Object Recognition of Robot Using 3D RFID System

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Abstract: Object recognition in the field of robotics generally has depended on a computer vision system. Recently, RFID (Radio Frequency Identification) technology has been suggested to support recognition and has been rapidly and widely applied. This paper introduces the more advanced RFID-based recognition. A novel tag named 3D tag, which facilitates the understanding of the object, was designed. The previous RFID-based system only detects the existence of the object, and therefore, the system should find the object and had to carry out a complex process such as pattern match to identify the object. 3D tag, however, not only detects the existence of the object as well as other tags, but also estimates the orientation and position of the object. These characteristics of 3D tag allows the robot to considerably reduce its dependence on other sensors required for object recognition the object. In this paper, we analyze the 3D tag’s detection characteristic and the position and orientation estimation algorithm of the 3D tag-based RFID system.

Keywords: RFID, Tag, Mobile Robot, Object Recognition

1. Introduction

We cannot even think about something if that something does not exist. If something exists, we can understand or imagine about it no matter what it may be. Understanding and imagination in this way fully depend on recognition. A human being’s object recognition is executed in real time by identification intelligence, which is developed from experience, learning, and presumption. On the other hand, a robot’s object recognition is executed by sensation, perception, and identification. Sensation means the response to the stimulus and intensity of the object; for example, a vision system captures images obtained from a CCD camera [1]. Perception implies the estimation or acquisition of the object geometry, of which invariants are extracted from the two-dimensional luminance data. Identification matches and determines the object from a database based on the representations of the extracted geometry. These processes need to compute enormous data, so that real-time process is almost impossible. In addition, matching uncertainty is immanent in this recognition because the robot has much difficulty in identifying the existence of an object. Suppose that a robot agent is commanded to clean the room as illustrated in Fig. 1. The robot has sensors such as ultrasonic, vision, and laser range finder. When executing the cleaning mission, it receives another order, that is, to bring the commander his/her mobile phone. Executing this mission needs the classification of physical objects which is to be kept or cleaned. At the same time, it should find the mobile phone. But sensors that should recognize objects for cleaning are beyond their computational capacity. Thus, the robot stops cleaning, and then begins to find the mobile phone. First, it scans all objects using vision, sonar, etc., and then will try to compare the objects with the target mobile phone. It, however, cannot find the target despite every effort because the sensor cannot scan the target object, which is hidden by the bottles and a dish. Consequently, the robot cannot even confirm the existence of the target in the room and it will conclude that the target is in another room. RFID is an attractive technology to supplement the limitation of robot faculty as such. The basic but powerful function of this technology is to identify the existence of the object. In the same missions, there is another robot with the RFID system and all objects have built-in tags. This tag gives to the robot the information which is the property or characteristic of the object. To clean the room, the robot easily chooses the objects which should be removed or kept. To execute the second mission, the robot searches the ID lists of objects which have been obtained while cleaning. Through the robot has already known that there is the target mobile phone in the room. To find the target, this robot moves to the position where the target has been detected, and then scans nearby objects using its sensors. Hence, the robot can complete its task more easily after object identification. The robot, however, hardly ever knows where the target is because the sensors cannot detect the target, which is hidden by other objects. Finally, the mission is not completed. Obviously the target is there, but something, however, is often thought not to exist if it is not detected. Hence, the RFID system also cannot present the solution for object recognition because it is not enough to identify and confirm the existence of the object.

In order to overcome this limitation, the authors have developed the advanced RFID system based on 3D tag. The proposed RFID system cannot only identify, but also estimate the position and orientation of the object. Owing to these characteristics, the automated systems together with robots can easily and rapidly recognize objects. Naturally, this recognition mechanism can also simplify other robot processes such as localization, navigation and manipulation. The authors have developed the algorithm and application for such processes of the robot on the basis of the proposed advanced RFID system. In this paper, we mainly focus on the fundamental principle and algorithm of this system. Firstly, the basic idea is addressed. Sections III and IV describe the structure of the system and the 3D tag which characterizes the system. The algorithms for estimating the position and orientation of objects are given in Section V, and experimental results are briefly presented.

