A Broad-Typed Multi-Sensing-Range Method for Indoor Position Estimation of Passive RFID Tags

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***Abstract*— The RFID (Radio Frequency IDentification) system is paid attention as a technology that can realize a ubiquitous environment. Each RFID tag has a unique ID code, and is attached on some object with the information of the objects. A user reads the unique ID code using RFID readers and obtains the information of the object. One of the important applications of RFID technology is the indoor position estimation of RFID tags. It can be applied to a navigation system for people in complex buildings.**

In this paper, we propose an effective position estimation method named Broad-typed Multi-Sensing-Range (B-MSR) to improve the conventional methods using sensor model on the estimation error. In B-MSR, we introduce a new reader antenna with two flexible antenna elements. For two flexible antenna elements, we can adjust the distance between them. Thus, we can control two kinds of system parameters, the distance between two antenna elements and the transmission power of the RFID reader. In this paper, we settle four sensing ranges. Moreover, B-MSR is adaptable to the three dimensional (3D) position estimation with sufficient accuracy. We further propose a 3D position estimation algorithm for B-MSR. The performance evaluation shows that B-MSR reduces the initial estimation error, the number of the different sensing points and finally the time to require the estimation than the conventional methods.

***Keywords*—RFID reader; RFID tag; position estimation ; sensor model; Broad-typed Multi-Sensing-Range method**

I. INTRODUCTION

The RFID (Radio Frequency IDentification) system is paid attention as a technology that can realize a ubiquitous environment. The RFID system consists of RFID tags, an RFID reader, and software to process the RFID tags reading. The RFID reader receives the RFID tag's unique ID code and information stored in their memory. In many cases, RFID tags are attached to some objects and their unique ID codes are related to information on the objects. The RFID system is considered to be very useful in various kinds of industrial fields.

RFID tags are classified into two types, active RFID tag and passive RFID tag. The passive RFID tag system has remarkable characteristics that are low-cost and can be downsized. In this paper, we discuss only the passive RFID system.

One of the important applications of RFID technology is the indoor position estimation of passive RFID tags. This technology is to estimate the location of RFID tags. It can be applied to a navigation system for walkers, particularly handicapped persons. So, it has been studied enthusiastically and there are a number of conventional methods for indoor positioning of RFID tags [1]-[7].

One of the most practical methods is proposed in the paper [1]. This method is the position estimation method using a sensor model. This method uses the Bayesian rule and estimates the position of an RFID tag by using single sensing range. We call this Single-Sensing-Range (SSR) method. SSR has the following serious problems. 1) The initial estimation error is very high. 2) To reduce the estimation error, it needs a lot of different sensing points for one RFID tag. 3) Finally, the method takes a long time to estimate the position to move for many sensing points.

To solve the above problems, the previous papers [2], [3] proposed Multi-Sensing-Range (MSR) method which introduces three sensing ranges by controlling the transmission power of an RFID reader. This MSR can inquire the responses of three sensing ranges at one sensing point, reduce the number of different sensing points, and so reduce the estimation error, significantly. However, MSR has the disadvantage that the initial error is very large than SSR due to the difficulty of accurate processing on the boundary area of three sensing ranges.

In order to improve the large initial error of MSR, this paper proposes a Broad-typed Multi-Sensing-Range (B-MSR) method. The proposed method uses the power control and a new reader antenna with two flexible antenna elements. By adjusting the distance between the two antenna elements, we can adjust the width of a communication range. Thus, B-MSR can estimate in detail with four sensing ranges by adjusting both the transmission power and the distance between the antenna elements. For this reason, B-MSR can improve the initial estimation error and the estimation error convergence.

By the experiments in 2D and 3D measurement environment, we show that B-MSR can reduce the initial estimation error and the number of different sensing points. This paper is organized as follows. In section 2, SSR method is discussed. In section 3, we propose B-MSR method and position estimation algorithm in 3D. Sections 4 and 5 present the performance evaluations by the simulations and experiments, respectively. Finally, we conclude this paper in section 6.

