

A Presence-detection Method using RSSI of a Bluetooth Device

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Abstract This paper proposes a presence-detection method using a Bluetooth equipped device. This method overcomes some of the problems with existing products and technologies for detecting user presence (e.g., security threats caused by human error, high introduction cost, and low detection accuracy). The characteristics of the Bluetooth device's RSSI (Received Signal Strength Indication) value were analyzed in preliminary experiments. According to the results of these experiments, the proposed method combines processing using RSSI value threshold and handling of instantaneous variation of RSSI value. The optimum values of the two key parameters used in the combined method (i.e., threshold RSSI value: -22 dB; and judgment time: 7 s) were determined by performance evaluation tests, and the effectiveness of the proposed method was verified by simulation.

Keywords: Bluetooth, RSSI, Mobile devices, Information security

1 INTRODUCTION

Nowadays, various information-security measures to prevent the increasing number of threats to security have been tightened. One example is "presence-detection processing" to detect when the user leaves his/her personal computer. Presence-detection is an effective measure for protecting the user's privacy and preventing information leaks and computer abuse by a third party. This measure is necessary not only for companies but also for the general public. The existing products for presence-detection use USB devices [1] and original radiowaves [2]. These products, however, suffer problems like security deterioration if a key device (authentication key or USB key) is misplaced or lost, high introduction cost, and poor detection accuracy.

The penetration rate of mobile devices has increased year by year [3]. Additionally, most people who have a mobile device also have an internet connected personal computer (PC) [4]. In other words, there is a correlation between mobile devices and PCs. "Bluetooth" is a compact, low-power-consumption, short-range radio technology [5]. These days, many mobile devices support Bluetooth connectivity [6]. Studies on presence-detection using Bluetooth include position detection systems such as Bluetooth-based indoor proximity sensing [7], a location awareness system [8], and delay calculation [9]. These position detection systems are insufficient for presence-detection because they can only detect a small region and are generally very expensive (since they need many devices). Given those drawbacks, the authors have

developed a presence-detection system using Bluetooth's received signal strength indication (RSSI) that provides relatively precise detection accuracy at modest cost.

2 PRESENCE-DETECTION METHOD

2.1 Requirement

Presence-detection for a person using a PC must meet the following two requirements. Note that 95% and over of the presence-detection processing must meet the two requirements at once.

Requirement 1: When the user moves away from front of the PC

The PC must run the presence-detection system when the distance between the user and PC is from 10 to 30 m, which was assumed as the best distance range in general.

Requirement 2: When the user is sitting in front of the PC

The PC must not run the presence-detection system when the user is sitting in front of the PC, because it would affect the convenience of user. It is also important to reduce the number of erroneous decisions.

2.2 Methods using Bluetooth

As for presence-detection, the two methods described below are utilized: Inquiry function of Bluetooth (inquiry method) and monitoring communication link (communication link method).

a) Inquiry method

A "master device" is the basic device of a Bluetooth network. A "slave device" is a device connected to the master. The master can get circumjacent slave information (Bluetooth address, Bluetooth clock, etc.) when it runs the inquiry function of Bluetooth.

The inquiry method detects the user's presence by using the inquiry function. The Bluetooth device (i.e., a Bluetooth dongle) of the PC (master) gets the slave information of surrounding Bluetooth devices by running the inquiry function regularly. The PC then judges that the user is sitting in front of the PC if the acquired slave information indicates that the user's Bluetooth device is specified as an authentication key (Fig. 1). The existing product BlueLock [10] uses this inquiry method for presence-detection.

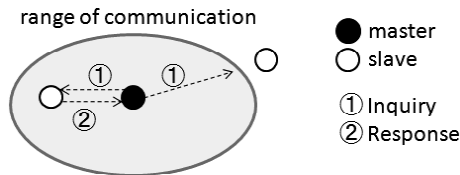


Figure 1: Inquiry method

b) Communication link method

A communication link is data transmission connection between a master and slave for sending and receiving data packets. The master sets up a communication link to a slave by using slave information when the master establishes a connection with the slave, and it controls data transmission to confirm whether the slave can communicate with it.

