DATA ACQUISITION FOR STOCHASTIC LOCALIZATION OF WIRELESS MOBILE CLIENT IN MULTISTORY BUILDING

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ABSTRACT: This paper describes a method for the localization of wireless mobile clients in multistory buildings using a wireless LAN system. The method uses public wireless LAN access points for users and robots that are settled at many places in a multistory building. Data on the physical position of personal electronic devices or mobile robots are important in information services and robot applications for construction automation such as the maintenance task in the large scale building. By integrating the data and stored information on objects and places, people and robots can be provided with information on the location of the devices for achieving the tasks. The localization method using few devices is expected for real application such as a navigation of the mobile robots, information services for users who have mobile clients. The paper focuses on the data acquisition for stochastic localization of the wireless LAN client in multistory building. The data acquisition is a crucial issue for making and verification of the localization system. Experimental results show feasibility of the proposed method.

Keywords: *Wireless LAN, Localization, Multistory Building, Data Acquisition, Stochastic Estimation*

1. INTRODUCTION

Data on the physical position of personal electronic devices or mobile robots are important in information services and robot applications. By integrating the data and stored information on objects and places, people and robots can be provided with information on the location of the devices [1]. Many kinds of localization services have been presented for personal devices and mobile robot; however, the localization method takes much cost and needs special devices mostly. Therefore, the localization method using few devices is expected for real application such as a navigation of the mobile robots, information services for users who have mobile phones. A number of studies for the localization method using the signal strength from wireless LAN access points have been proposed [2, 3, 6, 7].

This paper deals the simplified measurement for signal strength from the wireless LAN access points to make the localization system in the multistory building. Umetani et al. has been presented the localization of the wireless LAN client in the multistory building using the neural network (see Fig. 1) [3]. To make the estimation system based on the fingerprinting, the simplified measurement of the signal

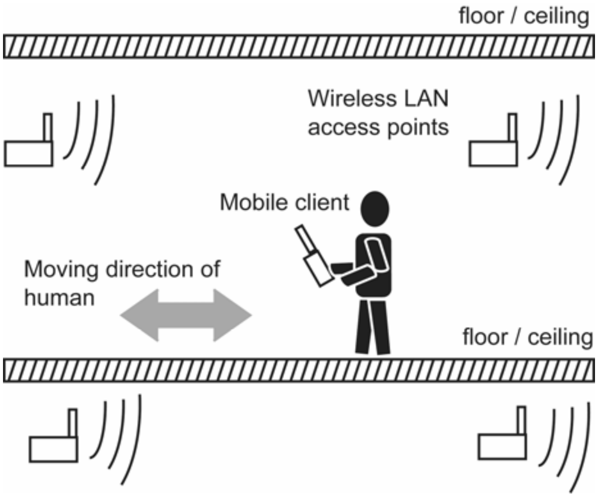

Fig. 1: Localization of wireless LAN client using signal strength from the wireless LAN access points. Moving direction of the client is horizontal on each floor in the building.

strength is needed; lots of data of the signal strength at various positions in the building are needed.

We focus on the simplified measurement with respect to the request interval for measurement of the signal strength, and the position measurement by the pacing using an accelerometer. We examine impact of the measurement interval for data collection of the signal strength. Then, the position measurement of the wireless LAN client by pacing is proposed. We construct an estimation system of the floor number and the position of the wireless LAN client based on a sparse Bayesian learning scheme [8]. Experimental results show feasibility of the proposed method.

2. IMPACT OF MEASUREMENT INTERVAL FOR COLLECTION OF SIGNAL STRENGTH

This section describes the impact of measurement interval of correction of signal strength in the building. First, we introduce the experimental environment. Then, the measurement method is explained. Finally, we discuss the measurement results.

2.1 Experimental Environment

Our experimental test bed is Building #13 at Konan University. The building is three-storied. Figure 2 shows the layout of the building. The dotted line indicates the paths along which the wireless LAN client was carried. The corridor in each floor is in the direction of east and west. The length of corridor is about 110 [m] on the second and third floor and about 45 [m] on the first floor. About half size of the floor of the corridor on third floor is the open ceiling space and the stairwell area.

