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A New Indoor Position Estimation Method of RFID Tags for Continuous Moving Navigation Systems

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Abstract— **The RFID (Radio Frequency Identification) is considered as one of the most preferable ways for the position estimation in indoor environments, since GPS does not work in such situations. In RFID system, an RFID reader enables to estimate the position of RFID tags easily and inexpensively. In applications with the position estimation of RFID tags, indoor robot navigations are very important for human society. The problem is how to obtain the position estimations of RFID tags as accurately as possible.**

Previously S-CRR (Swift Communication Range Recognition) has been proposed for the appropriate estimation method of this kind of applications. This method is capable of the accurate position estimation of an RFID tag in very short time. The disadvantage of S-CRR is that the mobile robot must stop to search RFID tags accurately at each position. In indoor robot navigations, mobile entities like robots have to move continuously because they need to navigate smoothly and safely.

In this paper, we propose a new position estimation method of RFID tags with continuous moving only using RFID technology. We call this Continuous Moving CRR (CM-CRR). CM-CRR uses two communication ranges, long and short ranges and switches them appropriately. The system estimates the position of RFID tags using their approaches and continuous moving. To show the effectiveness of CM-CRR, we evaluate the estimation error of an RFID tag by computer simulations. From the results, CM-CRR can accurately estimate the position of RFID tags with continuously moving of the mobile robot and be applied to indoor robot navigations.

Keywords-component; RFID sysytem; position estimation; RFID tag; continuous moving; indoor robot navigation

I. INTRODUCTION

Today, Global Positioning System (GPS) is one of the most useful systems to obtain the location information such as people, vehicle, and other objects. When we use GPS technology, it is possible to obtain a position estimation accuracy of about 10m [1]. However, GPS generally does not work indoors because of satellites signal attenuation. Thus, an alternative to GPS is required to localize accurately in indoor environments.

In indoor environments, position information is typically obtained by ubiquitous sensors (e.g. Wi-Fi, UWB, and IR) [2]-[5]. Previous papers [2], [3] use a Wi-Fi access point database to estimate positions. The systems work indoors and outdoors, and its estimated accuracy is often comparable to GPS. However, the systems are expensive in terms of their infrastructure requirements.

Another kind of ubiquitous sensors is the RFID (Radio Frequency Identification). The RFID system consists of RFID tags, an RFID reader and a PC. Each RFID tag has a unique ID and can be related to some useful information (e.g. product, tracking, and position information) [6]-[8]. From the unique ID and position information, a user can recognize the location of the RFID tag easily. RFID tags are classified into two types: passive and active tags. Both of the tags are used for the position estimation. Passive tags are particularly attractive for the position estimation because they are inexpensive and need not maintenance.

By the above-mentioned reasons, new applications using the position estimation by passive RFID system is expected very much (e.g. medical systems, and indoor pedestrian and robot navigations) [8]-[13]. In indoor robot navigations, the system consists of the position estimation function of RFID tags and a reader, the control function of a mobile robot and so on [14]-[17]. The accuracy of the system especially depends on that of the position estimation of the RFID tags. So, we focus on the position estimation issue of passive RFID tags for the indoor robot navigations.

Previous papers [12], [13] have proposed the position estimation methods of RFID tags for indoor robot navigations. The paper [12] combines RFID and odometry systems. By communicating with RFID tags at the ceiling, a mobile robot moves to its destination. The method shows that the average position error can be reduced with a low tag density. However, the method is very complex. In the paper [13], the system consists of RFID technology, eight received signal strength (RSS) antennas and fuzzy logic controller (FLC). FLC compares the values of RSS from eight antennas and controls direction of a mobile robot. The system can successfully navigate the mobile robot with a satisfactory tracking error regardless of the path's complexity. However, the system is considerably expensive because of eight RSS antennas.

S-CRR (Swift Communication Range Recognition) was previously proposed for the position estimation of RFID tags [18]. S-CRR is capable of the accurate position estimation of an RFID tag in very short time. S-CRR, however, has a disadvantage that a mobile robot must stop to search RFID tags accurately at each position. If we use S-CRR with continuous moving, the performance will be degraded. To apply to indoor robot navigations, the mobile robot has to move continuously because they need to navigate smoothly and safely.

To solve the problem of S-CRR, we propose a new position estimation method of RFID tags named Continuous Moving CRR (CM-CRR) with continuous moving only RFID technology. CM-CRR uses two communication ranges, long and short ranges and switches them appropriately. The approach of CM-CRR is the following four steps. 1) Detection of an RFID tag by the long range. 2) Detection of the RFID tag by the short range. 3) Re-detection of the RFID tag by the long range. 4) Estimation of the RFID tag's position. CM-CRR enables to estimate the position of RFID tags with high accuracy and small delay. To show the effectiveness of CM-CRR, we evaluate the estimation error of an RFID tag by computer simulations.