The communication link method detects the user's presence by monitoring communication links. The PC (master) monitors the communication link when the Bluetooth device connected to the PC establishes a connection with a nearby Bluetooth device as an authentication key (slave). The PC judges that the user is sitting in front of the PC if the Bluetooth device connected to the PC establishes a connection with the user's Bluetooth device specified as the authentication key (Fig. 2).

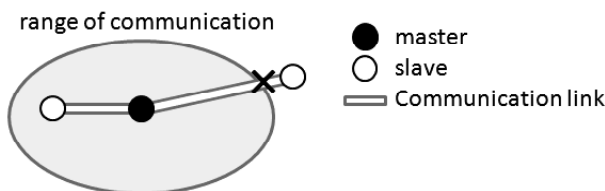


Figure 2: Communication link method

2.3 Performance evaluation

The success rate (pass rate) of the two methods described in section 2.2 in satisfying the two requirements stated in section 2.1 was evaluated. Fig. 3 plots the results of a performance evaluation of the inquiry method and communication link method. The commercially available product BlueLock [10] was used to evaluate the performance of the inquiry method, and a program using BlueSoleil6.2 [11] was used to evaluate the performance of the communication link method. A USB Bluetooth dongle (BT-MicroEDR2 [12]) was used as the master device, and a Bluetooth device (HT-1100 [13]) was used as the authentication key in both experiments. The USB Bluetooth dongle was placed on one side of the PC desk.

a) Distance measurement

Firstly, a distance measurement experiment with the two methods was performed. This experiment measured the distance between the user and the PC when the inquiry method or communication link method detected that the user had left the PC. The user walked away from the PC at a velocity of 1 m/s. In the experiment, the distance was measured 30 times by each method in three environments (namely, A: a spacious room and metal desk; B: a small room and wooded desk; C: a small room and metal desk). Fig. 3(a) plots the relationship between the requirement 1 pass rate (vertical axis) and the distance (horizontal axis) in the distance measurement experiment. The requirement 1 rate is

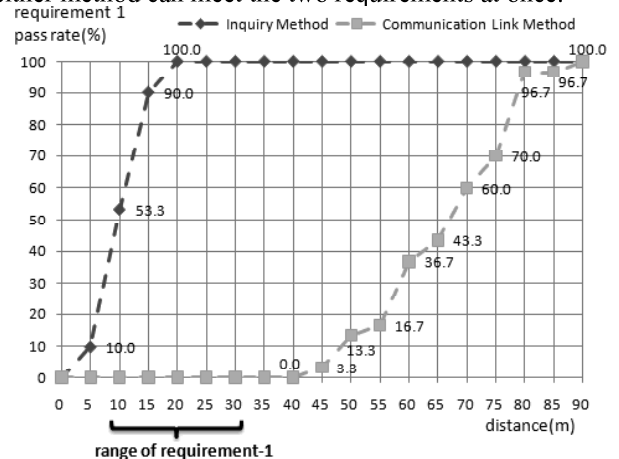
the proportion (in percent) of times out of 30 measurements that the method satisfies requirement 1. It is clear from the graph that either the inquiry method or the communication link method meet requirement 1 if requirement 1 pass rate is over 95%.

The inquiry method satisfies requirement 1, because the requirement 1 pass rate of BlueLock was 100%. In contrast, the communication link method does not satisfy requirement 1, because the requirement 1 pass rate of the program using BlueSoleil 6.2 was zero.

