An Efficient Localization Algorithm in the RFID Sensor Space for Mobile Robot Localization

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Abstract

This paper proposes an efficient localization algorithm in the RFID sensor space for the precise localization of a mobile robot. The RFID sensor space consists of embedded sensors and a mobile robot. The embedded sensors, that is, tags are holding the absolute it is called as antenna usually, gets several tag data at the as position data and provide them to the robot which carries a reader and requests the absolute position for localization. The reader, me time within its readable range. It takes time to read all the tags and to process the data to estimate the position, which is a major factor to deteriorate the localization accuracy. In this paper, an efficient algorithm to estimate the position and orientation of the mobile robot as quickly as possible has been proposed. Along with the algorithm, a new allocation of the tags in the RFID sensor space is also proposed to improve the localization accuracy. The proposed algorithms are demonstrated and verified through the real experiments.

Keyword: RFID, Tag allocation, Localization, Mobile robot, Estimation error.

1. Introduction

An RFID (Radio Frequency IDentification) technology is a non-touching recognition system that transmits and processes the information on events and environments using a wireless frequency and small chips [1]. The RFID system can read the tags at high-speed and send data within various distances. Therefore, the application of the RFID technology has recently been increased and an RFID has been applied for the robot technology [2]. With the development of the personal robot and advanced ubiquitous network robots, it is essential for the robots to recognize their own location and environment and to keep high security in a common space with people. If an RFID technology is properly applied to the robot, the services for the users can be provided by the service robot at anytime at any place.

The passive RFID technology has been utilized for the researchers to recognize the position of the service robot [3]. The method is that RFID passive tags are arranged on the floor to provide the absolute position data, which are free from the problems of conventional systems [4]. Note that dead reckoning sensors suffer from accumulating errors, laser and ultra-sonic sensor from line-of-sight errors, and CCD from the illumination. The absolute location of the robot can be obtained robustly, with the RFID tag and reader in sensor network space [5] where sensors are properly embedded several places to provide the absolute position information to the service robot. However some shortcomings are found in the localization systems using the RFID [6]. The antenna detects several tags within its detecting range and the numbers of detected tags are not constant at all times, which causes the position estimation error.

On account of this, the precise localization is not feasible using the RFID tags unless it is located many tags in a very short interval ignoring economics. Also, in the posture estimation of the mobile robot, two antennas are necessary to recognize the orientation of the robot since the orientation cannot be detected by using only one antenna.

In this paper, the problem of acquiring position information, including the orientation of the robot, is introduced in the robot localization using the RFID system. Also, the algorithms to reduce estimation error of the robot and to achieve more efficient localization are newly proposed.

2. Position Estimation of a Mobile Robot

In order to estimate the location of the robot using RFID system, RFID tags are arranged in a fixed pattern on the floor. Absolute coordinates of the location have been stored in each tag to provide the position data to the mobile robot. An RFID reader (antenna) has been installed to read the tag data on the bottom of the mobile robot. If the robot moves and stays on any tag, the RF field is formed by RFID reader antenna. All the tags within the circle of radius, r, which are under the effective area of RFID antenna, are activated.

When the localization process starts, the RFID reader gathers the position data of the tags under the effective area of antenna. The RFID reader repeatedly gathers the tag information sequentially when there are more than one tag in the RF field, since it can recognize only one tag signal at a time. In order to receive other tag data within the effective area of the RF reader, the tag data previously read are stored to the PC. Then, the reader gathers the next tag information, and

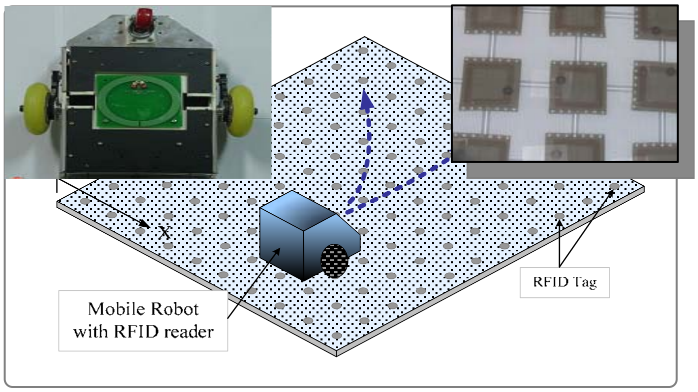


Fig. 1. Configuration of the Experimental System..

repeats this procedure until there is no unread tag left within the RF field. The configuration of the experimental system is shown in Fig. 1.