This paper is organized as follows. Section II discusses S-CRR for the position estimation of RFID tags. Section III proposes a new position estimation method of RFID tags named CM-CRR for indoor robot navigations. Section IV presents the performance evaluations by computer simulations. Finally, Section VI concludes this paper.

II. SWIFT COMMUNICATION RANGE RECOGNITION (S-CRR) METHOD

A. *Outline of S-CRR*

S-CRR is an extended improvement of previous CRR [19] on the estimation delay. In S-CRR, position of an RFID tag is estimated by using communication area models. The communication area model is the envelope of the communication range corresponding to the relative angle between the RFID reader and tag. The method uses two types of communication area models: one made with first detection of an RFID tag and the other with last one. S-CRR rotates the RFID reader at each observation point. By this operation, the RFID reader recognizes two communication area models with first and last detection of the tag. Thus, the position of the RFID tag is estimated by an intersection of the communication area models. S-CRR enables the position estimation of the RFID tag in very short time because the method can localize at only one observation point. Consequently, S-CRR is much more efficient than CRR. In S-CRR, however, a mobile robot must stop to search RFID tags accurately at each observation position. So, S-CRR is not appropriate for indoor robot navigation which requires continuous moving.

B. *Position estimation procedure of S-CRR*

The position estimation procedure of S-CRR is composed of five steps. Here, we assume that an RFID reader is equipped with a mobile robot.

Step 1: Movement of a mobile robot

To search an RFID tag, the mobile robot is moving while rotating the reader and radiating the signal from the reader at regular intervals.

Step 2: Detection of an RFID tag

If the RFID reader receives the ID response, the mobile robot stops at the position: which is the observation point.

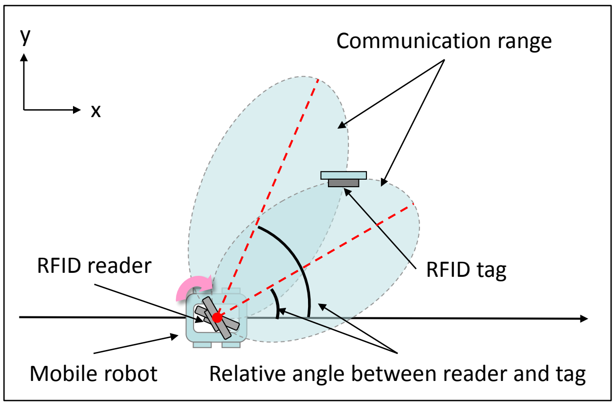

Figure 1. Rotation of the RFID reader.

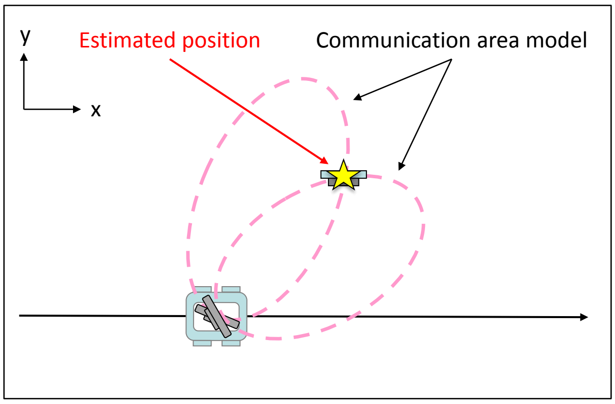

Figure 2. Estimation of the RFID tag's position.

Step 3: Rotation of the RFID reader

Fig. 1 shows the rotation of the RFID reader. If the system detects the RFID tag, it recognizes two communication ranges, first and last detection ranges.

Step 4: Generation of the communication are models

The communication area models are calculated by first and last detection of the RFID tag.

Step 5: Estimation of the RFID tag's position

Fig. 2 shows the estimation of the RFID tag's position. The RFID tag's position is estimated by the intersection of two communication area models. Even if there are two or more intersections, the estimated position of the RFID tag is defined as the center of gravity of those [18].

III. CONTINUOUS MOVING CRR (CM-CRR) METHOD

A. *Outline of CM-CRR*

In indoor robot navigations, it is important for a mobile robot to move continuously. The reason for this is that the system needs to navigate smoothly and safely. To realize the system, it is essential to estimate the position accurately with continuous moving of the mobile robot. In most of the navigation systems, however, the mobile robot stops at each point because of the position estimation. So, we propose a new position estimation method with continuous moving of the mobile robot using only RFID technology as simple as possible.