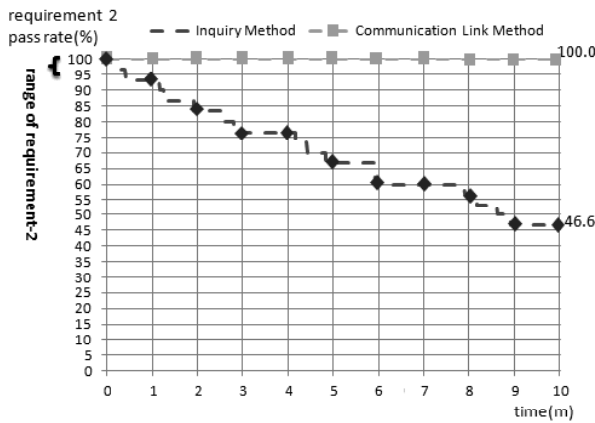
b) Erroneous detection

Next, an erroneous detection experiment was performed. In this experiment, the time until erroneous detection occurred while the user sat in front of the PC for 10 minutes was measured. Measurement was performed 30 times while the PC was using either of the two methods in three environments (A: spacious room and metal desk; B: small room and wooden desk; C: small room and metal desk). Fig. 3(b) plots requirement 2 pass rate (vertical axis) against time (horizontal axis) for the erroneous detection experiment. If the PC is detecting existence of the user for 10 minutes, the method will satisfy requirement 2. The pass rate in the requirement 2 is the proportion (in percent) of times out of 30 measurements that the method satisfies requirement 2. It is clear from the Fig. 3(b) that either the inquiry method or the communication link method can meet requirement 2 if the requirement 2 pass rate is set to over 95%.

The communication link method satisfies requirement 2, because the requirement 2 pass rate for the program using BlueSoleil 6.2 was 100%. In contrast, the inquiry method does not satisfy requirement 2, because requirement 2 pass rate of BlueLock was 46.6%. These two results indicate that neither method can meet the two requirements at once.



(a) Performance evaluation of distance measurement



(b) Performance evaluation of erroneous detection

Figure 3: Results of evaluations of two methods

3 PRELIMINARY EXPERIMENTS

3.1 Improvement of two methods

The two methods were improved according to the results presented in section 2.3. That is, the inquiry method with improved judgment conditions was renamed the “advanced inquiry method,” and the communication link method with additional comparison processing using received signal strength indication (RSSI) and a threshold value was renamed the “RSSI method”.

a) Advanced inquiry method

The advanced inquiry method uses different judgment conditions from those of the normal inquiry method, which judges that the user is sitting in front of the PC if the acquired slave information includes a Bluetooth device specified as the authentication key. Because the judgment condition used in the inquiry method is strict, this method made erroneous detections (see section 2.3) when the user was sitting in front of the PC. Accordingly, the advanced inquiry method makes the judgment in a different manner, as follows. The inquiry function is run as regularly as done by the inquiry method. If the Bluetooth function of the PC (master) gets the slave information of the authentication key once within a set period of time, the advanced inquiry method judges that the user is sitting in front of the PC. Erroneous detections can be reduced by changing the judgment conditions in this way.

b) RSSI method

In telecommunications, RSSI is a measure of the power of a received radio signal; that is, RSSI quantifies the strength of a radio signal. In general, the value of RSSI decreases as the relative distance with a communication partner increases. RSSI can therefore be used as a measure for expressing relative distance with a communication partner.

In a similar manner to the communication link method, RSSI establishes a connection with the authentication key. The PC then begins to compare the RSSI value and the threshold value that was set for user. The PC judges that the user is sitting in front of the PC if the RSSI value is higher than the threshold value (Fig. 4). The communication link method can be finely controlled by comparing the RSSI and threshold values.

In this study, the RSSI method was chosen because it was thought that it could more effectively satisfy the two requirements than the advanced inquiry method.

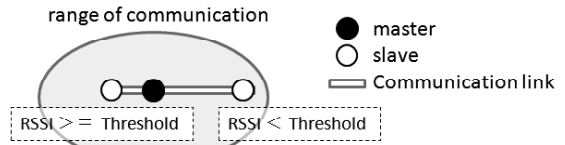


Figure 4: RSSI method.

