Dual Type Communication Range Recognition Method (D-CRR) for Indoor Position Estimation of Passive RFID Tags

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***Abstract*- Recently, the radio frequency identification (RFID) system is paid attention as an identification source that can realize a ubiquitous environment. One of the important technologies that apply the RFID system is the indoor position estimation of RFID tags. For example, it can be applied to an indoor navigation system for handicapped person and recognition of ambient environment by a mobile robot, etc. In this paper, we propose a new positional estimation method to estimate the RFID tag position by using the tune of the antenna directivity of the RFID reader (D-CRR). This method controls the directivity of the antenna by dynamically changing the distance between the antenna elements of the RFID reader. We show the effectiveness of the proposed method by computer simulations.**

***Keywords*- Dual type communication range recognition method; position estimation; RFID reader; RFID tag; flexible antenna**

I. Introduction

Recently, the Radio Frequency Identification (RFID) system is paid attention as a new identification source that can realize a ubiquitous environment. The RFID system consists of RFID tags and an RFID reader, and they communicate wirelessly with each other. An RFID tag has a unique ID information, and is attached to an object. In addition, a unique ID is exchanged between a pair of RFID reader and an RFID tag by using radio waves. A unique ID is associated with a given object. By reading the unique ID, it can be easy to find the desired object from many objects. One of the important information is the location information of an object with an RFID tag. Since users can associate the unique ID with location information of the RFID tag, it is possible to automatically recognize the position of the object. Hence, the position estimation of RFID tags can be applied to the navigation system which can track the person's own position. It is useful for elderly or handicapped people to move smoothly to his destination in a complex building.

One of the important applications that can make use of the RFID technology is the indoor position estimation. This technology can apply recognition of the position by a robot and navigation system [1], [2], [5].

In this research, we propose a new method for quick position estimation of the passive RFID tag. S-CRR has been proposed as a conventional typical position estimation method [3], [4].S-CRR estimates the position of the RFID tag from the communication area of the RFID reader in the boundary angle whose communication between RFID tag and RFID reader is attained. S-CRR has two advantages as follows. (1)Position estimation of the RFID tag can be performed by the measurement from single observation point, that is to say movement for observation is not needed and necessary observation time can be reduced. (2) The communication area of the RFID reader adapts to change of the relative angle between RFID tag and RFID reader. However, S-CRR has the disadvantage that producing variability at the operation time of position estimation. So when performing position estimate by S-CRR, angle of rotation of the RFID reader may become large. It causes the problem that the S-CRR needs unnecessary time by the antenna rotation of position estimation.

To solve the above problem, we propose Dual type Communication Range Recognition method (D-CRR) with the directive change of a new flexible antenna. By this system, the antenna is performed by tuning the element interval of the antenna of an RFID reader dynamically. By making the extreme breadth of each antenna elements of the RFID reader, we reduce the process time of RFID tag detection, and the degree of rotation angle of the RFID reader is controlled. So it becomes possible to shorten sharply the estimation time of RFID tag.

This paper is organized as follows. In section 2, S-CRR for position estimation of an RFID tag is discussed. In section 3, we propose a D-CRR method. In section 4, we conduct basic experiments. In section 5, we present the performance evaluations by computer simulations. Finally, we conclude this paper in section 6.

II. S-CRR Method

A. Outline of the S-CRR method

In the S-CRR method, the mobile robot having the RFID reader estimates the location of the object with the passive RFID tag. Before the S-CRR method performs position estimation of the RFID tag, it is necessary to grasp the approximation area of a communication area called a communication area model. A communication area model is defined based on the communication area measured at a given relative angle between the RFID tag and the RFID reader. When the RFID reader is rotated, two boundary angles of possible communication between the RFID tag and the RFID reader is measured. Then the communication area model according to the relative angle between the RFID tag and the RFID reader in each boundary angle is generated virtually. The intersection of these two communication area models shows estimated position of the RFID tag. Consequently, the S-CRR method can estimate the position of the RFID tag at only one observation point.