Fig. 1. Recognition for executing a task

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2. Problem Statement and Idea

RFID system has been used for the artificial landmark to obtain the geographical information for navigation and localization of the mobile robot [2] – [8]. Using this system, several researchers have developed the application of RFID system to support object recognition [9] – [11] and manipulation [11]. Their studies are very useful and practical in that the RFID system supplements the limitation of the robot’s capability.

3. Characteristics of 3D RFID System

3.1. Recognition Module

The proposed RFID system is composed of a antenna and reader to detect 3D tag. Antenna can be swept by the actuator as shown in Fig. 2(a) and has the uni-directional read range as shown in Fig. 4. These features are useful for estimating the position and orientation of 3D tag. The proposed RFID system is a part of the module called Recognition Module. The major function of the module is to recognize, and judge from the existing state of things with Sensor Module. This function should be required so as to execute the task or mission of a robot as a agent. For the effective target or subject recognition, this module has also a vision and voice recognition system. The systems are physically synchronized as shown in Fig. 3(b). They simultaneously try to scan the object with the same intension.
distance in the magnetic field of the electromagnetic wave from the antenna. If the tag is out of the range of detectable angle, it can not be sensed by the reader though it is placed in the detectable distance. The specific detectable angle and distance of RFID system can provide more definite information to the robot. The authors measures the sensing range of RFID antenna to the tag when 3D RFID system is combined into DRP I.

To measure the range in accordance with height and distance, the test space is (2000 mm × 3000 mm × 1000 mm) and 6 axis manipulator is used as illustrated in Fig. 5(c). The experimental sensing range is the geometry similar to the simulated sensing range. The fragmental non-detectable area, however, is present because of the effects of the robot body and ground as shown in Fig. 5(b). The sensor model including the fragmental area is designed so that the once detected tag should not be missed; even tag in the fragmental area is detected in a little time because the proposed RFID system is sweepable. The model should include all of range which can have the possibility to detect tags. This concept differs from that of the other sensor model such as sonar. The tag should not be neglected, if exists, because a matter of primary concern of RFID system is to determine the existence of the object.

Based on the experimental results, the detectable range of our system is modeled as an ellipsoid. The equation of the ellipsoid is Eq.1. The reference frame is denoted by \( \Sigma_A \), \( (c_x, c_y, c_z) \) is the center of the ellipsoid and \( r_x, r_y, \) and \( r_z \) are the radius of the ellipsoid.

\[
\frac{(x - c_x)^2}{r_x^2} + \frac{(y - c_y)^2}{r_y^2} + \frac{(z - c_z)^2}{r_z^2} = 1,
\]

where \( c_x = 0, c_y = 1350, c_z = 0, r_x = 700, r_y = 1350, \) and \( r_z = 1000 \). This equation can be rewritten in order to be suitable for the sweepable antenna. In spherical coordinates of the center of the ellipsoid, Eq.(1) is rewritten by

\[
P_x(\varphi_x, \phi_x) = \begin{bmatrix}
P_{x_x} & \cos \varphi_x \sin \phi_x \\
P_{y_x} & \sin \varphi_x \sin \phi_x \\
P_{z_x} & \cos \phi_x
\end{bmatrix},
\]

where \( P_x \) is the position vector inside the ellipsoid. \( P_{x_x}, P_{y_x}, \) and \( P_{z_x} \) are \( x_x, y_x, \) and \( z_x \) vectors of \( P_x \), respectively (\( |P_x| \leq r_x, |P_{y_x}| \leq r_y, |P_{z_x}| \leq r_z \)). \( \varphi_x \) is the azimuthal angle in the \( x_xy_x \)-plane from the \( x_x \)-axis and \( \phi_x \) is the polar angle from the \( z_x \)-axis (\( 0 \leq \varphi_x \leq 2\pi, 0 \leq \phi_x \leq \pi \)). The vector \( P_A \) of inside the ellipsoid, of which the reference frame is \( \Sigma_A \), can be written by

\[
P_A = C_A + P_x(\varphi_x, \phi_x),
\]

where \( C_A \) is the vector from \( \Sigma_A \) to \( \Sigma_e \).