3.2 Preliminary experiment on RSSI method

A preliminary experiment to determine whether the RSSI method could satisfy both requirements (Section 2.1) was performed first. It was assumed that the RSSI value changes with variations in ambient environment (e.g., desk material, position of Bluetooth dongle, and position of mobile device). In this case, the installation positions of some devices, namely, the Bluetooth dongle of the PC (i.e., the master device) and the mobile device of the user (i.e., the slave device) were different.

Table 1: Average value of RSSI

		Position of mobile device			
		on desk	inside bag	front pocket	back pocket
Position of Bluetooth dongle	direct	-4.6	-17.8	-16.9	-7.6
	side	-9.4	0	-8.8	-0.4
	floor	-21.5	0	-15.0	-18.3
	reverse	-16.8	0	-5.1	-3.8

[dB]

Table 2: Minimum value of RSSI

		Position of mobile device			
		on desk	inside bag	front pocket	back pocket
Position of Bluetooth dongle	direct	-11	-22	-21	-11
	side	-16	0	-17	-5
	floor	-25	-4	-21	-23
	reverse	-23	-2	-14	-9

[dB]

In the preliminary experiment, RSSI value was measured for three minutes when installing the Bluetooth dongle and the mobile device in various positions. Tables 1 and 2 list the average and minimum values of RSSI. The RSSI acquisition program BlueSoleil6.2 base was used to acquire RSSI values. This program can acquire the integral value of RSSI in the range of about -30 to 0 dB. If RSSI becomes less than -30, the communication link will be cut.) The Bluetooth dongle was connected to the PC at four installation positions: directly to the PC on a desk (Fig. 5: “direct”), to a USB extension cable on the right or left side of the desk (Fig. 6: “side”), on the floor underneath the desk (Fig. 7: “floor”), and on the reverse side of the desk top (Fig. 8: “reverse”). The mobile device of the user was placed in four positions: on a desk, inside a bag, in the front pocket of the user’s pants, and in the back pocket of the pants.

Table 1 lists the average RSSI values for the dongle installation positions and mobile device positions stated

above. It is clear from the table that RSSI value tends to differ when the positions of the Bluetooth dongle differ. In particular, when the dongle is positioned as shown in Figs. 5, 7, and 8, the average RSSI value decreases. However, for the “side” position (Fig. 6), the RSSI value is higher than that for the other positions. The relation between RSSI (vertical axis) and distance (horizontal axis) for the side-position case when the user leaves the PC is plotted in Fig. 9(a). The relation between RSSI value (vertical axis) and time (horizontal axis) when the user is sitting in front of the PC is plotted in Fig. 9(b). As shown in Fig. 9(a), when the user leaves the PC, RSSI drops to the range of -25 to -20 dB at 10 to 30 m of requirement. Moreover, as shown in Fig. 9(b), when the user is sitting in front of the PC, RSSI momentarily drops. The position of the mobile device and operation of the user are considered to be the causes of this RSSI drop.



Figure 5: Position of Bluetooth dongle: “direct”



Figure 6: Position of Bluetooth dongle: “side”

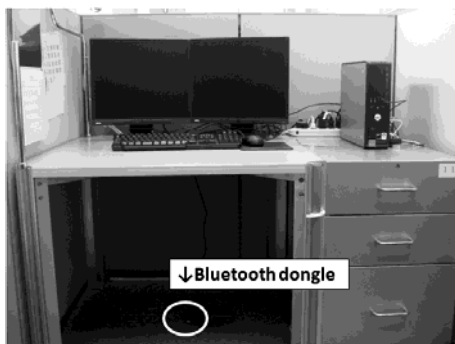


Figure 7: Position of Bluetooth dongle: “floor”