The orientation of the robot can be estimated using the multiple sets of the tag position data. The initial orientation can be estimated using the sets of position readings. And the traveling orientation can be estimated by the two sets of position data, the previous and current position data, assuming that the mobile robot is moving forward all the times.

3. Uncertainty of Position Estimation

In the passive RFID localization system, the utilization of tag information is dependent on the system characteristics. In other words, even though the RFID reader detects RFID tags within the recognition area, it cannot obtain a precise location value from the tags since there is no position information between tags. The distance between RFID reader and tag is also a variable to be considered in the localization process. Therefore the classical localization system based on the triangulation technique with three distance data has too big error to be used for the mobile robot navigation.

The estimation error is unavoidable when the robot location is estimated by the coordinates of tags within the recognition area of the reader. The estimation error is modeled in this research to minimize this estimation error. When the tags are arranged in a square pattern and the distance between them does not exceed the range of reader, the recognition area of the reader for the tags can be represented as a circle as shown in Fig. 2.

The position of the mobile robot (x_{est}, y_{est}) that carries a reader antenna on the bottom, can be obtained through the position data of the tags that are located within the recognition area of the reader as

$$x_{est} = \frac{\max\{x_1, \cdots, x_N\} + \min\{x_1, \cdots, x_N\}}{2} \tag{1}$$

$$y_{est} = \frac{\max\{y_1, \cdots, y_N\} + \min\{y_1, \cdots, y_N\}}{2} \tag{2}$$

where N represents the number of tags detected by the reader and $x_1, x_2, x_3, y_1, y_2, \cdots$ represents the coordinates information of the tags.

The position of antenna --coordinates of the mobile robot-- is estimated by Eqs. (1) and (2) using the absolute coordinates in the tags. However, the real position of mobile robot has the estimation error because of the gap between the tags. Therefore the estimation error is proportional to the gap between the RFID tags. Figure 2 illustrates the relationship between the estimation error and the gap between the RFID tags where only X-dimensional tags are considered. Each tag from left to right has coordinates, $a_1, a_2, a_3, \cdots, a_{n-1}, a_n$, and a_{n+1}, and the gap between the tags is d_{tag}.

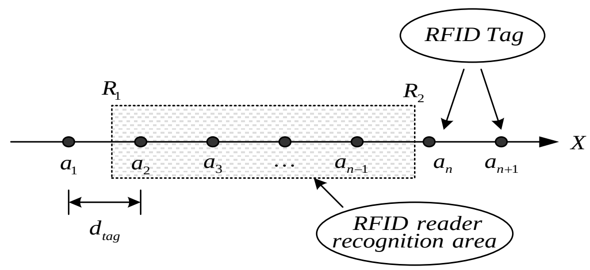


Fig. 2. Estimation error and the gap of tags.

The left boundary of the reader recognition area is denoted as R_1 and the right as R_2. That is, the RFID reader can detect tags located between R_1 and R_2. The estimated coordinates, R_{est_x}, and the real center position of the reader R_{real_x}, are represented as follows:

$$R_{est\_x} = \frac{a_2 + a_{n-1}}{2} \tag{3}$$

$$R_{real\_x} = \frac{R_1 + R_2}{2}. \tag{4}$$

The estimation error, e_{est}, is defined as

$$\begin{aligned} e_{est\_x} &= \left| R_{est\_x} - R_{real\_x} \right| \\ &= \left| \frac{R_1 + R_2}{2} - \frac{a_2 + a_{n-1}}{2} \right| \end{aligned} \tag{5}$$

where the ranges of R_1 and R_2 can be described as

$$\begin{cases} a_1 < R_1 < a_2 \\ -d_{tag} < R_1 - a_2 < 0 \end{cases} \tag{6-a}$$

$$\begin{cases} a_{n-1} < R_2 < a_n \\ 0 < R_2 - a_{n-1} < d_{tag} \end{cases} \tag{6-b}$$

