Localization and Map-building of Mobile Robot
Based on RFID Sensor Fusion System

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Abstract-In this paper, we propose an improved localization system for an indoor mobile robot using RFID (Radio Frequency IDentification) system and wheel encoders. Nowadays, RFID technology is widely used in the robot field. We investigate recent RFID localization system based on (passive) tag-floor for mobile robot, and analyze the problems and limitation of previous researches. First, RFID and wheel encoder localization system’s uncertainty, which may result in inaccurate location data, is modeled. And then, the algorithm for estimating each uncertainty is proposed for localization. Finally, a proposed algorithm successfully demonstrated through simulation experiments conducted under certain assumption.

I. INTRODUCTION

A mobile robot localization problem is most important and fundamental issue in the robotics and must be considered ahead of the path-planning or autonomous task-execution. A lot of researches on localization system have been proposed so far and various kinds of the sensor (CCD camera, IR sensor, DR sensor, etc.) have been also used according to proposed methods. There are two general methods for the mobile robot localization: 1) relative-localization using dead-reckoning sensors such as encoders or gyroscopes which can measure the displacement to the initial position and orientation [1, 2] and 2) absolute-localization using a camera, ultrasonic, GPS, or infrared sensors to recognize the geometry location from reference point [3-5]. The former scheme, simple and easy to implement, is subject to the accumulation error that may result in inaccurate position data in case of long moving-distance. The latter scheme, used to solve the problem of former scheme, can provide precise location data. However, there are many environmental factors to get reliable and accurate location. For example, a CCD camera is utilized under good illumination conditions for determining the location and GPS cannot be used in indoor localization.

Recently, an RFID technology [6] has been applied for the robot technology, and especially the localization of mobile robot. Originally, an RFID technology is developed for object recognition, but now it is applied to robotics and regarded as a novel localization system like image processing or artificial intelligence. The features of the RFID technology, which can be used practically, are 1) storage of location and environment information within RFID passive tag, 2) classification of information by private ID code, 3) convenient approach to information, and 4) robustness for environment change. Through these features, we can implement a new-forming robot sensor system for localization which can solve the problem of conventional sensor system. But the technical limitation of RFID sensor system is appearing like conventional sensor system. The algorithm and method is proposed to overcome such weakness and limitation [7-9].

This paper propose the improved algorithm for localization system to estimate the uncertainty efficiently, as the expansion of research results which are announced in 2005 [10], in 2006 [11], respectively. In this paper, we assume the RFID system with passive tag based on tag-floor mode, which was used in [10, 11]. In order to remove the uncertainty that appears in RFID system, we use the relative-localization method using wheel encoders and organize combination localization system.

This paper is organized as follows. Section II shows a limitation of related work. In Section III, the uncertainty modeling using error function for RFID system and encoder system is described. In Section IV, volatilization scheme to estimate the each uncertainty is proposed. The experiments environment and computer simulation results are shown to prove the validity of the proposed method in Section V. Finally, in Section 6, conclusion and further research topic are presented.

II. RELATION WORK

The feature and function of RFID system is altered greatly according to RF frequency (13.56 MHz~900 MHz), power-supplying method to tag (passive, active) [6]. Because of this, several localization method are proposed according to the configuration of RFID system. In this paper, we deal with the localization method based on tag-floor using passive tag as shown in fig. 1. The configuration of this method is as follow. Passive RFID tags are arranged in a fixed pattern on the floor. Absolute coordinates of the location has 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 RFID reader reads the coordinate value of RFID tags on the floor to localize the mobile robot.
The absolute location of the mobile robot in the tag-floor is estimated regardless of existence obstacles and Landmarks. The representative problem based on passive RFID technology is that the accurate position and distance between RFID reader and RFID tags is not measured. This is the technical limitation of RFID system. If RFID tags are found within reader’s recognition area, the existence of tags can be just checked. Because of this, the position estimation error is generated according to the gap between the tags and reader’s recognition area. The estimation error is explained in full in Section III.

Several algorithms have been proposed to reduce the estimation error so far. The studies on various allocation pattern of RFID passive tag such as triangular or parallelogram pattern are addressed to reduce an error. S.W.Kim et al [12, 13] proposed how to distribute RFID tags and how to place on the tag-floor. In [14], note that the triangular allocation pattern is efficient pattern for estimation error. Since the uncertainty of RFID system is not eliminated completely, the case of increasing an error can be generated according to robot’s path or environmental condition. The probabilistic approach [15] is proposed for reduction of estimation error. In [15], estimation error is compensated using Particle filter based on probabilistic theory. However, uncertainty of RFID system is not eliminated. When the reader cannot read new coordinate information of tags, the coordinates of robot is not updated and error is increased. To solve a problem, the additional localization system is required to compensate the limitation and uncertainty in RFID system. In this paper, we propose relative-localization based on wheel encoder as additional system.