Public wireless LAN access points Cisco Aironet 1210 are located in the corridors and the large rooms at the building. The number of the access points is 19; eight, six, and five access points are settled in first, second and third floor, respectively. The total number of received signals that can be detected is 38. The access points that are marked with (A) – (D) in Fig. 2 indicate the access points that are target access points in the measurement experiment.

The wireless LAN access points utilize the following standards: IEEE 802.11a, 802.11b, and 802.11g. We can identify these access points from those are settled at each laboratory room using the extended service identifier (ESSID). We use the strength of the signal strength of the received signals from the public wireless LAN access points.

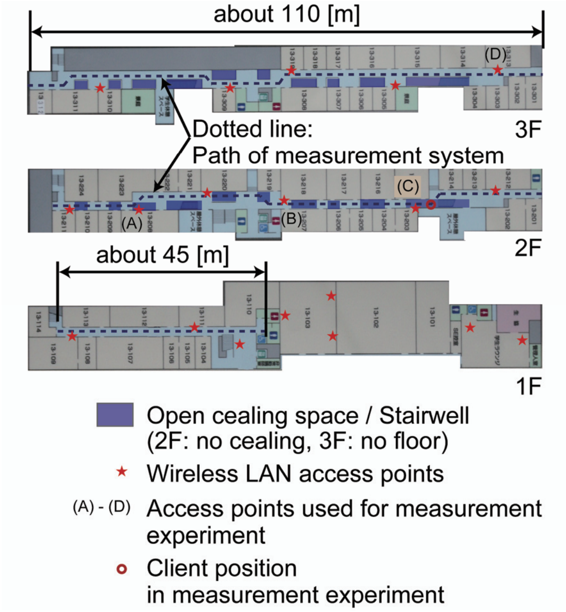

Fig. 2: Experimental environment.

2.2 Measurement Method

We use the wireless LAN client ICOM SU-50W, which supports IEEE 802.11a, 802.11b, and 802.11g standards. The wireless LAN client is connected with the notebook PC and set on the upper side of the moving carriage.

We define “One request” as the sequence that the PC requests the measurement of the signal strength to the wireless LAN client, then, the PC receives the signal strength from the wireless LAN client after the interval. The interval for data request to the collection is needed for data collection. We have set the interval 6[s] in our former study. In this paper, we set the interval 1[s], and compare the measurement result with that where the interval is set 6[s]. The reason that we set the interval 1[s] is supposed because of the cycles for the walk pattern of the human, and the measurement time for application.

In the data collection, the interval of strength of the received signal is from -100 to 0 [dBm], and the strength is expressed as the integer value. For the measurement experiment, we set the same experimental conditions; after the measurement experiment where the request interval is 6[s] is carried out, the measurement experiment where the interval is set 1[s]. The measurement result that the request interval is 1[s] is processed; the measurement result is the

Table 1: Result for received signal strength [dBm]. (Request interval is 6[s]; Condition I)

AP	A	B	C	D
Average	-74.6	-65.0	-55.3	-67.7
Max	-66	-54	-42	-55
Std. Dev.	2.96	-6.67	10.6	6.05

Table 2: Result for received signal strength [dBm]. (Request interval is 1[s]; Condition II)

AP	A	B	C	D
Average	-74.6	-64.9	-53.8	-66.2
Max	-70	-55	-44	-55
Std. Dev.	2.39	3.92	9.15	5.59

Table 3: Result for received signal strength [dBm]. (Request interval is 6[s], another day; Condition III)

AP	A	B	C	D
Average	-76.5	-69.0	-55.6	-71.9
Max	-70	-59	-46	-65
Std. Dev.	1.02	4.67	8.1	4.15

Table 4: Result for received signal strength [dBm]. (Request interval is 1[s], another day; Condition IV)

AP	A	B	C	D
Average	-72.8	-66.0	-59.6	-69.0
Max	-65	-54	-49	-65
Std. Dev.	3.52	5.07	5.43	1.99

Table 5: Change of average for access point "A".

	Cond. I	Cond. II	Cond. III	Cond. IV
Cond. I		0	1.6	1.8
Cond. II	0		1.9	1.8
Cond. III	1.6	1.9		3.7
Cond. IV	1.8	1.8	3.7	

moving average of the six samples of the measurement results. The length of the measurement experiment is set one hour for each condition. We have carried out the measurement experiment on the other day to examine the impact of the measurement days. The lengths of the measurement experiment are 360 minutes and 310 minutes for the interval is 1[s] and 6[s], respectively.