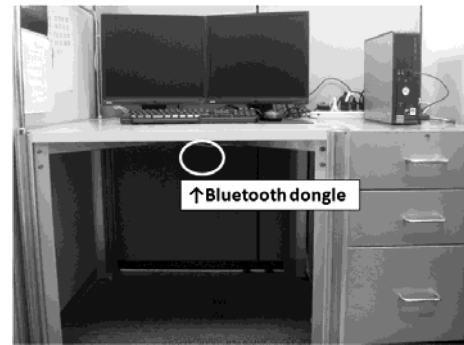
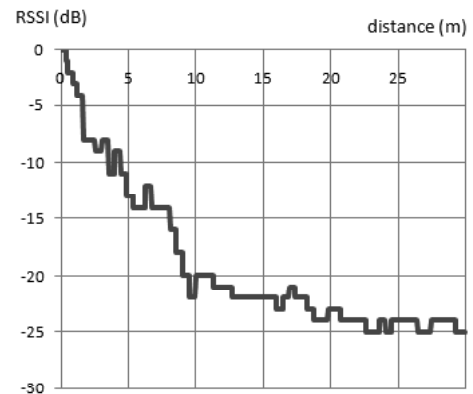
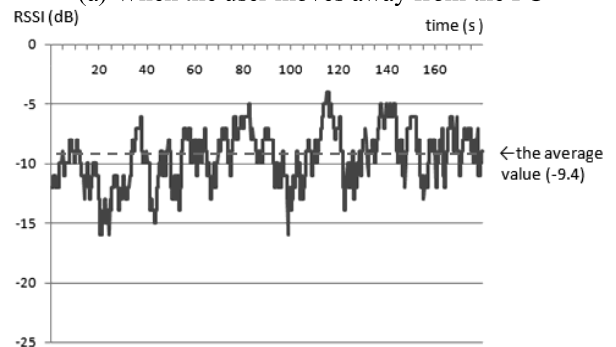


Figure 8: Position of Bluetooth dongle: “reverse”



(a) When the user moves away from the PC



(b) When the user is setting in front of the PC

Figure 9: Examples of variation of RSSI

3.3 Discussion of preliminary experiment

As described in the previous section, it was shown that RSSI value changes significantly in accordance with the position of the mobile device (see Table 1) and suddenly deviates from the average value (Tables 1 and 2). When the user moves away from the desk, as shown in Fig. 9(a), RSSI decreases to about -25 dB. A high RSSI value must be maintained when the user is sitting down in front of the PC. These results indicate that the standard RSSI method (which compares a threshold value with the average RSSI value) may make an erroneous detection when the user is sitting in front of the PC.

The average and minimum RSSI values in the case that the Bluetooth dongle was connected at the desk-side installation position (Fig. 6, “side”) are higher than in the cases of the other installation positions (“direct,” “floor,” and “reverse”) regardless of the position the mobile device. The problem of varying RSSI value under different surrounding environments can therefore be solved by connecting the Bluetooth dongle at the desk-side position (because the RSSI value is fairly stable

regardless of the surrounding environment). However, since RSSI can drop momentarily, as shown in Fig. 9(b), even if the problem of RSSI-value reduction due to the surrounding environment is reduced, the RSSI method still needs to accommodate the momentary fall in RSSI value.

4 PROPOSED METHOD

4.1 Preconditions

The proposed method is an extension of the RSSI method with the following preconditions added (in accordance with the results of the preliminary experiments described above) and solves the problem of varying RSSI value due to differences in surrounding environment.

Precondition 1: Fixation of installation position of Bluetooth dongle

According to the results of a preliminary experiment, the desk-side installation position of the Bluetooth dongle was selected because the RSSI value is comparatively stable for this position regardless of the surrounding environment and mobile device position.

Precondition 2: Specification of Bluetooth dongle and mobile device

As in the preliminary experiment, a BT-MicroEDR2 (PCI) was used as the Bluetooth dongle and an HT1100 (HTC) was used as the mobile device. Fig. 10 shows the system configuration utilizing these devices.

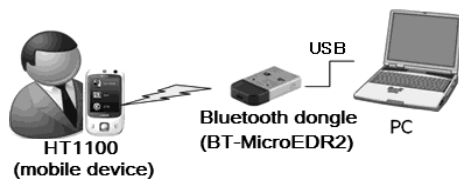


Figure 10: System configuration

4.2 Outline of proposed method

The proposed presence-detection method uses the RSSI function of the Bluetooth dongle to create a system that solves the problems described in Section 3.3 with high detection accuracy at modest cost. Fig. 11 shows the process flow of the proposal method, which detects the presence of a user in two processing steps using the RSSI value of a Bluetooth dongle acquired periodically.