The relative relative-localization systems based on wheel encoder have the shortcoming with accumulation error, but it can provide precise location in case of short-path or reset the accumulation error. Therefore, the proposed algorithm integrates the localization based on wheel encoder system and RFID system.

III. UNCERTAINTY MODELING

A. Uncertainty in RFID System

As shown in fig. 2, if the robot with RFID reader moves and stays on any tag, the RF field is formed by RFID reader antenna. The antenna of RFID leader which have been installed at the bottom of the robot organizes the recognition area as shown in fig. 2 (a). We assume that recognition area in 2D X-Y coordinates is approximated by a circle form as shown in fig. 2 (b). That is, the recognition area is expressed by equation of the circle as follows:

\[(x - x_k)^2 + (y - y_k)^2 = r_k^2.\]  

(1)

where, \(x_k, y_k\) is center of RFID reader, i.e., the real location of mobile robot, and \(r_k\) is radius of reader’s recognition area. In the passive RFID localization system, RFID reader cannot obtain a precise location value from the tag. The existence of tags within the recognition area is just checked because the distance between RFID reader and tag cannot be also provided in the localization process. Therefore, RFID system can obtain information that 4 tags are within the recognition area. But, it cannot receive the information where each tag is. Fig. 3 shows the case that estimation error is generated by difference between real robot position and estimated position. The position of the mobile robot can be obtained through the position data of the tags that are located within the recognition area of the reader as in [10, 11].

\[x_{est} = \frac{\max\{x_1, \ldots, x_N\} + \min\{x_1, \ldots, x_N\}}{2}\]  

(2)

\[y_{est} = \frac{\max\{y_1, \ldots, y_N\} + \min\{y_1, \ldots, y_N\}}{2}\]  

(3)

Where \(N\) represents the number of tags detected by the reader and \(x_1, x_2, x_3, y_1, y_2, \ldots\) represents the coordinate’s information of the tags.

The real robot position is represented as \(P_r = \{x_r, y_r\}\), and estimation position by tag A and tag B is \(P_{est} = \{x_k, y_k\}\) as shown in fig. 3. The Estimation error can be represented as follow:

\[e_{est} = |P_r - P_{est}| = [(x_k - x_r)^2 + (y_k - y_r)^2].\]  

(4)

Note that the estimation error is determined by the gap between tags and recognition area in [10, 11].
The current state, input, and error terms as follows: the general state equations are described by the main factors causing state vector estimation error of the mobile robot. The general state equations are described by the main factors causing state vector estimation error of the mobile robot. The general state equations are described by the main factors causing state vector estimation error of the mobile robot. The general state equations are described by the main factors causing state vector estimation error of the mobile robot. The general state equations are described by the main factors causing state vector estimation error of the mobile robot.

\[ x_{est} = f(x_{est-1}, u_t, \epsilon) \]

where \( x_{est} \) represents the estimated state, \( u_t \) is the input, and \( \epsilon \) represents noise source affecting the states assumed to be zeromean Gaussian with covariance \( Q = N(0, Q) \). The position uncertainty of the robot is modeled by means of a Gaussian distribution of probability centered in the vehicle position at a given moment. The position uncertainty can be represented in terms of the spatial position relationship, namely the mean and the covariance of the distribution function, must be determined. The covariance matrix related to the prediction in the case of non-linear spatial relationship is obtained from the Taylor series expansion. Therefore, the estimated position of a mobile robot and \( \hat{x}(k | k) \) covariance matrix equation are represented in (8) and (9), respectively.

\[ \hat{P}_{k+1} = f(\hat{P}_{k+1}, u_k) \]
\[ \hat{P}(k + 1 | k) = \nabla f_P(k | k) \nabla f_T + Q_k \]

where \( \nabla f \) is the Jacobian of the state transition function, obtained as the linearizing result around the estimated state. The Jacobian of the state transition function is described in (10) as follows:

\[
\nabla f = \begin{bmatrix}
1 & 0 & T \sin(\hat{\theta}(k | k)) \\
0 & 1 & T \cos(\hat{\theta}(k | k)) \\
0 & 0 & 1
\end{bmatrix}
\]

In order to estimate the vehicle position, odometer is insufficient. The \( \hat{x}(k | k) \) covariance matrix equation represented in (9) tends to grow continuously (Fig. 5). Using this covariance matrix, the position estimation uncertainty can be represented as a hyperellipsoid. In other words, the uncertainty hyperellipsoid can be defined [16] based on the singular value decomposition (SVD) of the covariance matrix. This SVD provides the principal axis by the left singular vectors and the length along the axis by the corresponding singular values. As an example, Fig. 5 illustrates the effectiveness of the uncertainty ellipsoid. It indicates that the uncertainty ellipsoid becomes larger with the movement of a mobile robot and the geometrical shape of the ellipsoid directly represents the position estimation uncertainty along a given axis.

\[
P_{R,k+1} = f(P_{R,k}, u_t) + \epsilon_t
\]
IV. PROPOSED ALGORITHM

In previous section, uncertainty in each system is modeled. In this section algorithm is proposed to compensate the uncertainty (fig. 6). Assumption for RFID system is follows:

1) The maximum gap between RFID tags is smaller than RFID reader’s maximum recognition area so that RFID reader always receives the data of tags.
2) The communication between tags and reader is always guaranteed.
3) The allocation pattern of tags is square pattern with same gap between tags.
4) The reader’s recognition area is modeled by circle shape.
5) The initial point of mobile robot is known.