2.3 Measurement Results

We have recorded 22 received signals from wireless LAN access points at the measurement position. Table 1 and 2 show the signal strength from the wireless LAN access points that the differences of the average signal strength between each experimental condition are largest and smallest case. Access point A and B are the access points that the difference of the average strength is smallest. Access point C and D are the access points that the difference of the average strength is largest. From the letters of A to D in Table 1 and 2 corresponds to the (A) to (D) in Fig. 2. The frequency band of wireless LAN access points A and D is 5[GHz], that of the access points B and C is 2.4 [GHz].The interval of difference of the average strength for each condition is 0 to 1.49 [dBm], the average of difference is 0.51 [dBm].

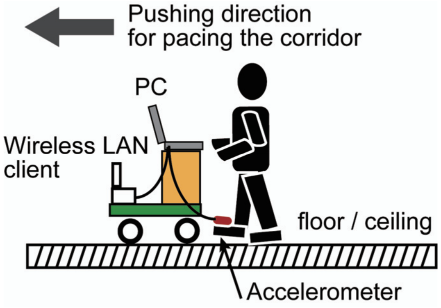

Fig. 3: Experimental setup.

Table 3 and 4 shows the measurement results for signal strength that are obtained on the other day. Table 5 shows the differences of the average strength for each experimental condition. From Table 5, the impact of the request interval for data collection is smaller than that of the date of the experiment. For the other signals, the same trends are shown. These results show the feasibility of the shortening of the request interval for data collection for the simplified measurement.

3 MEASUREMENT OF POSITION OF WIRELESS LAN CLIENT BY PACING DISPLACEMENT

This section describes a method for measurement of position of wireless LAN client by pacing displacement. An accelerometer is attached on the instep of the right foot of the measurer; the system measures the acceleration of the foot during the pacing.

Fig. 3 shows the experimental setup for the measurement of the acceleration. The pacing motion is detected based on principal component analyses of the acceleration data. We use the three-axis accelerometer Microstone MA3-10AD, and the Arduino microcontroller for the connection to the PC. The acceleration is measured by 50 [Hz]. The measurer pushes the moving carriage during the measurement; the signal strength is collected using the moving carriage.

Figure 4 shows the output values of the accelerometer for each axis during pacing motion. The vertical axis indicates the output value of the accelerometer; the output value is zero when the acceleration is 0 [m/s^2]. From Fig. 4, the absolute value of the acceleration is large when the right foot lands. The acceleration for each axis is recorded various values. Therefore, we analyze the principal component for the absolute value of the acceleration. The score for the first principal component is shown as follows:

$$u = 0.5883a_x + 0.5798a_y + 0.563a_z \tag{1}$$

where $a_{x,} a_y, a_z$ is the absolute value for the acceleration of each axis. The contribution ratio of the principal component is 0.701. Using the principal component, we detect the landing of the right foot in the pacing motion; the number of the steps is counted by two steps.

4 EXPERIMENTS FOR CONSTRUCTION OF ESTIMATION SYSTEM

This section describes the experiment for construction of estimation system based on the shortening of the request interval for the data collection and the pacing of displacement of the wireless LAN client.

4.1 Experimental parameters

We use the signal strength from the wireless LAN access points under two conditions about the request interval for data collection; the request interval for data collection is 6 [s], and the interval is 1 [s]. In addition, for the condition that the request interval is 1 [s], we measure the displacement of the wireless LAN client by pacing. The number of the received signals is 35 for both conditions. The relation between the displacement and the number of the steps for the pacing are obtained as follows:

$$d_s = \frac{l_f - l_{off\_r} - l_{off\_f}}{s_{total}} s + l_{off\_r} \tag{2}$$

where $d_s, l_f, l_{off\_r}, l_{off\_l}, s, s_{total}$ mean the position of the wireless LAN client, the length of the corridor, the initial position of the wireless LAN client, the final position of the wireless LAN client, the number of the data collection, and the total number of the data collection, respectively. The position of the wireless LAN client and the received signals are normalized to the interval [0, 1].