B. Position estimation algorithm of the S-CRR method

This section explains the position estimation procedure of the S-CRR method in detail. Each step in this figure is shown as follows. The communication boundary angle θ_1 is measured in the Step 1. A communication area model is chosen in the Step 2.The communication boundary angle θ_2 is measured in the Step 3. Position estimation of the RFID tag is performed in the Step 4. This method is performed on a two-dimensional plane, and we assume that a communication area model has already been determined.

Step 1

Fig. 1 (a) shows the measurement of communication boundary angle in θ_1. The RFID reader is fixed to arbitrary observation points. The RFID reader is horizontally rotated around of the center of an antenna. At this time, the RFID reader is radiating the signal to the RFID tag periodically. When beginning to detect existence of the RFID tag, the RFID reader measures the communication boundary angle in θ_1 .

Step 2

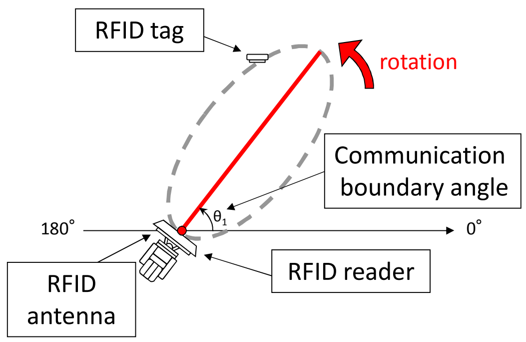
Fig. 1 (b) shows selection of a communication area model. The system asks for the relative angle between the RFID tag and the RFID reader from the communication boundary angle θ_1 by Step 1. And the system generates the communication area model of the RFID reader corresponding to the relative angle.

Step 3

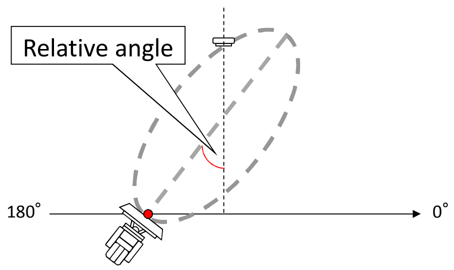
Fig. 1 (c) shows the measurement of communication boundary angle in θ_2. The RFID reader performs the same operation as Step 1. And the communication boundary angle θ_2 of impossible communication between the RFID tag and the RFID reader is measured. Then, the same operation as Step 2 is done and the communication area model of the RFID reader in the communication boundary angle θ_2 is generated.

Step 4

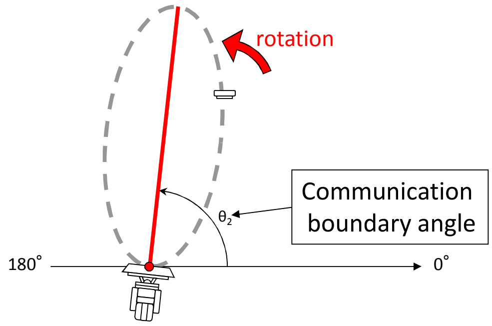
Fig. 1 (d) shows the calculation of the RFID tag. The estimated position of the RFID tag is the intersection of the communication area model of the RFID reader in each measured communication boundary angle.



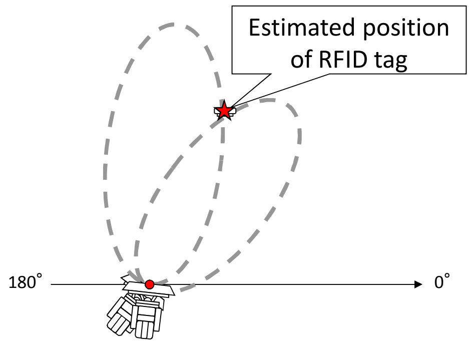
(a) S-CRR method (Step 1)



(b) S-CRR method (Step 2)



(c) S-CRR method (Step 3)



(d) S-CRR method (Step 4)