3.3. Detectable tag orientation

The detection rate of the tag is changed in accordance with the angle between the tag in the sensing range and the antenna. Let’s assume that the relation between the coordinate frames \( \Sigma_{ani} \) and \( \Sigma_{tag} \) is given by the vector \( \text{ant}P_{tag} \) without rotation in Fig. 6(a)\( (\Sigma_{ani} \) and \( \Sigma_{tag} \) are the coordinate frames of the antenna and the tag, respectively). Each detection rate of the tag rotating around \( x_{tag}, y_{tag}, \) and \( z_{tag} \) is measured as plotted in Fig. 6(b), so that the detectable angle range of tag is obtained as follows:

\[
[-180 \leq \alpha \leq 180],
\]

\[
[-45 \leq \beta, \gamma \leq 45],
\]

where \( \alpha, \beta, \) and \( \gamma \) are the angles of pitch, roll, and yaw, respectively.

The results mean that the detection rate can estimate the pose of a tag.
are twenty four kinds; the classification like this is useful in that a human frequently understands the pose of an object with the base of 90 degree such as top, bottom, front, back, left and right. On the other hand, the pose of the object with the built-in union tag is divided into twenty four classes from a different standpoint. Considering the tag unit $U_{TF}$, the pose of the object which allows $U_{TF}$ of the union tag to be detected is four kinds as shown in Fig. 8(b). This detection of $U_{TF}$ means the detection of one of the object’s two faces: the front side or top side of the object. Owing to this feature, the orientation of the object cannot be determined by the detection of one tag unit. Two tag units at the least should be detected so that one of the twenty four poses is determined. The most effective method is to detect two neighboring tag units. Let’s assume that the antenna of the robot detects the object from $-y_{uni}$ axis direction when the object is fixed as shown in Fig. 7(b), and then it does from $x_{uni}$ axis direction. 3D RFID system reads $U_{TF}$ and $U_{LT}$ in order. This means that 3D RFID system detects the front side denoted by $N_F$, and then the left side by $N_L$. $N_F$ and $N_L$ also denote the direction vectors which are normal to the faces of front and left, respectively (the subscripts $F$ and $L$ denote the front and left). The detection case by this order is only one. The sum of cases like this is twenty four as shown in Fig. 7(c) and each case determines the pose of the object. To generalize these cases, the authors developed the algorithm. We define that $U_i$ is the first detected tag unit and $U_j$ the second where $U_{m}(i, j)$ and $U_{r}=(j, j, 2), T, F, L, R, B$ and $D$ are denoted by 1, 2, 3, 4, 5 and 6, respectively. $[n_1, n_2]$ which means the first and second face detected is as shown in Fig. 8(d). The relation equations of these numbers are found through observation, and the relations can be written by

$$[n_1, n_2] = \begin{cases} \min(U_i) \quad \min(U_j) & \text{if } S_{MM} \leq 7 \text{ or } S_{MM} > 9, \\ \max(U_i) \quad \max(U_j) & \text{if } S_{mm} = 7, \\ \max(U_i) \quad \min(U_j) & \text{if } S_{MM} = 7, \\ \min(U_i) \quad \max(U_j) & \text{if } S_{mm} = 7, \end{cases}$$

where $S_{MM}, S_{mm}, S_{mM},$ and $S_{mm}$ are as shown below.