In this paper, we propose a new position estimation method of RFID tags named Continuous Moving CRR (CM-CRR) for indoor robot navigations. In CM-CRR, a mobile robot equipped with an RFID reader estimates the position of tags while it moves continuously. The process of CM-CRR is composed of the following four steps.

1) Detection of an RFID tag by the long range
2) Detection of the RFID tag by the short range
3) Re-detection of the RFID tag by the long range
4) Estimation of the RFID tag's position

CM-CRR is different from S-CRR in three points. First, it can estimate the position of RFID tags with continuous moving. Second, it does not rotate the RFID reader. Third, it uses two types of communication ranges, long and short ranges. To generate these ranges, we use the transmission power control [20].

B. *Position estimation procedure of CM-CRR*

The position estimation procedure of CM-CRR is composed of four steps. Each step is shown as follows.

Step 1: Detection of an RFID tag by the long range

Fig. 3 shows the situation of this step. The mobile robot with the RFID reader moves continuously in the field. It searches for an RFID tag by using the long range. When the system detects the tag first time, the communication area model is calculated as in S-CRR. We assume that the estimated position of the RFID tag exists on the traveling direction side of the communication area model.

Step 2: Detection of the RFID tag by the short range

Fig. 4 shows the situation of this step. We divide the communication area model into two, forefront and rear-end models using the short range. After the first detection of the RFID tag, reader switches from the long range to the short one for a regular observation time. The system recognizes whether it can detect the RFID tag by the short range. In case that the system can detect it, we assume that it exists in the short range, that is, on the rear-end model. On the other hand, in case that the system cannot, the RFID tag exists on the forefront model.

Step 3: Re-detection of the RFID tag by the long range

Fig. 5 shows the situation of this step. The system recognizes whether it can re-detect the RFID tag by the long range. After the step 2, the RFID reader switches from the short range to the long one. Then, we consider two cases: case 1 that the system can re-detect the RFID tag and case 2 that the system cannot.

Step 4: Estimation of the RFID tag's position

Fig. 6 shows the situation of this step. The system estimates the RFID tag's position according to the case. In the case 1, the communication area model is calculated at the last detection of the RFID tag. Then its position is estimated by the intersection of the forefront/rear-end and the communication area models. In the case 2, we assume that the RFID tag exists the top area of the forefront or the bottom area of the rear-end models. Then, its position is estimated the center of gravity of each area.

C. *Advantage of CM-CRR*

CM-CRR can accurately estimate the position of RFID tags with continuous moving. Therefore, the system can be applied to indoor robot navigations (e.g. auto run wheelchair systems and indoor patrolling). Additionally, it is inexpensive and simple because it uses only RFID system and does not rotate the reader. So, it is easy to introduce into the indoor robot navigations. For these reasons, CM-CRR is appropriate to the position estimation for indoor robot navigations very much.

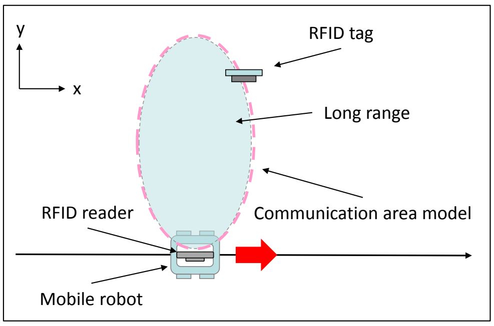

Figure 3. Detection of an RFID tag by the long range.

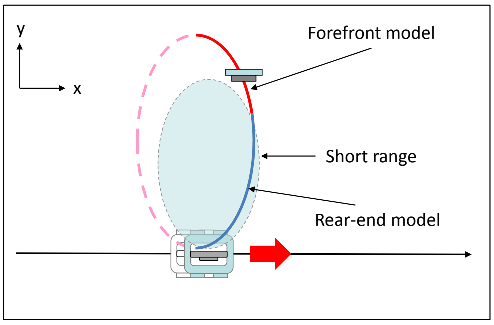

Figure 4. Detection of the RFID tag by the short range (In case that the system cannot detect the RFID tag by short range).

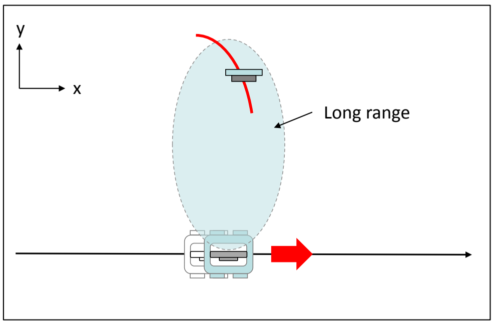

Figure 5. Re-detection of the RFID tag by the long range (Case 1).