Fig. 1 S-CRR method

III. Dual Type CRR Method (D-CRR)

A. Outline of the D- CRR method

The D-CRR method is the RFID tag position estimation method based on the S-CRR method. The feature of the proposed method is a system which uses the adaptive adjust of an antenna and performs the position estimation of the RFID tag. By the D-CRR method, the antenna is performed by tuning the element interval of the antenna of an RFID reader dynamically. Thus, it is possible to adjust freely the maximum communication width of the communication area of the RFID reader. The D-CRR uses two kinds of communication areas which are different in the maximum communication width. In consequence, the D-CRR method reduces the degree of rotation angle of the RFID reader by two communication area models which varied the maximum communication width. Therefore, the D-CRR method can perform the more high-speed RFID tag position estimation than the S-CRR method.

B. Position estimation algorithm of the D-CRR method

This section explains the position estimation procedure of the D-CRR method in detail. Each step in this figure is shown as follows. The communication boundary angle θ_1 is measured in the Step 1. The maximum communication width of a communication area is reduced in the Step 2. The communication boundary angle θ_2 is measured in the Step 3. Position estimation of the RFID tag is performed in the Step 4. This method is performed on a two-dimensional plane, and we assume that a communication area model has already been determined.

Step 1

Fig. 2 (a) shows the measurement of communication boundary angle in θ_1.The RFID reader is fixed to arbitrary observation points like the S-CRR method. The RFID reader is horizontally rotated centering on the center of an antenna. At this time, the RFID reader is radiating the signal to the RFID tag periodically. When beginning to detect existence of the RFID tag, the RFID reader measures the communication boundary angle of θ_1. Moreover, the system asks for the relative angle between the RFID tag and the RFID reader from the communication boundary angle θ_1 by Step 1. And the system generates the communication area model of the RFID reader corresponding to the relative angle.

Step 2

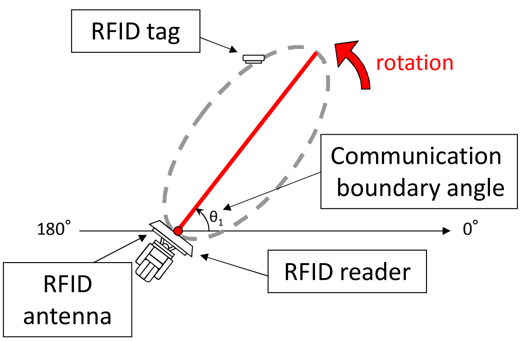
Fig. 2 (b) shows the maximum communication width of RFID reader is reduced. The antenna is performed by tuning the element interval of the antenna of an RFID reader dynamically in the communication boundary angle θ_1 measured by Step 1. Hence, the maximum communication width of the communication area of the RFID reader is reduced. At this time, the RFID reader can't recognize the RFID tag.

Step 3

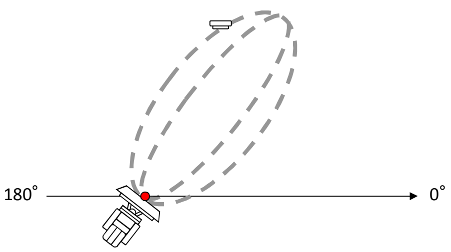
Fig. 2 (c) shows the measurement of communication boundary angle in θ_2. The RFID reader performs the same operation as Step 1. And the communication boundary angle θ_2 of possible communication between the RFID tag and the RFID reader is measured. Then, the same operation as Step 2 is done and the communication area model of the RFID reader in the communication boundary angle θ_2 is generated.

Step 4

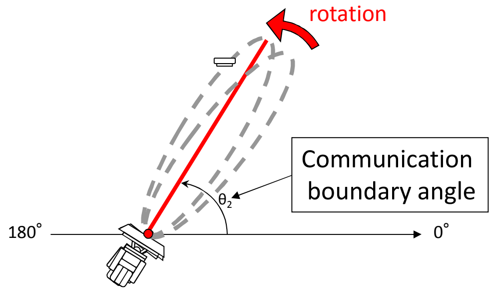
Fig. 2 (d) shows the calculation of the RFID tag. The estimated position of the RFID tag is the intersection of the communication area model of the RFID reader in each measured communication boundary angle.



