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

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***Abstract*— Recently, the RFID tag system is paid attention to as an identification source. Each RFID tag is attached to some object. With the unique ID of RFID tag, a user identifies the object provided with the RFID tag, and derives appropriate information about the object. One of the important applications of RFID technology is the position estimation of RFID tags. It can be very useful to acquire the location information concerning the RFID tags. It can be applied to navigation systems and positional detection systems for robots etc. In this paper, we propose a new position estimation method of RFID tags by using a probabilistic approach. In this method, mobile objects (person and robot, etc) with RFID readers estimate the positions of RFID tags with plural communication ranges. We show the effectiveness of the proposed method by computer simulations.**

***Keywords*— RFID (Radio Frequency IDentification), RFID reader, RFID tag, Position estimation, Passive tag, Likelihood, Transmission power**

I. INTRODUCTION

RFID (Radio Frequency IDentification) is paid attention to as a technology that achieves a ubiquitous environment. The RFID system consists of RFID tags and RFID readers. Each RFID tag has the unique identifier, say unique ID, and is attached to some object. A user reads the unique ID of an RFID tag with his RFID readers. That enables the user to identify the object provided with the RFID tag. So, the RFID tag system is applied in various fields. For example, in the fields of physical distribution, the technology to recognize multiple items in a cardboard box or a shopping basket at a time attracts attention.

The unique ID of an RFID tag can be related to some useful information. One of the important information is the location information of the object with the RFID tag . From the unique ID and the location information concerning the RFID tag, users can understand the position of the object with the RFID tag.

RFID tags are classified into two types. One is the passive type that is battery-less, and the other is active type that has own battery. The passive type tags are inexpensive and has long lifetime. For this reason, the passive tags can be used in all over the place. So, the technology for estimating the position of RFID tags can be applied to the grasp of the position by the robot and the navigation system, etc. As one of the researches, in indoor environment, a system to track persons or objects provided with RFID tags is developed [1].

In this paper, we focus on the position estimation issues with passive RFID tags. The previous papers [2]-[4] have proposed the position estimation methods by using a probabilistic approach. Those methods use the Bayesian estimation. In those methods, a mobile robot provided with an RFID reader estimates the positions of RFID tags with a single sensing range. The transmission power of the RFID reader is constant. The problem of the conventional methods is that the amount of the robot's movement between the observation points should be large to reduce the error of the position estimation. In other words, it takes a long time for the methods to reduce the estimated position error, and the power consumption of the robot's battery is large. To solve this problem, we propose a multi-sensing-range method for position estimation of passive RFID tags.

In the proposal method, an RFID reader has multi-sensing-ranges. For simplicity we set the three sensing range; long-range, middle-range, short-range in this paper. In other words, the transmission power of the RFID reader can be changed by three steps. First the robot searches for the presence of tags by the long-range at a certain position. Second, if the robot detects the presence of tags, it repeats the search by the middle-range and the short-range at the same position, i.e. the robot searches for the positions of tags within the long-range in detail. Therefore the proposed method can perform the prompt positional estimation, i.e. the method can reduce the amount of the robot's movement for accurate estimation of tag's positions.

In order to show the effectiveness of the proposed method, we will carry out computer simulations with some movement models of the robot.

This paper is organized as follows. In section 2, the conventional method for position estimation of RFID tags is discussed. In section 3, we propose a multi-sensing-range method. Section 4 presents the performance evaluation by computer simulations. Finally we conclude this paper in section 5.

II. CONVENTIONAL METHOD FOR POSITION ESTIMATION

In the conventional method, a robot equipped with RFID reader and RFID antennas performs the position estimation of RFID tags. To estimate tags' positions, posterior probability $p(x \mid z_{1:t}, r_{1:t})$ is evaluated. Here, x is position of the tag, $z_{1:t}$ are the observations at time step from 1 to t, and $r_{1:t}$ are the locations of the RFID antenna at time step from 1to t. Based on the

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Bayesian rule, the following equation is defined.