II. SSR METHOD

SSR evaluates the posterior probability $p(x|z_{1:t}, r_{1:t})$, for the decision of an RFID tag position. Here, x is the position of the RFID tag, $z_{1:t}$ are the sensing data at time step from 1 to t, and $r_{1:t}$ are the locations of an RFID reader at time step from 1 to t. Based on the Bayesian estimation, the following equation is defined.

$$p(x|z_{1:t}, r_{1:t}) \propto p(z_t|x, r_t)\, p(x|z_{1:t-1}, r_{1:t-1}) \quad (1)$$

Here, $p(z_t|x, r_t)$ expresses the likelihood of sensing datum z_t given the position x of the RFID tag and the location r_t of the RFID reader.

In SSR, RFID reader performs the position estimation of RFID tags. Fig.1 shows the sensor model which defines the distribution of likelihood. The detection range of the RFID reader is assumed to be ellipse shape from the directivity of the RFID reader. For a simple model of detecting RFID tags, we set the likelihood of this range as 0.9, and that of outside range as 0.5.

Next, we show the procedure of localization of RFID tags. To represent the posterior probability for the location of an RFID tag, the model uses sample positions in a reticular pattern. If the RFID reader detects a RFID tag first time, the system ingenerates sample position virtually as candidate position of the RFID tag in a square area around the location of the RFID reader. The system assigns the value of likelihood $p(z_1|x, r_1)$ to each sampled position with sensor model. In eq. (1), the posterior probability of each sample position is updated according to the likelihood. Fig.2 shows an example of updating the posterior probability at time step 1.

If the RFID reader detects the same RFID tag on another location, the system estimates the value of likelihood $p(z_2|x, r_1)$ with the sensor model and updates the posterior probability. By repeating this procedure, the center of gravity of the largest posterior probabilities is assumed as the location of the RFID tag.

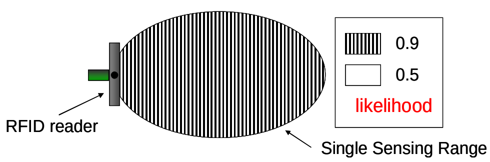


Figure 1. Simple sensor model

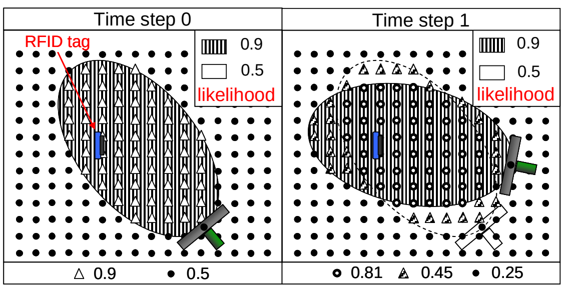


Figure 2. Update of posterior probability

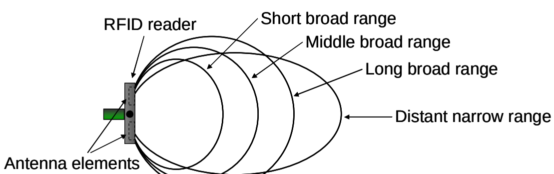


Figure 3. Sensing ranges

III. B-MSR METHOD

A. Outline of B-MSR

While MSR improves the estimation error and the long delay of SSR, its initial estimation error is nonetheless larger than one of SSR. For this problem, MSR requires still many sensing points which cause an RFID reader to move a lot. In other words, it takes time to improve the estimation error. So, we propose a novel position estimation method named Broad-typed Multi-Sensing-Range (B-MSR) to improve the initial estimation error. B-MSR uses flexible sensing rages by using a new reader between two antenna elements. In this paper, we introduce the four sensing ranges shown in Fig.3 by the transmission power control and the two elements antenna. We call the four sensing ranges as 1) distant narrow range, 2) long broad range, 3) middle broad range and 4) short broad range. B-MSR uses three sensing ranges selected according to whether RFID reader can receive responses from an RFID tag at one sensing point. Thus, B-MSR has four sensor models depending on the select of the sensing ranges. We can shorten the processing time of B-MSR by limiting the number of radiating electromagnetic wave. Then, we adopt four sensing ranges that are able to estimate position with sufficient accuracy. By subdividing the sensor model with the four sensing ranges, it is possible to improve the initial estimation error significantly.