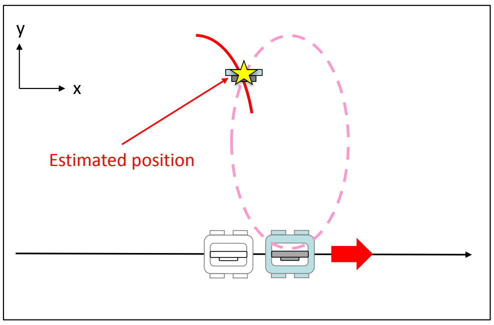

Figure 6. Estimation of the RFID tag's position (Case 1).

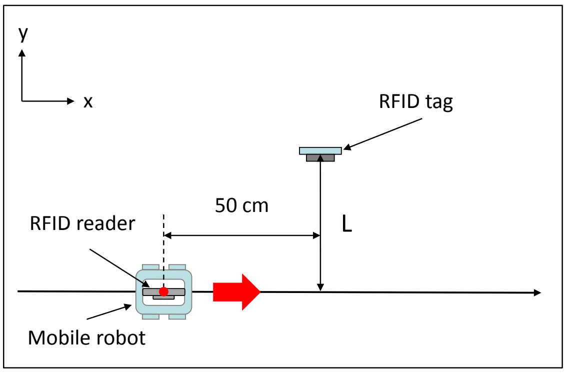

Figure 7. Preliminary simulation environment.

TABLE I. PARAMETERS OF COMMUNICATION AREA MODELS

	Long range	Short range	
Attenuation level	0 dB	1 dB	2dB
Major axis	75.8 cm	65.2 cm	58.4 cm
Minor axis	30.1 cm	25.3 cm	22.1 cm

IV. PERFORMANCE EVALUATIONS BY COMPUTER SIMULATIONS

To show the effectiveness of CM-CRR, we evaluate the estimated position error by computer simulations. We compare CM-CRR and S-CRR with continuous moving by using two types of moving models which are straight and curve moving models. Here, we assume that the communication range changes by the relative angle between an RFID reader and a tag, while the communication area model does not change [20]. Additionally, we define their shapes as ellipse.

A. Preliminary Simulations for model parameter setup

Before the performance evaluations, we carry out the preliminary simulations in order to determine parameters that affect the accuracy of CM-CRR. The parameters are the shape of the short range and the observation time with it.

Fig. 7 shows the preliminary simulation environment. In the preliminary simulations, we determine the parameters with the highest accuracy of the position estimation of an RFID tag. We assume that a mobile robot equipped with an RFID reader moves along the x axis at the speed of 25 cm/s. The plane of the RFID reader is parallel to x axis and a tag. There is the RFID tag in the position of (x, y) = (50 cm, L cm). L is the distance between the reader axis and the tag, and is changed 5 to 75cm with 5 cm interval. Here, the estimation error is shown as follows.

$$e = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{1}$$

where x_1 and y_1 are x and y axes of the position where the RFID tag exists, respectively. x_2 and y_2 are x and y axes of the estimated position of the tag.

Table I lists parameters of communication area models. The observation time for use in the preliminary simulations is shown as follows.

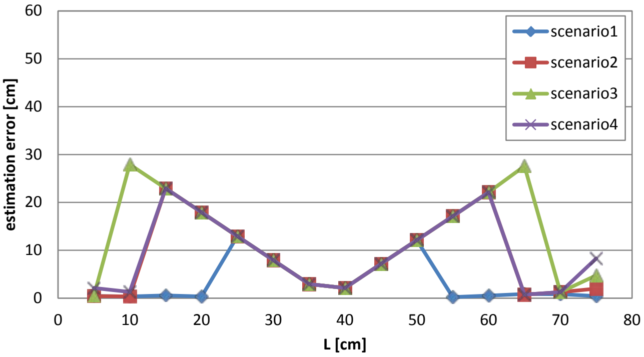

Figure 8. Estimation error in attenuation level = 1 dB for four scenarios.

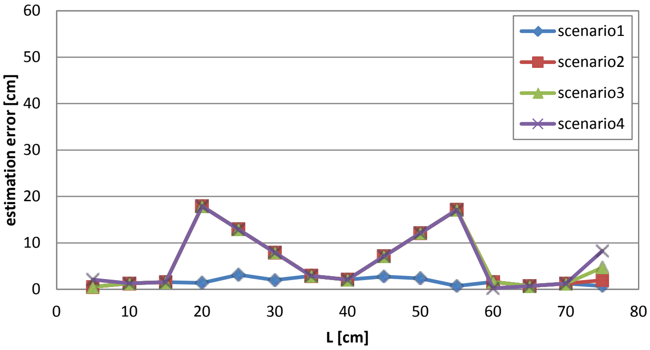

Figure 9. Estimation error in attenuation level = 2 dB for four scenarios.