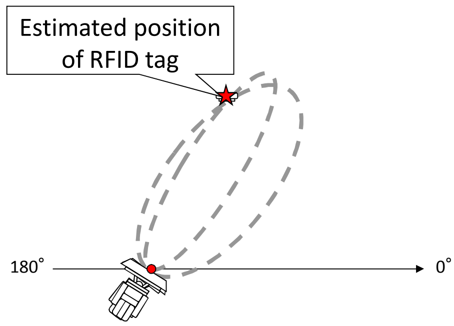
(a) D-CRR method (Step 1)



(b) D-CRR method (Step 2)



(c) D-CRR method (Step 3)



(d) D-CRR method (Step 4)

Fig. 2 D-CRR method

IV. Basic experiment

This chapter describes a basic experiment. We use a 2.45-GHz band RFID system (Japan RF Solutions: SDK-3).The purpose of this experiment is the following two points. 1) It is checking the adjust of the communication area of the RFID reader by tuning the element interval of two patch antennas dynamically, 2) It is checking the change of the communication area of the RFID reader by the relative angle between the RFID tag and the RFID reader. The position and inclination of a patch antenna is fixed in this experiment. The communication area is measured in the case which the element interval d of two patch antennas, is 12.24 cm (λ), 9.18 cm (0.75λ), 6.12 cm (0.5λ), and 4.5 cm. Moreover, the communication area is measured in the case which the inclination θ of the RFID tag, is 0, 20, 40 , 60 and 80 degrees in the state where it was considered as the element interval of d= 12.24 cm.

Each measurement result is shown in Fig. 3 and Fig. 4. Fig. 3 shows that adjust of the communication area by antenna element intervals. When the interval of two antenna elements is 12.24cm, the communication area becomes long and slender compared with the case of 4.5cm. From this result, the maximum communication area width contracts as the antenna element interval d becomes large. Fig. 4 shows that adjust of the communication area by inclination of the RFID tag. The received power from the RFID reader may decrease by inclination of the RFID tag. From this result, the communication area of the RFID reader adjusts with the relative angles between the RFID tag and the RFID reader.

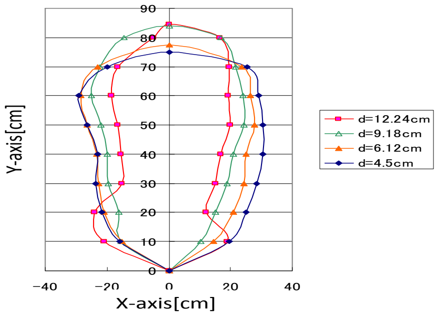


Fig. 3 Communication areas by antenna element intervals

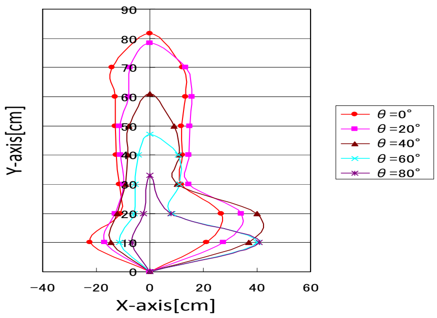


Fig. 4 Communication areas by inclination of the RFID tag

V. Performance evaluation

In order to show the validity of the proposed method, computer simulation performs a quality assessment. In this simulation, we compared the performance between the conventional S-CRR method and the proposed D-CRR method. We assume that the electromagnetic wave radiated from the RFID reader is not reflected on the wall.

A. Evaluation criteria

We compared the position estimation error of the RFID tag and the position estimation time of the RFID tag in this simulation.

In comparison to the position estimation time of the RFID tag, the time is the measurement of the communication boundary angle θ_2 from measurement of the communication boundary angle θ_1 in the position estimation process.