Fig. 6. Flow chart of new algorithm for localization

A. Step 1 (measurement by wheel encoder)
The initial state of mobile robot is defined as \( P_{R,0} = [x_{R,0}, y_{R,0}, \theta_{R,0}]^T \). When the mobile robot move, the state of mobile robot is represented as \( P_{R,k} \) \((k = 0,1,2,...)\) using the displacement, \( \Delta s = |P_{R,k} - P_{R,k-1}| \), which is measured by wheel encoder system. Because of error between initial state and estimation position, the localization by RFID system does not guarantee the accuracy location. Note that the estimation error by wheel encoder is not generated because of short movement from initial state.

![Diagram of localization process using RFID and encoder system](image)

B. Step 2 (new tags)
When the mobile robot moves continuously, the state of the mobile robot is also changed. There are two situation according to finding new tags within recognition area. If the new tags are not found, the state of mobile robot is continuously estimated by only the encoder system due to the uncertainty in RFID (step 1). If the new tags are found, the displacement is measurement by recognition area (step 3).

C. Step 3 (measurement by RFID)
As shown in fig. (b), the new tags(tag B) are found in mobile robot state, \( P_{R,k} \). The displacement, \(|P_{R,k} - P_{R,k-1}|\), can be obtained by movement of recognition area represented by equation of circle.

\[
(b_1 - x_{R,k})^2 + (b_2 - y_{R,k})^2 = r^2
\]

\[
(b_1' - x_{R,k-1})^2 + (b_2' - y_{R,k-1})^2 = r^2
\]

Where, \((b_1,b_2)\) is the coordinates of Tag B and \((b_1',b_2')\) is the predicted coordinates of tag B, the \((b_1,b_2)\) coordinates of in state \( P_{R,k} \). Therefore, the displacement \(|P_{R,k} - P_{R,k-1}|\), can be represented by \(|B' - B|\).

\[
|P_{R,k} - P_{R,k-1}| = f(|B' - B|)
\]

D. Step 4 (uncertainty in Encoder)
The displacement by RFID system in step 3 can be obtained, and then accumulation error based on wheel encoder is eliminated by obtained displacement. By new tag and displacement, accurate state \( P_{R,k} \) is updated. The current state, \( P_{R,k} \) is known completely like initial state, \( P_{R,0} \) in Step 1. The algorithm is repeated while the mobile robot move.

V. SIMULATION STUDY

For the localization of a mobile robot, it is assumed that the mobile robot moves along the designed path. Simulations were performed for mobile robot in RFID space based on tag-floor. To verified the proposed algorithm, the estimation error between real robot state and estimated robot state is measured.

A. Environments

The experimental parameters for computer simulation are listed in Table I. To achieve realistic conditions, the gap between tags and recognition area, and number of total tags are set.

<table>
<thead>
<tr>
<th>TABLE I</th>
</tr>
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<tbody>
<tr>
<td>SIMULATION PARAMETER</td>
</tr>
<tr>
<td>Parameter list</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Gap between tags</td>
</tr>
<tr>
<td>Recognition area</td>
</tr>
<tr>
<td>Number of total tags</td>
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</tbody>
</table>

The initial position and goal position of the mobile robot were set as \((0.25, 0.25, 90^\circ)\) and \((1, 0.7, -135^\circ)\), respectively. Fig. 8 shows the path of the mobile robot.
B. Results

The object of the experiment is to show reduction of the estimation error by the proposed algorithm in this paper. The mobile robot moves along a certain trajectory, and estimates its own position using the RFID localization system and wheel encoder. The experiments results show that estimation error of robot position decreases when the proposed algorithm is applied as shown in fig. 9 and table 2.

VI. CONCLUSION

In this paper, a new localization scheme is proposed for localization of mobile robot. This scheme overcomes the shortcomings of the conventional RFID localization system and improves the localization efficiency and accuracy. The main ideas are demonstrated by the simulation experiments. The localization is one of the fundamental functions for intelligent mobile robot. Future studies will involve improving the estimation accuracy for RFID localization system and applying this system to complex environments. Since the proposed algorithm have some assumptions, it is necessary to reduce these assumptions.

REFERENCES


Table II

<table>
<thead>
<tr>
<th>EXPERIMENT RESULT</th>
<th>Value</th>
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<tr>
<td>proposed algorithm</td>
<td>0.010 m</td>
</tr>
<tr>
<td>conventional RFID system</td>
<td>0.052 m</td>
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</tbody>
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