TABLE II. AVERAGE ESTIMATION ERROR AND MAXIMUM ESTIMATION ERROR IN THE TWO TYPES OF ATTENUATION LEVELS FOR FOUR SCENARIOS

Attenuation level: 1 dB				
Scenario	1	2	3	4
Average estimation error [cm]	3.29	8.64	12.47	9.24
Maximum estimation error [cm]	12.9	22.9	27.91	22.91
Attenuation level: 2 dB				
Scenario	1	2	3	4
Average estimation error [cm]	1.66	5.93	6.11	6.36
Maximum estimation error [cm]	3.14	17.91	17.91	17.91

$$t = \frac{d \times x}{v} \tag{2}$$

where d is the length of the miner axis of the short range, x is 1/8 to 4/8 with 1/8 interval and v is the speed of the mobile robot. We set the scenario 1 to 4 for x parameter i.e. in scenario 1, 2, 3, and 4, x is 1/8, 2/8, 3/8, and 4/8, respectively.

Fig. 8 and 9 show the estimation error in attenuation level = 1 dB and 2 dB for four scenarios, respectively. From these figures, we find that the estimation error is very small near L = 40 cm in all scenarios. The reason is that the communication area model is divided in nearly-half at the areas (i.e. the length of forefront model is nearly equal to that of the rear-end one).

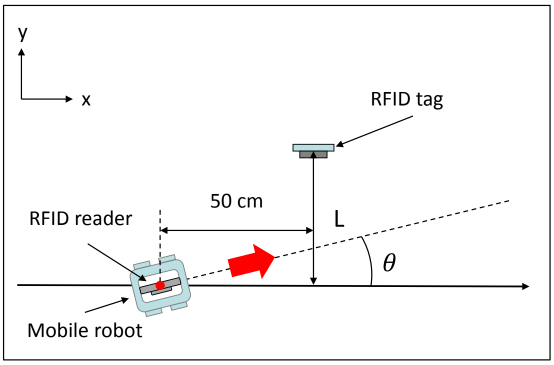

Figure 10. Straight moving model.

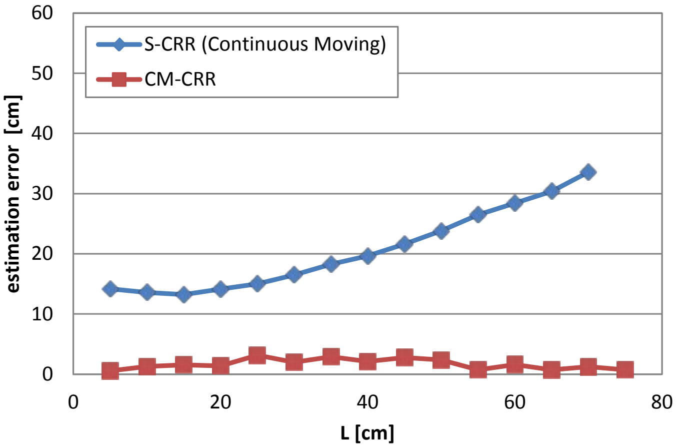

Figure 11. Estimation error in straight moving model for $\theta = 0^\circ$.

Table II shows the average and the maximum estimation error in the two types of attenuation levels for four scenarios. Theoretically, the accuracy of the estimated position of the RFID tag is the highest in case that the communication area model is divided the forefront and rear-end models into two equal parts. However, the rate of the parts changes by the shape of the short range and the observation time. Therefore, it affects the accuracy of the estimated position. As the results, the average and maximum estimation errors are the smallest in the attenuation level of 2 dB and the scenario 1. For this reason, we use these parameters in the performance evaluation.

B. Performance Evaluations

To evaluate the performance of CM-CRR, we introduce two types of simulations described as follows.

1) Straight moving model
2) Curve moving model

We assume that these moving models are very important in the study of the position estimation for indoor robot navigations. Here, the practical value of CM-CRR can be proven by evaluating the performance in these moving models. In these simulations, a mobile robot with an RFID reader moves continuously and estimates the position of a tag simultaneously. As mentioned in the preliminary simulations, CM-CRR uses the parameters of the scenario 1 and the attenuation level of 2 dB for the shape of the short range and the observation time with it.