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

Here, $p(z_t \mid x, r_t)$ expresses the likelihood of observation z_t given the position x of tag and the location r_t of the RFID antenna.

In this method, RFID reader requests the unique IDs to tags with constant transmission power of the RFID reader. In other words, this method has single communication range. Fig.1 shows a sensor model of the conventional method which defines the distribution of likelihood. The detection rage of RFID reader is assumed to be the inside area of the ellipse. For a simple model of detecting tags, papers [2]-[4] set the likelihood of this range as 0.9, and that of outside this range as 0.5.

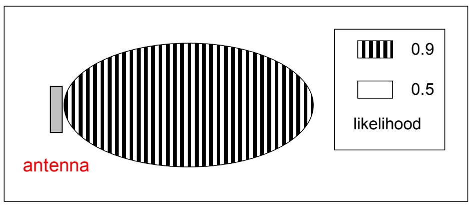


Fig. 1. Sensor model of the conventional method.

Next, we show the procedure for the position estimation shown in papers [2]-[4]. Fig 2 shows a flow chart of the position estimation. To express the procedure easily, we focus on the position estimation of an RFID tag by an RFID reader. To estimate the posterior probability of the tag's position, the conventional method uses sampled positions. If the RFID reader receives an ID response from the tag for the first time, the method samples positions in a square area around the location of antenna. The system assigns initial probability to each sampled position. The system assigns the value of likelihood $p(z_1 \mid x, r_1)$ to each sampled position with sensor model depicted in Fig.1. With the value of likelihood, the posterior probability of each sampled position is updated according to eq. (1).

Next the RFID reader moves to another location. If the RFID reader receives an ID response from the tag, the method determines the value of likelihood $p(z_2 \mid x, r_2)$ with the sensor model and updates the posterior probability. By repeating this procedure, the conventional method calculates the position of the RFID tag. If there are plural sampled positions that have the largest posterior probability, the papers [3]-[4] assume that the center of gravity of the sampled positions' area is the estimated position of the tag.

Fig.3 shows an example of updating the posterior probability at time step 1. Here, we consider that a robot equipped with RFID antennas moves and looks for a tag. In this example, the robot is at the observation point 1. It is assumed that the robot detects the tag at time step 1 for the first time. The probability of sampled positions marked with triangles are calculated by (initial probability 1)*(likelihood 0.9) = 0.9. The probability of sampled positions that marked with dots are calculated by (initial probability 1)*(likelihood 0.5) = 0.5. Then, the robot moves a little and repeats the procedure in this way.

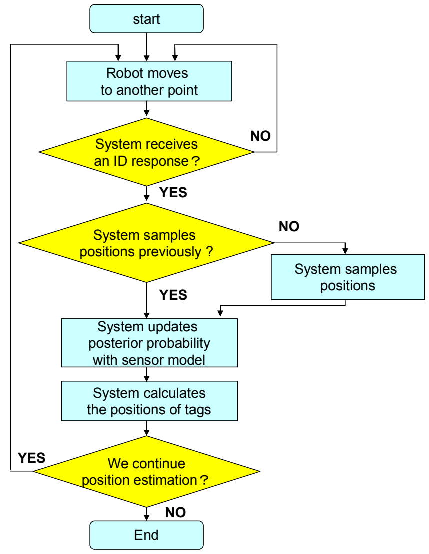
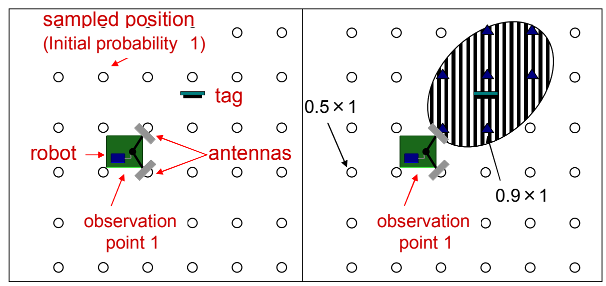


Fig. 2. Flow chart of position estimation.