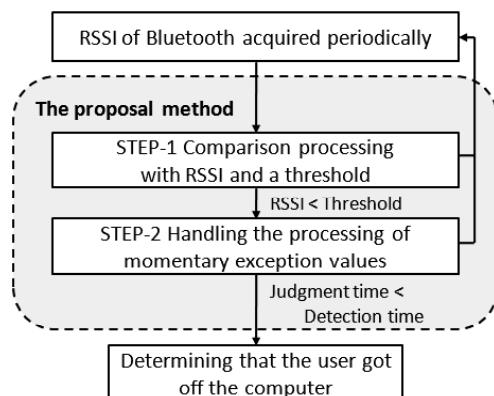


Figure 11: Processing flow of proposed method

STEP-1 Comparison processing with RSSI value and a threshold

Fig. 12 shows an example of change of RSSI value (vertical axis) and distance (horizontal axis). The RSSI value decreases, as in Fig. 12, when the distance to a communication partner increases. Accordingly, a threshold that satisfies the requirement 1 is set. The Bluetooth dongle establishes a connection with the mobile device, and the PC compares the RSSI value of the Bluetooth dongle acquired periodically with the threshold. If the RSSI value is lower than the threshold value, the following step (STEP-2 below) is performed.



Figure 12: Example of change of RSSI with distance

STEP-2 Handling the processing of momentary exception values

Fig. 13 plots RSSI value (vertical axis) against seating time (horizontal axis) in the case that the user is sitting in front of the PC. To satisfy requirement 2, the RSSI value must exceed a certain threshold value like that shown in data 1 in Fig 13. However, an erroneous detection might be included in the comparison processing using the RSSI value and the threshold. At this time, the PC may perform an erroneous detection because of a momentary fall of RSSI value. Accordingly, in the case of the proposed method, additional processing by using a “judgment time” as a momentary exception value is introduced.

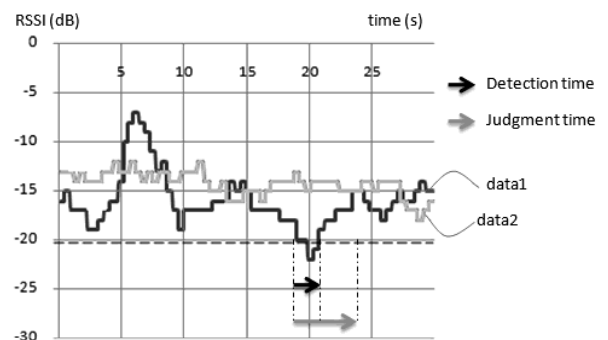


Figure 13: RSSI value against seating time in the case that the user is sitting in front of the PC.

The judgment time is set beforehand as the time that the RSSI value is monitored. In this processing, the PC measures “detection time,” that is, the time that the RSSI value is less than the threshold. It then judges that the user has left the PC if the detection time is longer than the judgment time. For

example, in data 2 of Fig. 13, although the RSSI value becomes momentarily lower than the threshold, the PC judges that the user is sitting in front of the PC, because the detection time is shorter than the judgment time. Thanks to this additional processing, the proposal method reduces the number of erroneous detections.

5 EVALUATION EXPERIMENT

5.1 Evaluation data

To determine the optimum values of the threshold and judgment time and to verify the usefulness of the proposed method, the following evaluation experiment was conducted. In this evaluation, the RSSI value of the Bluetooth device was obtained during the distance measurement experiment and erroneous detection experiment (see section 2.3) performed under various five experimental environments: A: spacious room and metal desk (Fig. 14); B: spacious room and wooden desk (Fig. 14); C: small room and metal desk (Fig. 15); D: small room and wooden desk (Fig. 16); E: spacious room and metal desk (Fig. 17). During the distance measurement experiment, the mobile device was in either of the following six states.