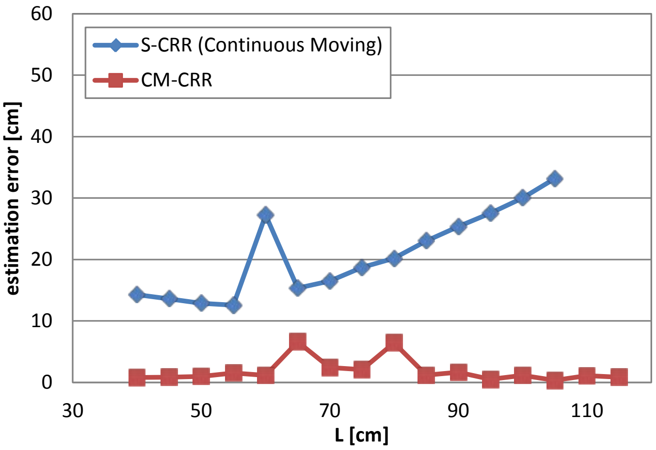

Figure 12. Estimation error in straight moving model for $\theta = 30^\circ$.

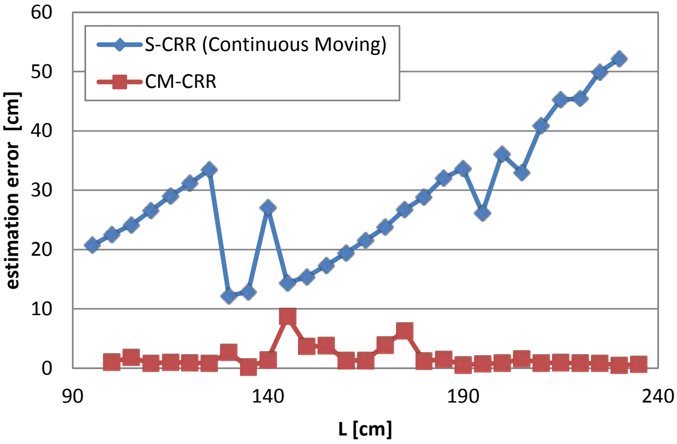

Figure 13. Estimation error in straight moving model for $\theta = 60^\circ$.

1) Straight moving model

Fig. 10 shows the straight moving model. In this section, we carry out a straight moving of a mobile robot with an angle of θ, and estimate the position of an RFID tag. We evaluate the performance of CM-CRR with continuous straight moving.

Fig.11, 12 and 13 show the estimation error in the straight moving model for θ = 0, 30, and 60°, respectively. From these figures, we find that the estimation error of S-CRR with continuous moving tends to become larger with the increasing of L. The reason is that the system recognizes two or more intersections in the top and bottom of two communication area models for continuous moving of the mobile robot, and then calculates the gravity of those. In Fig. 12 and 13, the estimation error of S-CRR is sharply increasing in L = 60 and 140 cm, respectively. This is because the system generates three intersections at the position estimation. In Fig. 13, the estimation error of S-CRR goes up and down. The reason is the system detects the RFID tag in the top or bottom of the communication range according to the rotation of the reader. In case that the system detects in the top, the estimation error is large, and in the bottom, it is small.

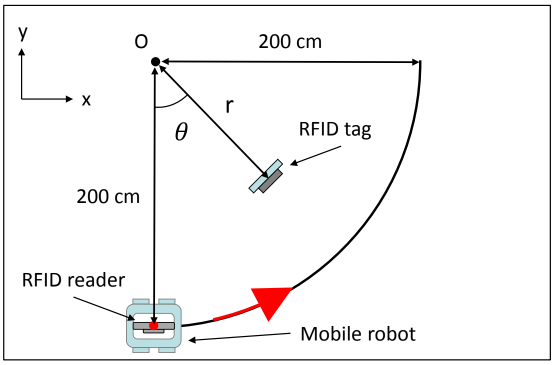

Figure 14. Curve moving model.

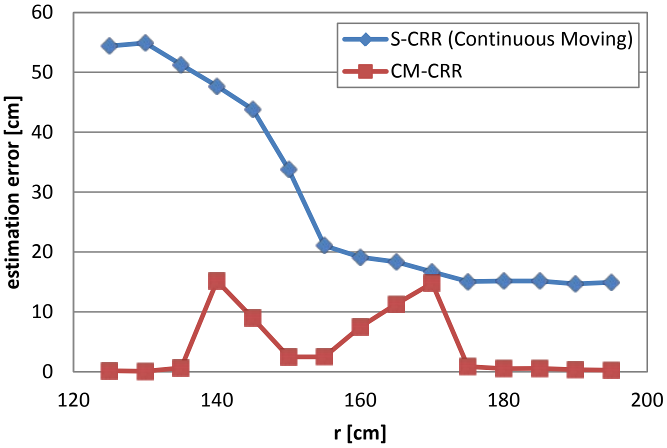

Figure 15. Estimation error in curve moving model for $\theta = 30^\circ$.