(a) System samples positions (b) System updates the posterior probability

Fig. 3. Update of posterior probability.

III. Multi-Sensing-Range Method

In the conventional method, an RFID reader transmits an ID request to tags with constant transmission power. In other words, the communication range between the RFID reader and tags is constant. However, we can know the positions of tags more precisely when we change the transmission power of the RFID reader by plural steps, i.e. changing the size of the communication range can make the efficient position estimation of tags. In this paper, we propose a multi-sensing-range method that takes the transmission power of an RFID reader into account.

In the multi-sensing-range method, an RFID reader transmits ID requests to tags at an observation point with its transmission power changed by three steps in this paper, i.e. the RFID reader transmits ID requests to tags with three communication ranges. Here, we define the communication range of the highest transmission power as the long-range, that of the second highest transmission power as the middle-range, and that of the lowest transmission power as the short-range.

A. Procedure for Multi-Sensing-Range Method

Fig.4 shows a flow chart of multi-sensing-range method for the position estimation of an RFID tag. First, at an observation point a robot searches for the tag with long-range that the transmission power of the RFID reader is the highest. If the robot receives an ID response from the tag, the robot transmits an ID request to the tag with middle-range in order to specify the tag's position within the long-range. 1) If the robot cannot receive an ID response from the tag, the robot updates the posterior probability of sampled positions with the corresponding sensor model, say model1. 2) If the robot can receive an ID response from the tag, the robot transmits an ID request to the tag with short-range. In this case, the robot updates the posterior probability of sampled positions with the corresponding sensor model after the observation regardless of presence of an ID response from the tag. ⅰ) If the robot cannot receive an ID response from the tag, the robot updates the posterior probability with sensor model 2. ⅱ) If the robot receive an ID response, the robot updates the posterior probability with sensor model 3.

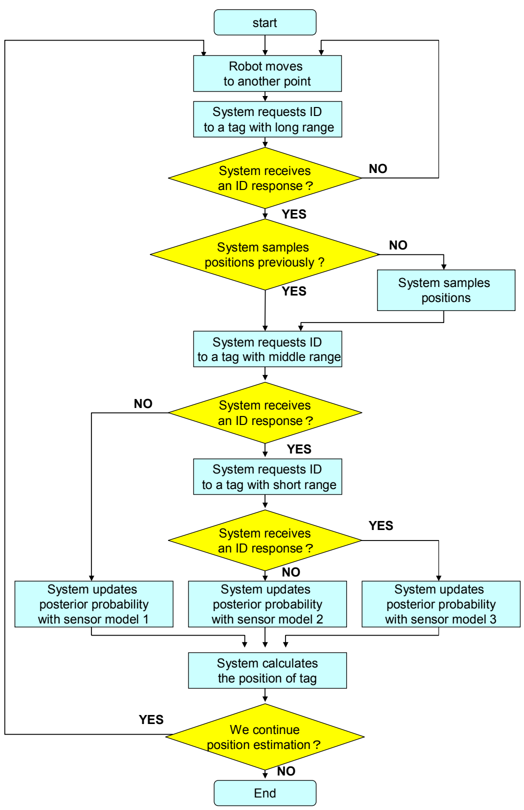


Fig.4. Flow chart of the multi-sensing-range method

B. Sensor Models of Multi-Sensing-Range Method

In the proposed method, if a robot receives an ID response from a tag with the long-range at an observation point, the robot repeats the search with middle-range and short-range at the same observation point. For this reason, the proposed method has three sensor models. Fig 5 shows the sensor model that used in the case an RFID reader receives an ID response from a tag only with long-range. In this case, the possibility that the tag which has transmitted the ID response to the RFID reader exists inside the long-range and outside the middle-range is stronger than the possibility that the tag exists in the other areas. For this reason, we set the likelihood of the area inside the long-range and outside the middle-range as 0.9 and the other areas as 0.5

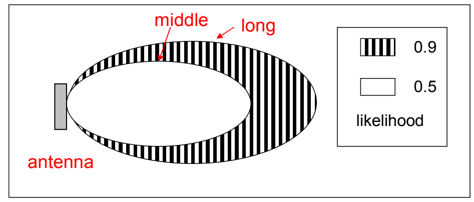


Fig.5. Sensor model 1.