B. Position estimation algorithm of B-MSR

First, a mobile robot equipped with an RFID reader repeats moving to one of sensing points and performs the sensing until the RFID reader can detect an RFID tag. At each point the RFID reader searches for an RFID tag with the distant narrow range. If the RFID reader detects an RFID tag, it ingenerates sample positions virtually in a square area around the location of the RFID reader and switches from the distant narrow range to the middle broad range. Then, it works as follows. 1) In case that the RFID reader can not detect the RFID tag with the middle broad range, it switches from the middle broad range to the long broad range. We select sensor model 1 or sensor model 2 according to whether the RFID reader can detect the RFID tag with the long broad range. 2) In case that the RFID reader can detect the RFID tag with the middle broad range, we use the short broad range. Sensor model is selected according to whether the RFID reader can detect the RFID tag with the short broad range. The system updates the posterior probability of sampled positions with the selected sensor model. At the end of estimation, the system assumes the center of gravity of the largest posterior probabilities as the location of the RFID tag. Fig.4 shows the sensor model 1 of four sensor models.

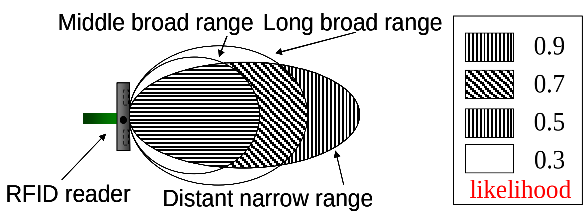


Figure 4. Sensor model 1

C. 3D position estimation alrorithm

In this paper, we carry out a three dimensional (3D) position estimation of an RFID tag by the RFID reader attached to the robot arm. The 3D position estimation algorithm consists of 4 steps.

Step1: Initial movement.

Step2: Detection of the Center Line (CL) by CRR method.

Step3: Estimation of the height of an RFID tag.

Step4: Estimation of the position of an RFID tag in 2D.

This 3D algorithm has two advantages. First, the algorithm can estimate 3D position of a passive RFID tag. Second, at an observation point, the algorithm can make the estimated position error smaller than the conventional methods.

IV. PERFORMANCE EVALUATION BY SIMULATIONS

We perform computer simulations with a straight movement model of a mobile robot shown in Fig.5. In this model, the mobile robot starts from the point A to the point B making observations whether the RFID tag responses the unique ID to it or not. When it reaches the point B, it turns around and goes back to the point A. The direction of the RFID tag is in parallel with the moving direction of the mobile robot. We consider two cases of distances, say L, between the RFID tag and the moving line of the mobile robot. Those distances are 100cm and 300 cm. Table 1 shows parameters.

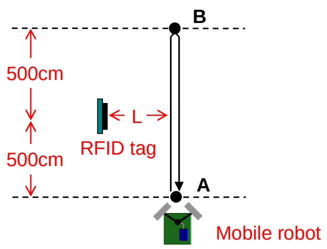


Figure 5. Straight movement model

TABLE I. PARAMETER OF SIMULATION

Number of RFID tag	1	
Distance between sensing points	25cm	
Communication distances	Distant Narrow Range	5m
	Long Broad Range	3.57m
	Middle Broad Range	2.5m
	Short Broad Range	1.25m
Sample pattern of positions	Grid of 5cm	

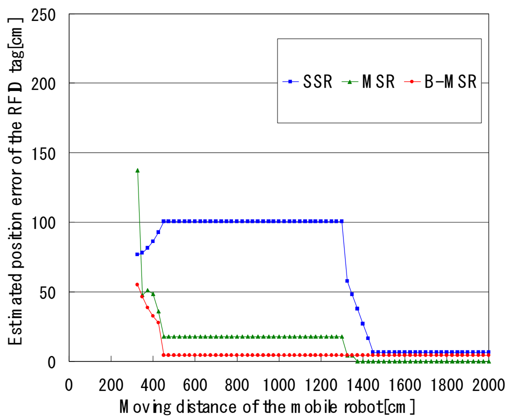


Figure 6. Estimated position error of the RFID tag vs. moving distance of the mobile robot (L=100cm)

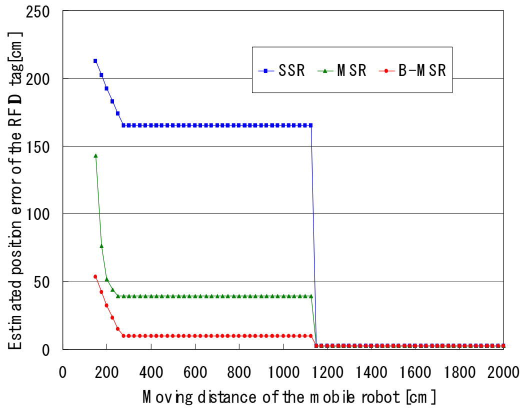


Figure 7. Estimated position error of the RFID tag vs. moving distance of the mobile robot (L=300cm)

Figs.6 and 7 show the estimation position error performance against the moving distance of the mobile robot. From those results, we find that B-MSR can reduce the estimated position error with shorter moving distance than the conventional methods.