- Held in hand
- Put in front pocket of pants
- Put in back pocket of pants
- Put in a bag
- Sending a text message
- Making a telephone call

In the experiment, a total of 300 RSSI measurement were taken (i.e., five experimental environments multiplied by six mobile device states multiplied by ten times). During the erroneous detection experiment, the mobile device was in one of the following six states.

- Placed on the desk
- Put in front pocket of pants.
- Put in back pocket of pants.
- Put in bag.
- Sending a text message
- Making a telephone call

In the erroneous detection experiment, RSSI value was measured 300 times (five experimental environments multiplied by six states multiplied by ten times).

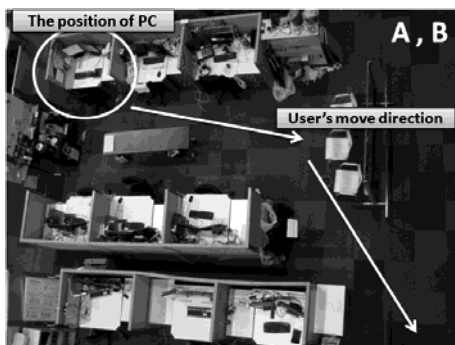


Figure 14: Experiment environments A and B

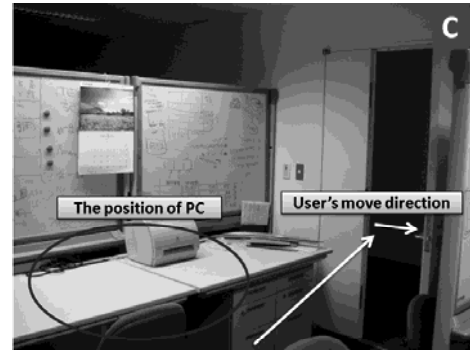


Figure 15: Experiment environment C

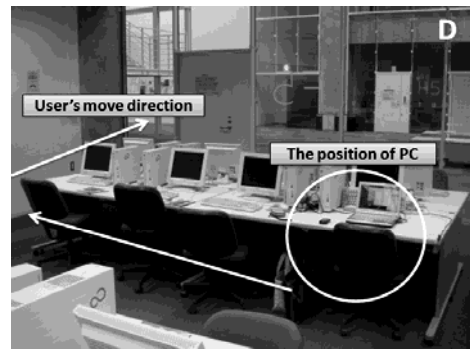


Figure 16: Experiment environment D

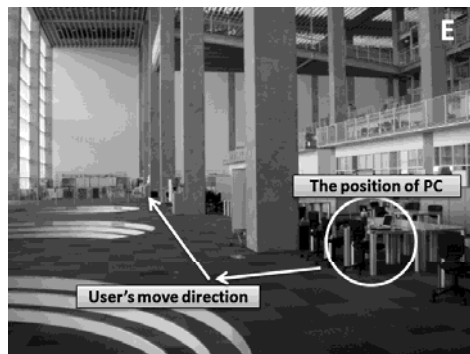


Figure 17: Experiment environment E

5.2 Evaluation simulator

The performance of the proposal method was evaluated by the simulator shown in Fig 18. This simulator outputs the result of the presence-detection by the proposed method using RSSI data (input value). It can freely set the two parameters, such as threshold RSSI value and judgment time, required for the proposal method.



Figure 18: Evaluation simulator

5.3 Performance evaluation

The optimal values of the two parameters (threshold RSSI value and judgment time) were determined from the evaluation data (RSSI values) given in section 5.1. Using these optimal values, the simulator (see section 5.2) was then used to evaluate the performance of the proposal method. There were thirty combinations of evaluated threshold RSSI value and judgment time as listed in Table 3.