Fig.6 shows the sensor model that used in the case that an RFID reader receives ID responses from a tag with long-range and middle-range. In this case, the possibility that the tag exists inside the middle-range and outside the short-range is stronger than the possibility that the tag exists in the other areas. Because the robot can receive an ID response from the tag with middle-range, but cannot receive an ID response with short-range. We set the likelihood of the area inside the middle-range and outside the short-range as 0.9, that of the inside of short-range as 0.7, that of the area sharing outside of the middle-range and inside of the long range as 0.7, and that of the other area as 0.5.

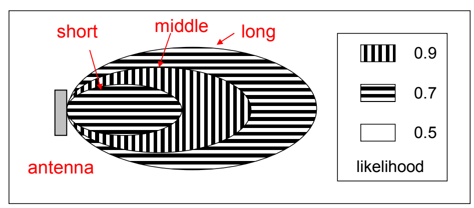


Fig.6. Sensor model 2.

Fig.7 shows the sensor model in the case that an RFID reader receives an ID response from a tag with all the communication ranges (i.e. with three transmission power of the RFID reader). In this case, the possibility that the tag exists inside the short-range is stronger than the possibility that the tag exists in the other areas. We set the likelihood inside the short-range as 0.9, that of the area sharing inside of the middle-range and the outside of the short-range as 0.8, that of the area inside the long-range and outside the middle-range as 0.7, and that of the other area as 0.5.

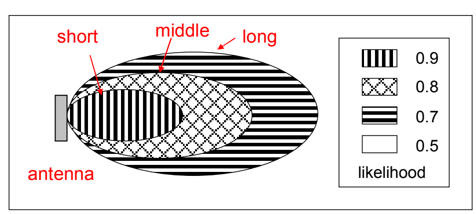


Fig.7 Sensor model 3.

IV. PERFORMANCE EVALUATION BY COMPUTER SIMULATIONS

We carry out the performance evaluation by computer simulations to show the effectiveness of the proposed method. In this paper, we assume that a mobile robot equipped with two RFID antennas to estimate the position of an RFID tag as shown in sect.2. In our simulations, we compare the performance of the proposed method with that of the conventional method. We use three movement models of robot that expressed in the later (i.e. a straight movement, a curve movement and a perpendicular turn movement).

In our simulations, we assume that a robot has two RFID antennas to right and left with 45 degrees from the moving direction as shown in Fig.8. The RFID antennas are fixed on the robot. To evaluate the performance of the proposed method, we define the following error of position estimation ε by

$$\varepsilon = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad (2)$$

Where x_1 and y_1 are x and y coordinates of the position where a tag exists, respectively. x_2 and y_2 are x and y coordinates of the tag's position that the robot calculates by using some observed results.

Next, we explain the robot's movement models used in our simulations and show the results of them.

A. Straight Movement

We perform computer simulations with a straight movement model of a robot shown in Fig.8. In this model, the robot starts from the point A to the point B making observations whether the 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 tag is in parallel with the moving direction of the robot.

We consider three cases of distances, say L, between the tag and the moving line of the robot. Those distances are 100cm, 200cm and 300 cm. Table 1 shows parameters common to three simulation models.

Figs.9 to 11 show the estimated position error performance against the moving distance of the robot for L=100 cm, 200cm and 300 cm, respectively. In Figs.9 to11, the distances at which the robot can receive ID responses are shaded. From those results, we find that the proposed method can reduce the estimated position error with shorter moving distance than the conventional one. That means the errors can be reduced with the smaller number of observation points by using the proposed method. In the cases of L=100 cm and 200 cm, the error can be reduced drastically before the robot turns around at the point B. This is because the robot can receive ID responses from the tag with smaller communication range than the long-range at some observation points. For L=300 cm, the performance of the proposed method isn't better than the performance of L=100cm and 200cm, since the robot can receive ID responses only with the long-range. However the performance of the proposed method is better than that of the conventional one.