From (5) and (6), now the range of estimation error can be represented as

$$e_{est\_x} = \left| \frac{(R_1 - a_2) + (R_2 - a_{n-1})}{2} \right| \le \frac{1}{2} \left| d_{tag} \right|. \quad (7)$$

Equation (7) shows that the estimation error is proportional to the gap between the tags and the maximum value is half of the gap. Therefore, the maximum estimation error in the X-Y Cartesian coordinates is represented as

$$e_{est\_\max} = \sqrt{(1/4)d_{tag}{}^2 + (1/4)d_{tag}{}^2} \cong 0.707 d_{tag}. \quad (8)$$

4. Algorithm for Reduction and Compensation of the Error

For the localization process of the mobile robot in the RFID sensor space, two schemes are introduced to reduce the error in this paper.

When the gap between the tags is reduced, the accuracy of the estimation is improved as described in the previous section. But, this solution increases costs because it increases the number of tags. The optimal allocation of the RFID tags in the sensor space proposed in this paper aims at improving the accuracy of the position estimation without increasing the number of tags. Traditionally tags have been allocated in a square pattern (Fig. 3), but in this paper a triangular pattern (Fig. 4) is proposed to decrease the estimation error without increasing the number of tags.

Figure 5 illustrates the decrease of the estimation error in the triangular pattern space.

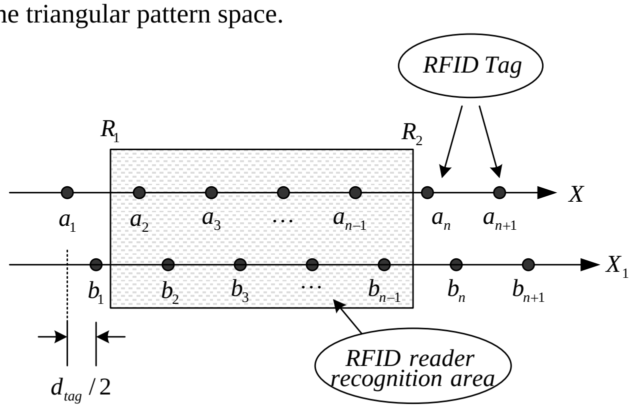


Fig. 3. Estimation error decrease in triangular pattern.

The coordinates of R_1 and R_2 are represented as follows:

$$\begin{cases} b_1 < R_1 < a_2 \\ -\dfrac{d_{tag}}{2} < R_1 - a_2 < 0 \end{cases} \quad (9\text{-a})$$

$$\begin{cases} b_{n-1} < R_2 < a_n \\ 0 < R_2 - b_{n-1} < \dfrac{d_{tag}}{2} \end{cases}. \quad (9\text{-b})$$

When the RFID tags are arranged in the triangular pattern, the estimation error in x-direction can be decreased as follows:

$$e_{est\_x} = \left| R_{est\_x} - R_{real\_x} \right| = \left| \frac{R_1 + R_2}{2} - \frac{a_2 + b_{n-1}}{2} \right| \quad (10)$$

$$e_{est\_x} = \left| \frac{(R_1 - a_2) + (R_2 - b_{n-1})}{2} \right| \le \frac{1}{4} \left| d_{tag} \right|. \quad (11)$$

Therefore, the maximum estimation error in X-Y Cartesian coordinates can be represented as

$$e_{est\_\max} = \sqrt{(1/2)d_{tag}{}^2 + (1/4)d_{tag}{}^2} \cong 0.58 d_{tag}. \quad (12)$$

5. Experiments and Results

For the localization of a mobile robot, it is assumed that the mobile robot moves along the designated path.

5.1 Experimental environment

The main frequency of the RFID is 13.56 MHz, The positions of the tags are pre-stored, and the tags are regularly allocated following a designed pattern. To show the superiority of the triangular pattern, the tags are allocated at every 0.05m in a row for both patterns. The size of the RFID reader antenna is 0.1m*0.1m and that of epoxy tags is 3cm*3cm. The mobile robot moves in the 1m*1m space along the designed path. The velocities of right and left wheels are sent in radio frequency from the main computer to the differential-driving mobile robot. The reader antenna is at the bottom of the robot, and is connected to the reader. The reader and main computer are linked through the RS-232 serial communication channel.