$$S_{MM} = \max(U_i) + \max(U_j),$$

$$S_{mm} = \min(U_i) + \max(U_j),$$

$$S_{mM} = \min(U_i) + \min(U_j),$$

$$S_{mm} = \max(U_i) + \min(U_j).$$

### 5. Position and Orientation Estimation of Object

#### 5.1. Position Estimation

To complete the mission, the robot should know the position of the target. Fig. 9 shows how 3D RFID system is used. The proposed system can rotate the RFID antenna for scanning objects. This scanning ability makes the robot estimate the position of 3D tag or the object. As shown in Fig. 9(a), the robot rotates the antenna from the right-hand to the left-hand. 3D tag is initially detected when the direction angle of the antenna is $\varphi$, and the tag is detected until the angle is $\varphi_f$. Thus, it can be said that the tag will be placed in the common area 1 through this scanning procedure. In the next step, the robot moves to the second position, and then repeats the procedure. From the steps 1 and 2, the position of 3D tag is one point in the common area 3. Detecting objects by scanning has been used by the other robots which has the sensors with detection range. But the results obtained from scanning of these sensors differ from the results by the usage of 3D RFID system. For examples, main purpose of the procedures using ultrasonic sensors gives the robot not the position but geometry data of environments such as walls and obstacles (the position is already determined because the distance and direction of the object has been measured when detected). Or the procedure is performed so as to compensate the mistaken data when the sensor does not detect the object because the object is a slender edge shape, etc. The ultrasonic sensor or laser range finder is very useful for sensing unspecified objects such as mapping environments or avoiding obstacles, but these sensors cannot find and sense the specified target because what the target is. On the other hand, the robot with 3D RFID system what the target is, but the scanning procedure by 3D RFID system cannot determine the position of the target because RFID antenna itself cannot read distance and the position is always uncertain. Thus, the scanning should be used not for determining, but for estimating the position of target. The steps in Fig. 9(a) are the pre-process for the position determination by other sensors capable of distance measuring. These sensors of the robot based on 3D RFID system can easily detect the object and determine rapidly the position because the robot has already known roughly the position of the object, moreover, whether or not the object exists, what the object is, and how it poses. Fig. 9(b) shows the position estimation of the proposed system. In this figure, $\Sigma_G$ and $\Sigma_r$ are global and robot coordinates. $P_{obj}$ is the position vector of the object in global coordinates. $P_1$ and $P_2$ are the position vectors of the robot at $P_1$ and $P_2$, respectively. $P_{obj}$ can be written...
To define the pose of the target, two sides of 3D tag should be based on the characteristic which 3D tag’s detectable angle is limited. The proposed method for estimating the orientation of the object is orientation estimation which will be presented in the next section. Since the steps 1 and 2, however, should be required to execute the common area 1 is determined with the two ellipsoid computed. This Eq.(10) is obtained from the relations of the steps 1 and 2. The θobj is, the angle of ϕ 

\[ P_{obj} = P_1 + P_1P_{obj}, \]  

where θ_1 and θ_2 are the angular differences between the global and robot frames at P_1 and P_2, φ_1, which means antenna direction angle is, the angle of P_1P_{obj} from the x_r-axis and φ_2 is the angle of P_2P_{obj} from the x_r-axis, \( |P_1P_{obj}| \) is rewritten by

\[ |P_1P_{obj}| = |P_1P_2| \cdot \frac{\sin(\theta_2 + \phi_2 - \psi)}{\sin(\phi_2)} \]  

where (ψ = tan^{-1} \( \frac{y_2 - y_1}{x_2 - x_1} \)) and φ_1 and φ_2 are obtained from (φ_1 + φ_2)/2 at P_1 and P_2, respectively. Thus, we finally obtain

\[ P_{obj} = \begin{bmatrix} x_1 + |P_1P_2| \cdot \sin(\theta_2 + \phi_2 - \psi) \\ y_1 + |P_1P_2| \cdot \sin(\phi_2) \end{bmatrix} \]  

This Eq.(10) is obtained from the relations of the steps 1 and 2. Theoretically, the position can be estimated with the only step 1 because the common area 1 is determined with the two ellipsoid computed. The steps 1 and 2, however, should be required to execute the orientation estimation which will be presented in the next section. Since the orientation estimation is always accompanied with the position estimation and the position estimation by the two steps is more accurate, the position estimation using these steps is reasonable.