The position estimation error of the RFID tag can be defined by the distance in a straight line of the position coordinate (Xr, Yr) actually arranged and the estimated position coordinates (Xe, Ye) of the RFID tag. The estimated position error is defined as follows.

$$\text{Error} = \sqrt{(X_r - X_e)^2 + (Y_r - Y_e)^2} \tag{1}$$

B. Simulation environment

This section explains the simulation environment in each position estimation method. Simulation environment is shown in Fig. 5. The RFID reader is leaned to 0 degree to the direction of the X-axis, it arranges in an initial position (-200, 0). And the RFID tag is arranged on the Y-axis. First, position estimation of the RFID tag is performed at the Start point of the RFID reader. In this point, we measure the position estimation time and the position estimation error of the RFID tag. Next, 10 cm movements of the RFID reader are made along the direction of the X-axis, and the position estimation time and the position estimation error of the RFID tag are measured again. Henceforth, the above-mentioned measurement is repeated. When position estimation of the RFID tag becomes impossible, this simulation is stopped. Moreover, in this simulation, we measured the position estimation time and error by changing the relative distance L to the RFID tag. Note that we did not considered multi-path in this simulation.

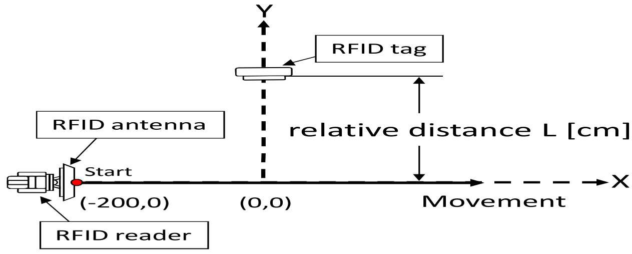


Fig.5 Straight moving model

C. Simulation results

Fig. 6 and 7 show the simulation results as for the distance to the RFID tag in L = 60 and 80 cm. The horizontal axis shows the X-axis coordinates X[cm] of the RFID reader. The vertical axis of Fig. 6(a) and 7(a) show the vertical axis of position estimate time. And Fig. 6(b) and 7(b) show the vertical axis of position estimate error.

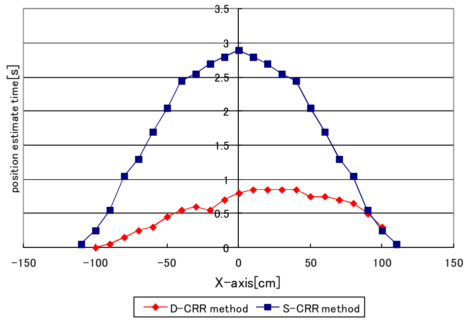
Fig. 6 (a) shows that the position estimation time of the proposed method is shorter than the conventional method, and all the RFID tag position estimation time is less than 1.0 second in each observation point by the proposed method. However, the proposed method has taken position estimation time slightly in observation point of X= 100 than the conventional method. This is because the RFID tag is detected in the front edge of a communication area. Moreover, when the observation point X=-100 and 100, the RFID reader is impossible for position estimation of the RFID tag by the proposed method. In this reason, the conventional method is performed using the communication area in the boundary angle of the moment of detecting the RFID tag, and the moment of stop detecting the RFID tag. Meanwhile, the proposed method is intercepted the RFID tag once when the maximum communication area width is reduced. And the RFID reader asks for the communication area in the boundary angle of the moment of detecting the RFID tag again. The position estimation is performing using these two communication areas. Therefore, when the RFID tag exists near the tip of a communication area at the 1st communication boundary angle measurement by the proposed method, the RFID reader may be unable to detect the RFID tag again. This is due to the maximum communication area is reduced by the relative angle between the RFID tag and the RFID reader. For this reason, the position estimation of RFID tag was not completed at the observation point of X=-100 and 100 by the proposed method

Fig. 6 (b) shows that the position estimation error of the proposed method is smaller than that of the conventional method at the observation point of X=-100 to -50 and 50 to 100 in the position of the RFID reader. In the case of L= 60 cm, it is considered that the proposed method gets exact communication boundary angle since the communication area model of the proposed method is more exact than that of the conventional method.