We discuss the power consumption of proposed scheme by using this simple simulation model. The communication distance is in proportion to the square root of RFID reader's transmission power. In this simulation, the ratio of transmission power of long-range to that of middle-range to that of short-range is 100:49:16. Therefore the ratio of total power consumption of conventional scheme to that of proposed one per an observation point is 100:165.

In the case of L=100 cm, the conventional scheme needs 12 observation points in order to reduce the estimated position error to 11cm. In contrast, the proposed one needs 6 observation points. Therefore the improvement in total power consumption by proposed scheme becomes 40 percents.

In the case of L=200 cm, the conventional scheme needs 13 observation points in order to reduce the estimated position error to 3cm. In contrast, the proposed one needs 4 observation points. Therefore the improvement in total power consumption by proposed scheme becomes 49 percents.

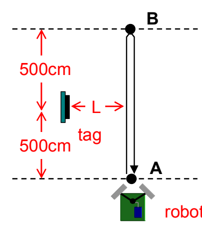


Fig.8. Straight movement model.

Table 1. Parameters of simulations.

Number of tag	1	
Distance between observations	25cm	
Frequency used by the RFID system	860MHz ~ 960MHz	
Communication distances	Long-range	5m
	Middle-range	3.5m
	Short-range	2m
	Conventional methods' range	5m
Sample pattern of positions	Grid of 5 cm	

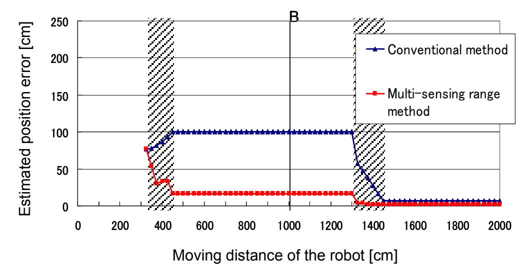


Fig.9. Estimated position error vs. moving distance of robot L=100 cm.

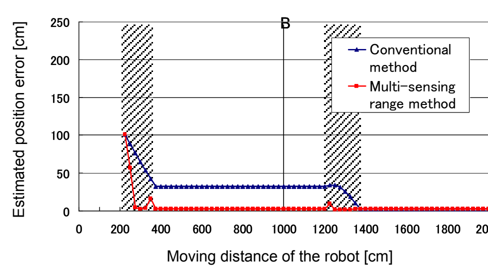


Fig.10. Estimated position error vs. moving distance of robot L=200 cm.

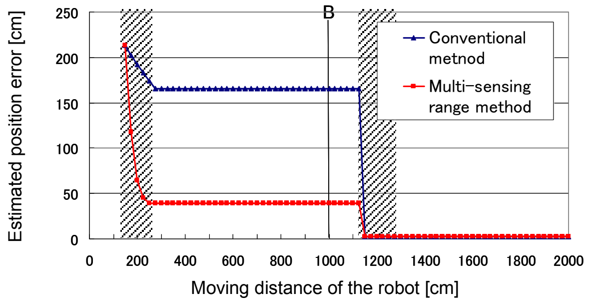


Fig.11. Estimated position error vs. moving distance of robot L=300 cm.

B. Curve Movement

We carry out the performance evaluation by using a Curve movement model of a robot as shown in Fig.12. In this simulation, the robot starts from the point A to the point B with its track drawing the circular arc. The length of the circular arc is quarter length of the complete circle that has the radius of R. The center of the circle is the point O. We set the tag on the straight line that passes on the point O and the point C. The line OC and the line OA meet at an angle of 45 degrees. We consider four cases of distances, say L, between the tag and the point O. Those distances are R+50cm, R+150cm, R+250 cm and R+350 cm. Here, we set R as 100 cm. We define the angle composed of the point A , the point O and the place of the robot as θ . In this simulation, θ is increased by 5 degrees. The parameters of this simulation are same as those of the straight movement model shown in Table 1 except the distance between observations.