On the other hand, CM-CRR has small estimation error even if the value of L and θ is increasing. In CM-CRR, the system can reduce the generation of some intersections since the system divides the communication area model into two (the forefront and rear-end models). As the results, CM-CRR can achieve the accuracy of the position estimation as well as S-CRR (without continuous moving) [18]. From these figures, the estimation error of CM-CRR becomes larger in the vicinity of the median of each L. This is why the division of the communication area model is not optimum in these areas. The system generates some intersections, and then increases the estimation error. However, it is small even if the system generates some intersections since CM-CRR uses the forefront and rear-end models.

In the straight moving model, CM-CRR makes the estimation error small (less than 10 cm) regardless of the increasing of L and θ while S-CRR makes it large. Additionally, the estimation error of CM-CRR is stable in all situations while that of S-CRR goes up and down in some cases. From these results, CM-CRR can reduce the estimation error and make it stable than S-CRR in the straight moving model. Hence, CM-CRR is appropriate method than S-CRR for the position estimation of the straight moving environments.

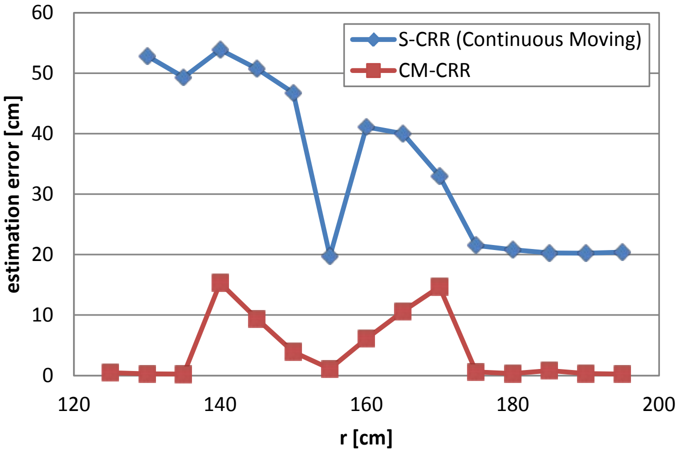

Figure 16. Estimation error in curve moving model for $\theta = 45^\circ$.

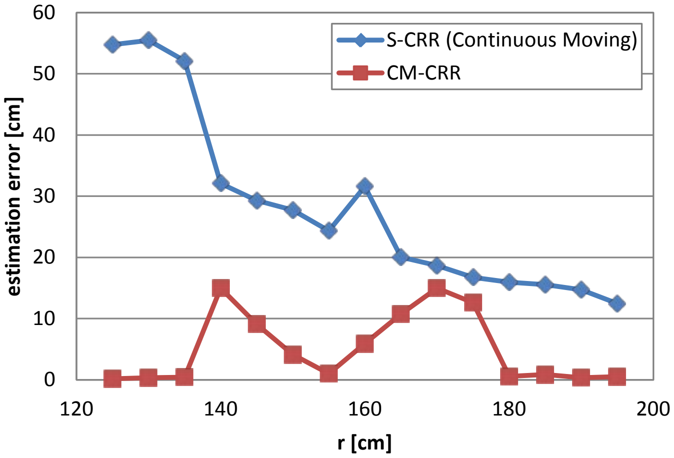

Figure 17. Estimation error in curve moving model for $\theta = 60^\circ$.

2) *Curve moving model*

Fig. 14 shows the curve moving model. In this section, we carry out a curve moving of a mobile robot and estimate the position of an RFID tag in order to evaluate the performance of CM-CRR with continuous curve moving. The mobile robot moves on a curve with radius 200 cm based on the position of O. The RFID tag is positioned in r [cm] from the O with an angle of θ.

Fig. 15, 16, and 17 show the estimation error in curve moving model for θ = 30, 45, and 60°, respectively. From these figures, S-CRR with continuous moving has large estimation error in case that the system recognizes three or more intersections (i.e. r = 125 to 140 for θ = 30, r = 130 to 150, 160 to 170 for θ = 45, and r = 125 to 140, 160 for θ = 60). On the other hand, in case that it recognizes two intersections, the estimation error is relatively small. The more the value of r, the more the system detects the RFID tag at the bottom of the communication range. As the results, the estimation error tends to become smaller with increasing of r. Additionally, S-CRR takes a little time to the first-to-last detection of the RFID tag compared to the straight moving model. This is why the traveling of the mobile robot in the direction of x axis decreases by the curve moving.