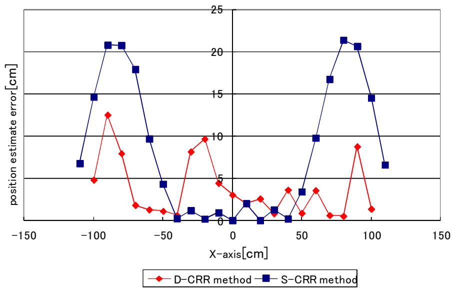
Fig. 7 (a) shows that the proposed method has better position estimation time than the conventional method. Furthermore, the position estimation time is less than 1.0 second in each observation point by the proposed method.

Fig. 7 (b) shows that the position estimation error of

RFID tag by the proposed method is less than 10 cm except for some observation points. The position estimation error by the proposed method is increasing sharply at the observation point of X=-100, -90, and 100. For this reason, the communication area model by the relative angle between the RFID tag and the RFID reader has setup at a given fixed angle. Consequently, it is the cause that the right communication area was not able to be generated in the communication boundary angle.

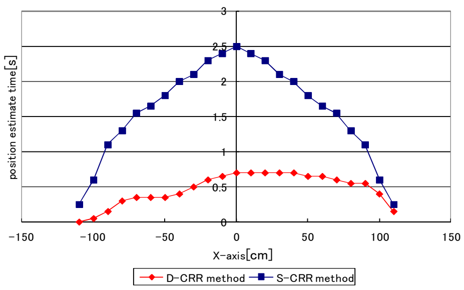


(a) Position estimation time

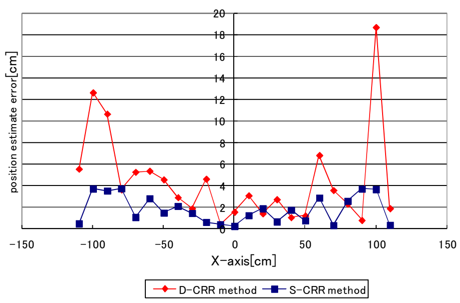


(b) Position estimation erorr

Fig.6 Simuration result(L=60cm)



(a) Position estimation time



(b) Position estimation error

Fig.7 Simuration result(L=80cm)

VI. Conclusions

In this paper, we have proposed a novel method named Dual Type Communication Range Recognition method for indoor position estimation of passive RFID tags. The proposed method uses a new RFID 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. By making the extreme breadth of the communication area of the RFID reader reduce in the process of the RFID tag position estimation, the rotation angle of the RFID reader at the time of communication boundary angle measurement is reduced. D-CRR method can significantly reduce the time of the RFID tag position estimation. In order to show the validity of the D-CRR method, computer simulations performed the quality assessment. The quality assessment was done from a viewpoint of position estimation time and position estimation error, and shown the performance of the conventional method and the proposed method quantitatively. As a result, the following conclusions were obtained.

1) In the proposed method, the reduction of the rotation angle of the RFID reader which communication boundary angle measurement takes was enabled by making the maximum communication area width reduce in process of communication boundary angle measurement. Therefore, as compared with S-CRR method, the proposed method showed that the position estimation time could be shortened sharply. Moreover, on the characteristic of an algorithm, even if the relative angle between the RFID tag and the RFID reader changed by the proposed method, there is no great difference in the time required by position estimation of the RFID tag from the 1st communication boundary angle measurement. Thus the D-CRR method reduced the variation in position estimation time sharply.
2) In the proposed method, the position estimation accuracy is slightly inferior to the accuracy of the S-CRR method. However, the average position estimation error of D-CRR method is just less than 5 cm. Thus the D-CRR method can realize the more high-speed the RFID tag position estimation with sufficient accuracy than the S-CRR method.

We will consider a navigation system using the RFID system for a mobile robot. This system realizes that a mobile robot can move automatically by tracking its own position. This technique would help the handicapped people's mobility on complicated floors.

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