5.2 Orientation Estimation

The proposed method for estimating the orientation of the object is based on the characteristic which 3D tag’s detectable angle is limited. To define the pose of the target, two sides of 3D tag should be detected as mentioned in the section V. If the robot detects the front side at the initial position P_1, and then detects left side at the second position P_2, the 3D tag poses from Fig. 10(a) to Fig. 10(c). To obtain the pose of the target, it is important for the robot to determine the second position. If the second position is not chosen properly, the left side is not detected because the antenna has the limited direction and sensing range for detecting 3D tag. The determination depends on the detectable angle range of the tag unit of 3D tag; the maximum is 45° and the minimum –45° from Eq.(5). When the tag poses as shown in Fig. 10(a), the angle between the vectors \( \vec{N}_F \) denoting the front side and \( -P_1P_{obj} \) should be less than 45° so as to detect the front side of 3D tag. In case if Fig. 10(b), \( \vec{N}_L \) and \( -P_2P_{obj} \) should be more than 45° so as to detect the left side. Thus, it is reasonable that the angle between \( P_1P_{obj} \) and \( P_2P_{obj} \) is 45°. In addition, when the robot is placed at the second position P_2, the target should be within the sensing range of the antenna. Hence, the distance between the target position \( P_{obj} \) and \( P_2 \) should be chosen properly. This distance is substituted with that between the common area 1 and P_1. In the previous section, the common area 1 is used so as to obtain φ_1 but the position of the area is not considered. In other words, this common area is used as the guide for the choice of P_2 so as to estimate the orientation even if the area is not used for the position estimation. Though the robot move to P_2, the left side of 3D tag cannot be detected as shown in Fig. 10(c). In such a case, the robot move to P_3 and detects the left side.

As shown in Fig. 10(e), the positions of P_1, P_2, P_3, and P_{obj} are solved as follows.

\[ P_2 = P_1 + P_1P_2, \]  

where \( P_1P_2 \) is written by

\[ P_1P_2 = \frac{\sqrt{2 - \sqrt{2}} \cdot |P_1P_{obj}| \cdot \cos 22.5°}{\sqrt{2 - \sqrt{2}} \cdot |P_1P_{obj}| \cdot \sin 22.5°} \]  

Thus, \( P_2 \) becomes Eq.(13).

\[ P_2 = \begin{bmatrix} x_1 + \frac{|P_1P_{obj}| \cdot \cos \theta_{22.5°}}{\sin(\phi_2)} \\ y_1 + \frac{|P_1P_{obj}| \cdot \sin \theta_{22.5°} \cdot \sin \phi_2}{\sin(\phi_2)} \end{bmatrix} \]  

\( P_3 \) can be written by Eq.(14)

\[ P_3 = P_1 + P_1P_3, \]  

where \( P_1P_3 \) is given by

\[ P_1P_3 = \begin{bmatrix} \frac{|P_1P_{obj}|}{|P_1P_{obj}|} \\ \frac{|P_1P_{obj}|}{|P_1P_{obj}|} \end{bmatrix} \]  

Thus, \( P_3 \) becomes Eq.(16).

\[ P_3 = \begin{bmatrix} x_1 + |P_2P_{obj}| \\ y_1 + |P_2P_{obj}| \end{bmatrix} \]  

Consequently, we finally obtain

\[ P_{obj} = \begin{bmatrix} x_1 + \frac{|P_1P_{obj}| \cdot \cos(\phi_1 + \phi_2 \cdot 22.5°)}{\sin(\phi_2)} \\ y_1 + \frac{|P_1P_{obj}| \cdot \sin(\phi_1 + \phi_2 \cdot 22.5°)}{\sin(\phi_2)} \end{bmatrix} \]  

Thus, \( P_{obj} \) is obtained as the following method. If the robot detects the front side of 3D tag at the position \( P_1 \), and detects the left side of 3D tag at \( P_2 \), as shown in the case 1 of Fig. 10(e), the orientation \( \theta_{obj} \) of the target can be written by

\[ -45° \leq \theta_{obj} \leq 0°. \]  

If the robot detects the front side of 3D tag at the position \( P_1 \), does not detect the left side of 3D tag at \( P_2 \), and then detects the left side of 3D tag at \( P_3 \), as shown in the case 2 of Fig. 10(e), the orientation \( \theta_{obj} \) of the target can be written by

\[ 0° \leq \theta_{obj} \leq 45°. \]
on the basis of the proposed system.

References