In CM-CRR, we find that it has the same estimation error characteristic (i.e. the estimation error tends to become larger in the vicinity of the median of each r) as that in the straight moving model. The reason is that the mobile robot is located in front of the RFID tag when starting the position estimation. Selected parameters (the shape of the short range and the observation time with it) in the preliminary simulations are determined by the performance based on the straight moving of the mobile robot. Therefore, the rate of the forefront and rear-end models changes, and then the estimation error slightly becomes larger. The estimation error is large compared to the straight moving model. However, CM-CRR obtains the accuracy of the position estimation compared to S-CRR with continuous curve moving.

In the curve moving model, CM-CRR has small estimation error (less than 20 cm) in all situations while S-CRR makes it large in some cases. Moreover, the estimation error of CM-CRR is stable as well as in the straight moving model while that of S-CRR is not. From these results, CM-CRR can reduce the estimation error and make it stable than S-CRR in the curve moving model. Hence, CM-CRR is appropriate method than S-CRR for the position estimation of the curve moving environments.

C. Discussions

In the preliminary simulation results, we find that the attenuation level of 2 dB and the scenario 1 (the shape of the short range and the observation time with it, respectively) are the most appropriate parameters for the use of the short range. The estimation error of using the attenuation level of 2 dB is smaller than that of 1 dB. The reason is that the 2 dB is divided the communication area model into two near-equal parts (the forefront and the rear-end models) than the 1 dB. So, the system of the 2dB mostly generates only one intersection when calculating the estimation position, and then the error is small. Also, the simulation results show that the system prefers short observation time (the scenario 1 is the shortest) in order to estimate the position accurately. In case that the time is long, the system cannot re-detect the RFID tag for the long range. Because of this, the position of the RFID tag is calculated by the center of gravity of the forefront/rear-end models, and then the error is large.

In the straight moving model, the estimation error of CM-CRR (less than 10 cm) is more satisfactory than S-CRR with continuous moving in all situations. The accuracy is almost the same as S-CRR (without continuous moving). CM-CRR can reduce the generation of some intersections since it divides the communication area model into the forefront and rear-end models. For this reason, the estimation error is small.

In the curve moving model, the estimation error of CM-CRR (less than 20 cm) is smaller than S-CRR as well as in the straight moving model. CM-CRR has the same estimation error characteristic as that in the straight moving model because the mobile robot is positioned in front of the RFID tag when estimating the position. The estimation error is slightly large compared to the straight moving model. However, the accuracy of the estimation error is sufficient in the indoor robot navigation environments.

From these results, we say that CM-CRR can reduce the estimation error in the indoor navigation environments than S-CRR. On the other hand, S-CRR with continuous moving has large estimation error because the system recognizes two or more intersections when calculating the estimation position. Hence, CM-CRR is an appropriate method for the position estimation in the indoor robot navigations.

V. CONCLUSIONS

In this paper, we have proposed a new indoor position estimation method of RFID tags named CM-CRR for indoor robot navigations. CM-CRR uses long and short ranges of an RFID reader with continuous moving of a mobile robot while switching them appropriately. CM-CRR estimates the position of an RFID tag in four steps. In CM-CRR, the system only uses RFID technology (without Wi-Fi, UWB, IR, ultrasound, and other ubiquitous sensors). This allows us not to require the knowledge of other ubiquitous sensors, and thus the system is inexpensive and simple.

To prove the effectiveness of CM-CRR, we have investigated the estimation error of an RFID tag by computer simulations (the preliminary simulations, the straight moving model, and the curve moving model). CM-CRR has been made much more effective by the position estimation with the straight and curve moving of the mobile robot than S-CRR with continuous moving. These simulations show that the estimation error of less than 20 cm can be obtained in the indoor environments. The results imply that the accurate position estimation of tags for indoor robot navigations is feasible with only RFID technology.

As future work we would like to carry out experiments how CM-CRR can work in real environments (in consideration of the influence of multipath and some obstructions). In addition, we plan to realize an indoor robot navigation using CM-CRR for the position estimation, which only requires some RFID tags attached at corridor walls in a building and a mobile robot carrying a person and RFID system (e.g. an auto run wheelchair carrying a person and RFID system navigates from one current position to another destination). This technology will help the mobility of the physically handicapped people (e.g. the elderly and visual-impaired people) in various indoor environments like hospitals, nursing homes, shopping centers, complex buildings, and so on.

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