Table 3: Combinations of RSSI threshold value and judgment time

Th	JT	Th	JT	Th	JT	Th	JT	Th	JT
-20	0	-20	3	-20	5	-20	7	-20	10
-21	0	-21	3	-21	5	-21	7	-21	10
-22	0	-22	3	-22	5	-22	7	-22	10
-23	0	-23	3	-23	5	-23	7	-23	10
-24	0	-24	3	-24	5	-24	7	-24	10
-25	0	-25	3	-25	5	-25	7	-25	10

Th: threshold (dB); JT: judgment time (s)

First, to evaluate whether the proposal method can satisfy requirement 1 (section 2.1), 300 measurements of the RSSI data acquired during the distance measurement experiment (section 5.1) were analyzed by the simulator. Table 4 lists the analytical results. To meet requirement 1, the PC has to perform the presence-detection processing for 95% (or more) of the time that the distance of the user to the PC from 10 to 30 m. Among the 30 combinations of the two parameters, 14 combinations meet requirement 1 (see Table 3). Moreover, when the judgment time is long, the probability of meeting requirement 1 is high.

Second, to evaluate whether the proposed method can meet the requirement 2, the 300 measurements of the RSSI data acquired in the erroneous detection experiment (section 5.1) were analyzed by the simulator. Table 4 lists the analytical results. To clear the requirement 2, the PC does not have to perform the presence-detection processing for 95% (or more)

of the time that the user is sat in front of the PC. Among the 30 combinations of the two parameters, 16 combinations meet requirement 2 (see Table 3). Moreover, when the threshold RSSI value is low, the probability of meeting the requirement 2 is high.

As shown in Table 4, when the threshold RSSI value is -22 dB and judgment time is 7 s, the proposed method meets the first and second requirements simultaneously. Accordingly, this RSSI value/judgment time combination is the optimal one under various conditions. In addition, this result demonstrates that the proposed presence-detection method is highly effective because it can acquire RSSI data in various environments (e.g., various widths of room) with difference states of mobile device. Moreover, the effectiveness of the proposed method was confirmed by simulation utilizing the results of experimental measurements.

6 CONCLUDING REMARKS

To develop a presence-detection system with high detection accuracy at modest cost, a presence-detection method using the received signal strength indication (RSSI) function of a Bluetooth device was developed. The performance of this method under various environmental conditions was evaluated by a simulator. According to the evaluation results, when threshold RSSI was -22 dB and judgment time was 7 s, the proposal method met the two specified requirements (section 2.1) simultaneously. It is therefore concluded that the proposal method is effective under various environments. Note that although the types of Bluetooth dongle and mobile device were specified in this study, even if other devices are used, the proposed method can be used by adjusting these two parameters (threshold RSSI value and judgment time).

In future work, the mechanism of automatically setting the parameters used in the proposal method will be investigated, automatic verification of the PC by using a mobile device will be tested, and various applications of presence-detection using the proposal method will be studied. In addition, the advanced inquiry method described in section 3.1 (another proposed method) will be experimentally evaluated.

Table 4: Results of performance evaluation of proposed method

		Judgment time(s)									
		0sec		3sec		5sec		7sec		10sec	
		Req 1	Req 2	Req 1	Req 2	Req 1	Req 2	Req 1	Req 2	Req 1	Req 2
Threshold (dB)	-20	60.7%	100%	79.0%	100%	85.0%	100%	88.3%	100%	90.7%	98.7%
	-21	68.0%	100%	85.3%	99.7%	90.3%	99.7%	92.7%	99.0%	94.7%	97.0%
	-22	78.7%	100%	90.7%	99.3%	93.7%	98.7%	96.0%	95.7%	97.0%	92.0%
	-23	83.0%	99.3%	94.3%	97.7%	96.3%	93.3%	98.0%	89.0%	98.7%	81.7%
	-24	89.0%	94.7%	98.0%	88.3%	99.3%	82.3%	99.3%	77.7%	99.7%	70.7%
	-25	95.0%	87.3%	99.3%	70.7%	99.3%	64.7%	99.3%	60.7%	100%	54.0%

Req 1: requirement 1; Req 2: requirement 2

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