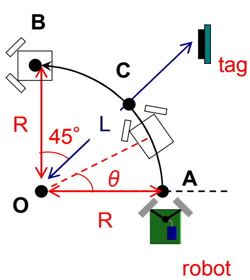


Fig.12. Curve movement model.

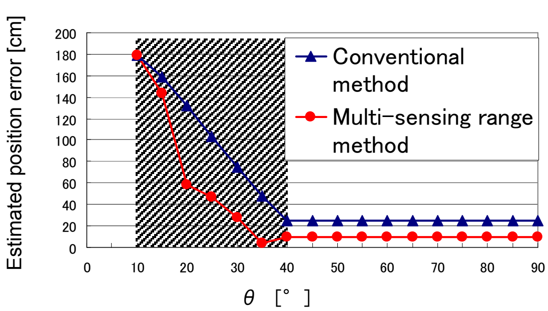


Fig.13. Estimated position error vs. an angle of θ as L = 150 cm.

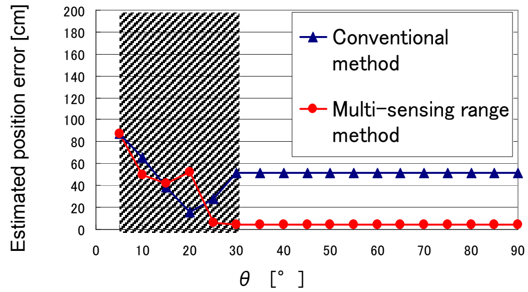


Fig.14. Estimated position error vs. an angle of θ as L = 250 cm.

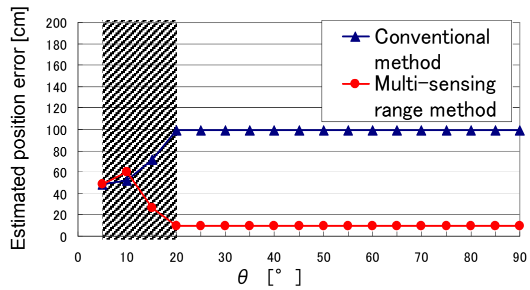


Fig.15. Estimated position error vs. an angle of θ as L = 350 cm.

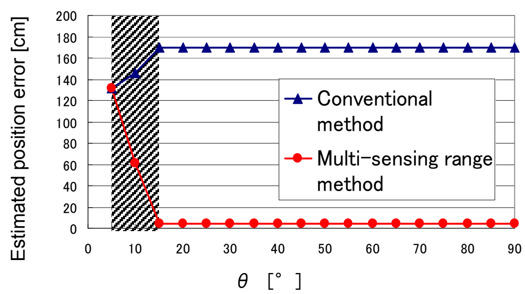


Fig.16. Estimated position error vs. an angle of θ as L = 450 cm.

Figs.13 to 16 show the estimated position error performance against the angle θ for L=150 cm, 250cm, 350 and 450 cm, respectively. From these results, we see that the proposed method can reduce the estimated position error compared with the conventional one.

In the case of L= 250 cm, the performance of the proposed method is not so good at 20 degrees. This is because the posterior probability of sampled positions far from the tag becomes high as the robot approaches to the tag. However the error of the proposed one is smaller than that of the conventional one at 25 degrees or more.

In the cases of L=350cm and 450cm, when the robot can receive the unique ID from the tag, the lager θ becomes, the larger the error of the conventional method is . In contrast, that of the proposed one becomes smaller. This is because the transmission power of the conventional method is constant. In other words, the method has single communication range. For this reason, the method cannot reduce the estimated position error. On the other hand, the proposed method can drastically reduce the estimated position error.

C. Perpendicular Turn Movement

Fig.18 shows a perpendicular turn model of a robot used in this simulation. The robot moves from the point A to the point B, then it turns left at the point, and heads for the point C. The parameters of this simulation are same as those of the straight movement model shown in Table 1. We consider three cases of distances, say L, between the tag and the moving line of the robot. These distances are 100cm, 200cm and 300 cm.