V. PERFORMANCE EVALUATION BY EXPERIMENTS

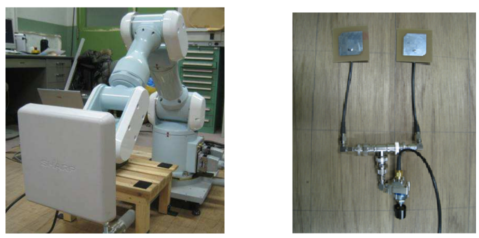
We evaluate the performance through experiments to show the effectiveness of the proposed method B-MSR. We used a 2.45-GHz RFID system (Japan RF Solutions: SDK-3). The Specifications are listed in Table 2.

To move the RFID reader antenna, we used the robot arm. The RFID reader antenna is mounted on the tip of the robot arm. Fig.8(a) shows the robot arm with the RFID reader antenna and shows the side view of the experimental apparatus. The RFID tag is attached at the height of 50 cm of a pole. To carry out experiments using B-MSR, we use a new reader antenna shown in Fig.8(b). The area of the experiment was 160 cm x 240 cm. The initial location of the RFID reader is (x[cm], y[cm], z[cm]) = (0, 50, 40) and the location of the RFID tag is (x[cm], y[cm], z[cm]) = (10, L+50, 50). Where, L is the relative distance between the RFID reader and the RFID tag in the direction of y-axis.

Fig.9 and Fig.10 show the distribution of the largest posterior probabilities versus the elevation angle in Z and CL directions at L = 35cm. From those results, MSR and B-MSR can narrow down the distribution of the largest posterior probabilities in Z direction according to the

TABLE II. SPECIFICATIONS OF THE RFID SYSTEM

RFID reader		RFID tag	
Carrier frequency	2,427~2,470.75 [MHz]	Name	RZ-1TG4
Process time	12 [ms](read)	Read distance	200 [cm]
RF transmission power	300 [mW]	Polarization	Circular polarization



(a) RFID reader with robot arm (b) New reader antenna

Figure 8. Experimental equipment

decreasing of the elevation angle. This is because MSR and B-MSR use plural sensor models. Moreover, B-MSR can narrow down the distribution of the largest posterior probabilities in CL direction according to the decreasing of the elevation angle. This reason is that B-MSR uses segmented sensor models by the reader antenna with two flexible antenna elements. Thus, B-MSR can improve the estimation error in CL direction.

Fig.11 shows the estimated position error in 3D versus the moving distance of the robot arm at L = 35cm. While MSR is highly accurate on the position estimation in only Z direction shown by Fig.9, B-MSR is highly accurate method for the 3D position estimation. Fig.11 shows that B-MSR improves the estimation error substantially in two dimensions than SSR and MSR. Particularly, B-MSR can reduce the estimation error in span of few movement distances. In other words, B-MSR can improve the initial estimation error in two dimensions, considerably.

Then, we consider the required time for the estimation. If the rotation speed of the RFID reader is 10 degrees/s and the moving speed of the mobile robot is 10 cm/s, we can consider that the operation time of the equipment until the completion of the estimation for SSR and MSR is less than 30 seconds. B-MSR requires the same time and also requires an additional several seconds to adjust the distance between two antenna elements. It looks like a little disadvantage for B-MSR. However, B-MSR requires much less number of different sensing points than SSR and MSR, and the total operation time of B-MSR is the shortest of three methods.