The size of the training dataset is 896 for the proposed method, and 600 for the conventional condition. The number of the validation data is 450 (1F: 150, 2F: 150, and 3F: 150). We obtain the received signals by the pacing for 9, 3, 3 times for 1F, 2F and 3F, respectively. The request interval for the data collection is 1[s]; the request interval for the data collection in the conventional condition is 6 [s].

4.2 Construction of position estimation system

We make the estimation system for the position of the wireless LAN client based on a sparse Bayesian learning scheme [8]. Let $\mathbf{x}$ be the input vector consists of the signal strength from the access points. The element of $\mathbf{x}$ is corresponding to the BSSID of the wireless LAN access points. In the position estimation, the input value includes the estimated floor number, which is 1, 2, and 3.

The floor number of the client $y_k^{(f)}$ is expressed as follows:

$$y_f^{(k)} = \frac{\exp\left(a^{(k)}\right)}{\sum_j \exp\left(a^{(j)}\right)} \tag{3}$$

where $a^{(k)} = \mathbf{w}^{(k)T} \phi(\mathbf{x})$. $\mathbf{w}^{(k)}$ is the weight parameter vector for the floor number k. $\phi(\mathbf{x})$ is the data-centric bases function vector expressed by

$$\phi(\mathbf{x}) = \begin{bmatrix} 1 & k(\mathbf{x}, \mathbf{x}_{t1}) & \ldots & k(\mathbf{x}, \mathbf{x}_{tN}) \end{bmatrix}^T \tag{4}$$

where $k(\mathbf{x}, \mathbf{x}_k)$ is the data-centric basis function

$$k(\mathbf{x}, \mathbf{x}_k) = \exp\left(- \frac{\|\mathbf{x} - \mathbf{x}_k\|^2}{2\sigma_k^2} \right) \tag{5}$$

where σ_k^2 is the width of the kernel function, we set 1.0 experimentally. $\mathbf{x}_{t1}, \ldots, \mathbf{x}_{tN}$ are the training data set for the input vector. The elements of $\mathbf{w}^{(k)}$ are estimated in advance [5].

The position of the wireless LAN client is expressed by the normal distribution, where the mean y and the variance σ^2 are expressed as follows:

$$y(\mathbf{x}) = \mathbf{w}^T \phi(\mathbf{x}) \tag{6}$$

$$\sigma^2(\mathbf{x}) = \left(\beta^*\right)^{-1} + \phi(\mathbf{x})^T \Sigma \phi(\mathbf{x}) \tag{7}$$

where $\mathbf{w}$ is the weight parameter, β^* is the hyperparameter of the precision parameter for the estimated position, and Σ is the covariance matrix for the weight parameter vector. $\mathbf{w}, \beta^*.\Sigma$ are estimated using the training data set in advance [4].

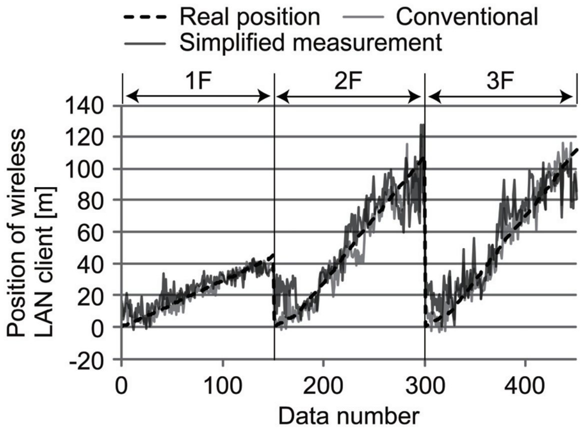

Figure 4: Experimental result.

4.3 Experimental results

Figure 4 shows the relation between the estimated position and the real position of the wireless LAN client. The horizontal axis indicates the number of collected data, and the vertical axis indicates the displacement of the wireless LAN client. The thick line indicates the estimation result for the proposed method, and the gray line indicates the estimation result based on the conventional method, the dotted line indicates the measurement displacement by the roller encoder. The obtained data from #1 to #150 correspond to the first floor and those from #151 to #300 correspond to the second floor. The data from #301 correspond to the third floor.

