLAN driver can receive the packets not only to itself but also to access point. The driver retrieves a RSSI value and a source MAC address from a received packet, and then passes them to WiPS server through WiPS client daemon. WiPS server uses an averaged RSSI value of five successive packets.

WiPS server software is developed on Java platform. A notebook PC which consists of J2SE 1.4.2, Windows 2000, Intel Pentium III 600 MHz, 256MB RAM is used as a WiPS server. WiPS server receives the RSSI reports from all PDAs, and then estimates distances between all pairs of PDAs. WiPS server determines each PDAs location by heuristic algorithm described in [9, 10]. RSSI values contain error which is attributable to multipath fading, antenna characteristics and other fluctuations. For this error, the distance list of all pair of PDAs also contains error.

4 Experiment — Flag Game

Our experiment is a Japanese classical "flag game." We evaluate the motion sensing performance of WiPS through this game. In the game, a person raises and lowers the hands. WiPS detects this movement of the hands.

There are two players in the flag game. A person says a command such as "raise left flag or "lower both flag." Another person hears the command, and then raises and lowers the hand holding a flag. In this experiment, the latter person holds a PDA in each hand, instead of a flag. WiPS calculates the location of both PDAs to determine each hand is up or down every 1 sec. We measure the response time between the command and the correct result of WiPS.

Fig. 5 is a screenshot of the flag game. Fig. 5 shows the situation that the left hand is up and the right hand is close to down. The indicator on each side, which consists on five squares, shows the status of each hand. When WiPS determines the hand is up, all squares are turned on. All squares are turned off when the hand is down.

Three PDAs are used in the experiment. Two PDAs are held in both hands of the operator. Last PDA is put on the desk, which is placed in front of the operator. The distance between PDAs on the desk and the hand is changed between about 40 cm (down state) and 1.3 m (up state). WiPS detects 90 cm movement of PDA.

To determine the states of both hands, the flag game program measures the current measured distances from the PDA on the desk to left and right hands, which are denoted by d_l and d_r respectively, and records the maximum and minimum distance of each hand, which are denoted by $\max(d)$ and $\min(d)$. For instance of left-hand detection, the flag game program decides the hand is up, if $d_l \geq 0.7\max(d_l) + 0.3\min(d_l)$. If $d_l \leq 0.3\max(d_l) + 0.7\min(d_l)$, left-hand state is determined as down. When d_l is intermediate of both thresholds, the hand is in undetermined state and the indicator of Fig 5 goes partially on.

To set initial values of $\max(d)$ and $\min(d)$ of both hands, the operator processes a calibration before the experiment. The calibration process is a simple action: the operator raises both hands and lowers both hands for a while. When the person is changed, the calibration process runs again.

We measure the response time from a command such as "raise left hand" to the correct response of the flag game program. A total number of operators is 6, each operator moves the hands about 25 times. A total number of measurements are 146 times.

The average of response time is 4.8 sec. The flag game response is swung by the error. While the operator keeps the position of hand, the displayed state is varied between the correct and undetermined state. However, we measure the period from the time of a command to the first time that WiPS shows correct state.

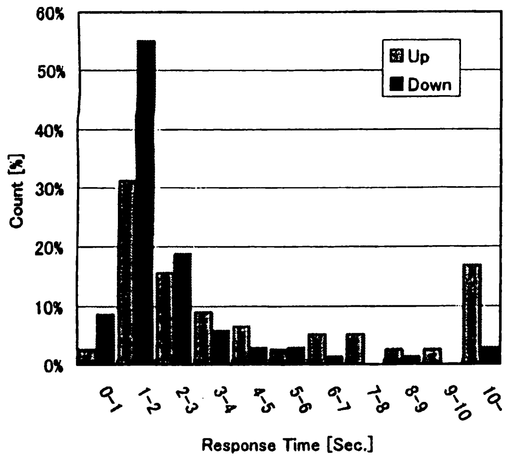

Figure 6. Histogram of response time.

In Fig. 6, we show the response time of an up case and a down case separately . The up case means that the operator raises the hand from lower to upper. The down case is the opposite action. The average of response time is 6.9 sec. on the up case, and 2.5 sec. on the down case. The down case marks better response time than the up case.

The result of the down case is summarized as follows: 64% of trials are responded within 2.0 sec., 83% within 3.0 sec. The best response time is 0.7 sec., and the worst is 14 sec.

The result of the up case is slower than the up case. 49% of trials are responded within 3.0 sec. The best response time is 0.8 sec. However, 17% of trials are responded longer than 10.0 sec. The worst is 52.2 sec. The slowness of the up case is caused by the smaller gradient of RSSI in longer distance shown in Fig. 2. When the distance is longer, the error of RSSI value has a larger impact to the estimated distance. This property has an additional impact to the maximal distance $\max(d_r)$ and $\max(d_l)$ of the flag game parameter.

5 Conclusion

In this paper, we describe the implementation of WiPS and show the flag game as its experimental application.

WiPS is implemented using off-the-shelf PDAs with CF-type IEEE 802.11b wireless LAN cards as positioning targets and references. Wireless LAN driver on the PDA is modified to record RSSI values of other PDA's packets. WiPS server aggregates RSSI values of WiPS clients and determines clients' location.

We evaluate WiPS by the flag game. In the game, three PDAs are used. Two PDAs are held in both hands and the last PDA puts on the desk in front of the person. WiPS determines relative position of three PDAs. The flag game program detects the movements of hands, using relative position determined by WiPS server. PDAs in both hands move 90 cm from up state to down state. A distance between the PDA on the desk and the PDA in the hand are changed between about 40 cm to 130 cm. The flag game program detects this change and shows the correct state in 4.8 sec. on an average.

A goal of our research is positioning system which is freed from site calibration and site configuration. We will evaluate WiPS in more suitable situation for practical use. When the positioning system can be used anywhere, human communication is enforced naturally by mobile terminals.

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