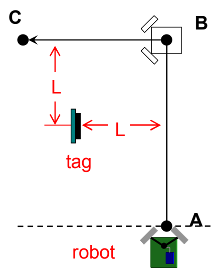


Fig.18. Perpendicular turn movement.

Figs.19 to 21 show the estimated position error performance against the moving distance of the robot for L=100 cm, 200cm and 300 cm, respectively. From these results, we see that the proposed method shows the high performance compared with the conventional one in all the cases. In the cases of L=100 cm and 200 cm, the proposed method can suppress the error small after the robot turns left at the point B. In contrast, the error of the conventional one is still large. This is because the transmission power of the conventional one is constant. For L=300 cm, the proposed method can drastically reduce the estimated position error before the robot turns left at point B.

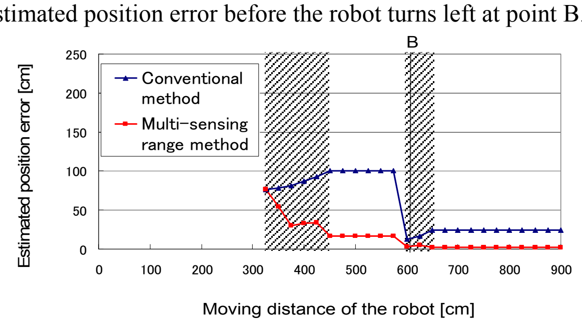


Fig.19. Estimated position error vs. moving distance of robot L=100 cm.

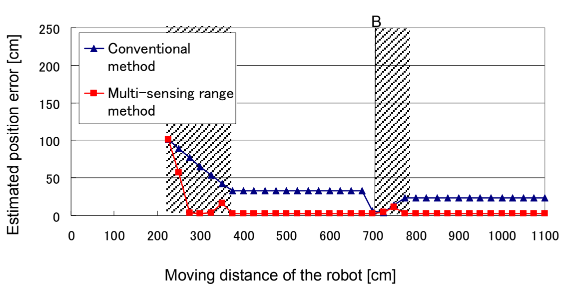


Fig.20. Estimated position error vs. moving distance of robot L=200 cm.

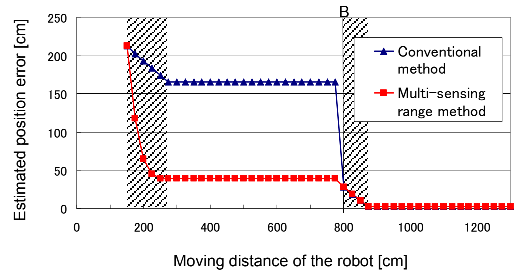


Fig.21. Estimated position error vs. moving distance of robot L=300 cm.

V. CONCLUSIONS

This paper has dealt with the position estimation of RFID tags. We have assumed the situation that some mobile objects like robots are equipped with RFID readers, and try to acquire the positions of RFID tags. We have proposed a multi-sensing-range scheme to search for the position of the tags efficiently at an observation point. In the proposed method, a robot searches for the position of tags with the three steps' transmission power; long-range, middle-range and short-range. First, at an observation point, the robot searches for the presence of tags with long-range. Second, if the robot detects the presence of the tags, the robot repeats the search with middle-range and short-range at the same observation point. In this way, the robot searches for the tags' positions within long-range accurately.

By computer simulations with three movement models of a robot, we have shown the effectiveness of the proposed method. In our method, we have reduced the estimated position error more quickly with less total consumption power than the conventional method. The proposed method is much effective in the robot's movement like the curve movement. In the movement, the conventional method has the cases that make the estimated error large. In such the cases, the proposed method is able to reduce the estimated error. Thus the proposed method has the tolerance toward the complex movements of robots.

We will carry out the experiments of the proposed method with the real RFID system and consider the control algorithm of robot's movement to reduce the estimated position error.

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