Figure 5 shows the cumulative rate for the distance error of the estimation result. The horizontal axis indicates the distance error. The vertical axis indicates the cumulative rate of the distance error. Table 6 and 7 show the uncertainties of the estimation result for each floor. The root mean square (RMS) error is 12.24 [m] for the result under the simplified measurement condition; that is 7.76 [m] for the conventional measurement method. The average error is 9.06 [m] for the simplified measurement condition, 5.74 [m] for the conventional method.

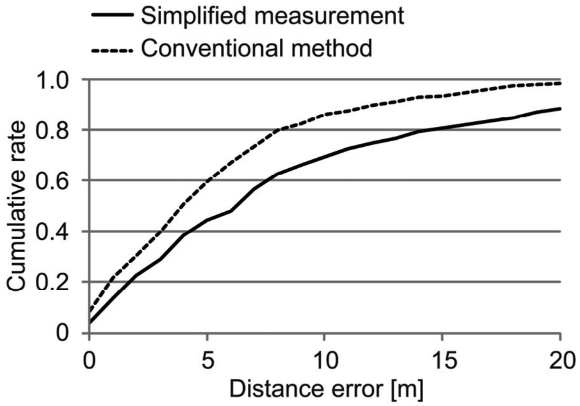

Figure 5: Cumulative rate for distance error.

Table 6: Uncertainty of estimation result for each floor (Simplified measurement).

	Average error [m]	Root mean square (RMS) error [m]
1F	4.98	6.46
2F	11.19	14.48
3F	11.02	14.08
Total	9.06	12.25

Table 7: Uncertainty of estimation result for each floor (Conventional).

	Average error [m]	Root mean square (RMS) error [m]
1F	3.19	4.24
2F	6.54	8.61
3F	7.47	9.41
Total	5.74	7.76

Table 8: Relation between floor numbers determined from measurement and estimated floor numbers.

		Estimated floor number		
		1	2	3
Floor number (measured)	1	150	0	0
	2	4	133	13
	3	0	1	149

Table 8 indicates the relation between the floor number determined from measurements and the estimated floor number. The rows represent the floor numbers determined floor measurements, while the columns denote the estimated floor number. The number of diagonal elements in the table is the number of times that the estimation system correctly identified the floor number. From Table 2, the number of correct result for floor number identification is 432 in 450 samples. The ratio of correct result is 96.0 [%]. The ratio of correct result on each floor is 100 [%], 88.7 [%], 99.3 [%], respectively.

The number of bases functions, in-model feature vectors, is 154 in 896, 9 in 2688 candidates for the position estimation and the floor number estimation, respectively.

4.4 Discussions

We have shown feasibility of the construction of the estimation system for localization and floor identification in the multistory building using the simplified measurement with respect to shortening of the request interval for data collection and the distance measurement by the pacing motion. Figure 4 and 5 show that the estimated position of the wireless LAN client is related to the measured position; however, the localization error by the estimation system based on the simplified measurement is larger than that based on the conventional method. From Table 6 and 7, the estimation error for the first floor is smaller than that for the other floor. The increase of the sample data for the other floor is needed to improve the localization accuracy.

In this experiment, we use the validation data, the request interval for collection of the received signal strength is set 6 [s]. The experiment using the validation data, under the condition that the request interval for data collection is set 1 [s], is needed.

From Table 8, the system identifies the floor number correctly about the data captured on each floor of the building. The estimation result shows the estimation system classifies the floor successfully based on signal strength from the wireless LAN access points in the building that has open-ceiling spaces.

Through the experimental result, the feasibility of the construction of the estimation system for localization and floor identification using the simplified measurement with respect to shortening of the request interval for data collection and the distance measurement by the pacing motion is shown.

5 CONCLUSION

This paper describes the simplified measurement for signal strength from the wireless LAN access points to make the localization system in the multistory building. We have proposed the simplified measurement based on the request interval for data collection and the pacing motion for the measurement of the displacement of the wireless LAN client. Experimental results show the feasibility of the method.

The increase of the sample data for the other floor is needed to improve the localization accuracy. The experiment using the validation data, under the condition that the request interval for data collection is set 1 [s], will be conducted as the future works.

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