5.2 Experimental results

The first experiment aims at the comparison of robot localization accuracies in triangular and rectangular patterns of tag allocation. The mobile robot follows the path-1 and path-2 in Fig. 4 with the velocity of 0.25 m/s and the sampling time of 0.04 sec.

The estimation errors are illustrated in Fig. 5 for path-1. As it can be seen by comparing the errors, the estimation errors for the triangular pattern are a lot smaller than the square pattern. For the Path-2, the same results are obtained.

To express correct values, the average position error and orientation error is represented in Table 1. The fact that the triangular pattern of RFID tag allocation reduces the estimation error is described in section 4 by using the error model and it is demonstrated by the experiment.

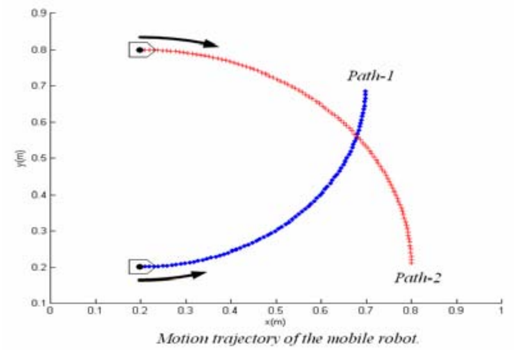
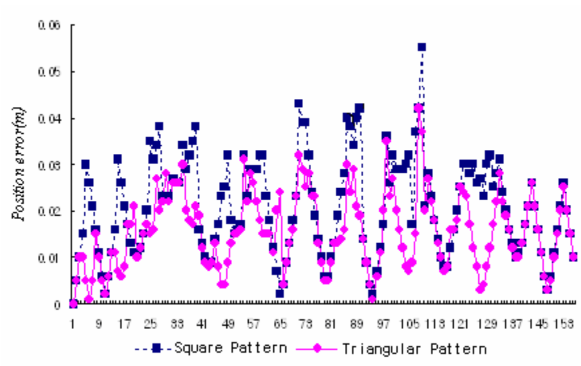
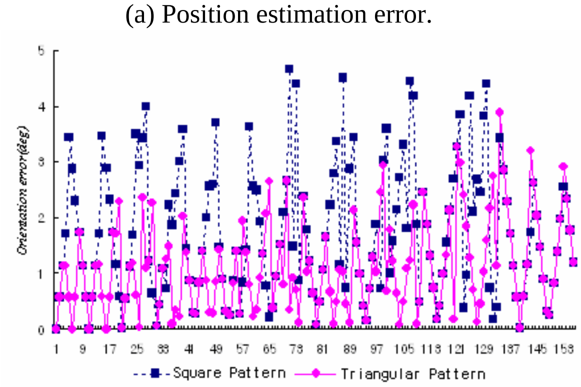


Fig. 4. Two different paths (Path-1 and Path-2).



(a) Position estimation error.



(b) Orientation estimation error.
Fig. 5. Estimation errors of Path-1.

Table1. Average of the position and orientation error

	Path-1		Path-2	
	Position Error(m)	Orientation Error(deg)	Position Error(m)	Orientation Error(deg)
Square Pattern	0.02	1.72	0.02	1.42
Triangle Pattern	0.016	1.12	0.015	0.89

6. Conclusions

This paper proposes a new localization scheme in an RFID based sensor space, which is derived from the new ideas on the tag allocation and on the accurate and efficient estimations. This scheme overcomes the shortcomings of the conventional absolute position estimations and improves the localization efficiency and accuracy. The main ideas are demonstrated by the experiments of a mobile robot navigating over the RFID based sensor space. To illustrate the improved accuracy and efficiency of the position estimation scheme, the square and triangular tag patterns have been compared. The triangular pattern has shown better performance than the square pattern for position estimation of a mobile robot. When the robot moves in the RFID sensor space, the velocity and position of the robot are estimated and compensated to reduce the estimation error according to the localization scheme developed in this paper. Therefore, this scheme is very effective for the position estimation of any object in the sensor space and it could be a good tool to form a ubiquitous environment for a mobile robot.

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