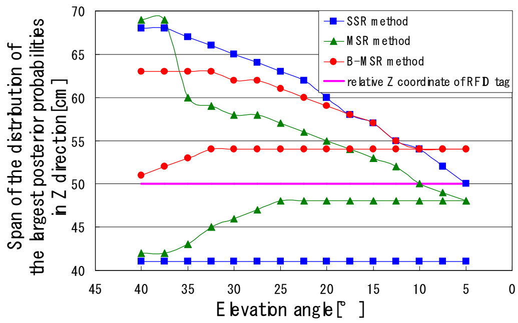


Figure 9. The distribution of the largest posterior probabilities vs. elevation angle in Z direction at L = 35cm

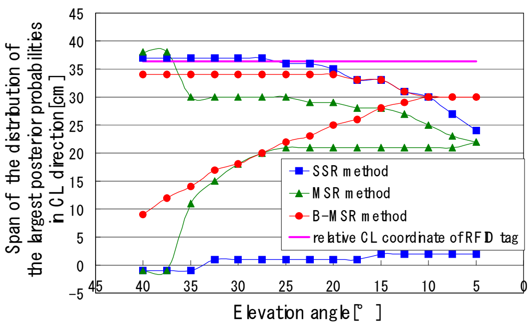


Figure 10. The distribution of the largest posterior probabilities vs. elevation angle in CL direction at L = 35cm

VI. CONCLUSIONS

In this paper, we have proposed a novel method named Broad-typed Multi-Sensing-Range (B-MSR) for the indoor position estimation of passive RFID tags. The

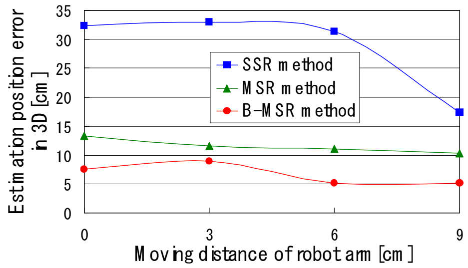


Figure 11. Estimation position error in 3D vs. moving distance of robot arm at L = 35cm

proposed method introduces a new reader antenna with two flexible antenna elements. For two flexible antenna elements, we can adjust the distance between them. Thus, we can control two kinds of system parameters, the antenna elements interval and transmission power of the RFID reader.

The proposed method has two purposes. The first is to realize the position estimation that can reduce the initial estimation error by using flexible sensing range. The second is to reduce the movement of an RFID reader.

In order to show the effectiveness of the proposed method, we have evaluated the estimation position error in Z and CL direction and three dimensions by a number of experiments. We have obtained the following results.

1) The proposed method can reduce the initial estimation error, and so the proposed method can reduce the estimation error with fewer movements of the RFID reader than the conventional methods.
2) The proposed method can reduce the estimation error on the CL-Z plane compared with the conventional methods.

REFERENCES

[1] D.Hahnel, W.Burgard, D.Fox, K.Fishkin, M.Philipose, “Mapping and Localization with RFID Technology,” IEEE International Conference on Robotics & Automation, vol.1, pp.1015-1020, April 2004.

[2] T. Hori, N. Uchitomi, Y. Ota, T. Wada, K. Mutsuura, H. Okada, “A Multi-Sensing-Range Method for Position Estimations of Passive RFID Tags,” 4th IEEE International Conference on Wireless & Mobile Computing, Networking & communication (WiMob 2008), Avignon, France, Oct. 2008.

[3] T. Hori, T. Wada, N. Uchitomi, K. Mutsuura, H. Okada, “A Multi-Sensing-Range Method for Effective Position Estimation by Passive RFID Technology,” IEICE Transaction on Fundamentals, vol.E92-A, no.10, pp.2609-2617, Oct. 2009.

[4] T. Wada, N. Uchitomi, Y. Ota, T. Hori, K. Mutsuura, H. Okada, “A Novel Scheme for Spatial Localization of Passive RFID Tags; Communication Range Recognition (CRR) scheme,” IEEE International Conference on Communications, pp.1-6, Dresden, Germany, June 2009.

[5] N. Uchitomi, A. Inada, M. Fujimoto, T. Wada, K. Mutsuura, H. Okada, “Accurate Indoor Position Estimation by Swift-Communication Range Recognition (S-CRR) Method in Passive RFID systems,” 2010 IPIN, Zürich, Switzerland, Sept. 2010.

[6] Bing Jiang, Kenneth P. Fishkin, Matthai Philipose, “Unobtrusive Long-Range Detection of Passive RFID Tag Motion,” IEEE Transactions on Instrumentation and Measurement, vol.55, no.1, pp.187-196, Feb. 2006.

[7] Manzoor, Farhan Huang, Yi Menzel, Karsten, “Passive RFID-Based Indoor Positioning System, An Algorithmic,” IEEE International Conference on RFID-Technology and Applications, Guangzhou, China, 17 - 19 June 2010.