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Object Recognition Using 3D tag-based RFID System

Se-gon Roh*, Young Hoon Lee*, and Hyouk Ryeol Choi*
*School of Mechanical Engineering, Sungkyunkwan University, Suwon, Kyunggi-do, Korea
Telelphone: +82-31-290-7481, Fax: +82-31-290-7507
Email: {robotian, vsmyself, and hrchoi}@me.skku.ac.kr

***Abstract*— RFID (*Radio Frequency IDentification*) technology has been rapidly and widely applied to various applications. Recently, RFID has been suggested as technology that supports object recognition. This paper introduces the advanced RFID-based recognition. The proposed RFID system not only identifies the existence of the object, but also estimates object's orientation and location. These characteristics considerably reduce the dependence on other sensors which are required for recognizing objects. In this paper, we analyze the characteristics of our system and present a novel tag named a 3D tag. The estimation methods of location and orientation using the system are discussed.**

***Index Terms*— Object recognition, RFID, Identification, orientation estimation, location estimation.**

I. Introduction

A human being's object recognition is executed in realtime by intelligence, which is developed from experience, learning, and presumption. On the other hand, the typical object recognition of autonomous systems such as vision systems is performed by different steps. First, sensation which means the response to the stimulus and intensity of the object is carried out. Second, the system estimates or acquires object geometry of which invariants are extracted from the two-dimensional luminance data. Finally, based on the representations of the extracted geometry, the feature of the object is matched to a model in the model database. The steps must consider various factors such as scene constancy, occlusion, segmentation, and classification. Considering the factors, hypothesis should be formed and verified. Since the formation and verification are heuristic and not generalized, the tasks are so complex as to perform in realtime. Thus, the typical object recognition systems cannot but be applied to the limited fields with the limited ability. In many applications, tasks for object recognition are assigned for the domain to identify the object and thus the difficulty of object recognition problem has close relation to identification.

For the identification of object recognition systems, RFID technology must be an attractive technology because the basic but powerful function of it is to identify an object. Some applications using identification by RFID technology to support object recognition [1], [2] and manipulation [3] have been developed recently. The identification step is performed by RFID and the other steps are then a matter of retrieving an object model and registering it to the image data. However, the meaning of the identification of the current RFID system is different from that of a typical object recognition system. To know what the object is, the typical system should naturally find where the targeted object is in advance. In other words, the typical object recognition is performed on the premise that the location and orientation of the object have been already determined. On the other hand, since an RFID system can only identify the object, the information of the location and orientation of the object cannot be obtained. The stage for estimation of its location and orientation still belongs to the domain of other sensors such as a stereo camera. This paper presents new applications of RFID technology as preliminary recognition system to considerably reduce dependence on such sensors. The proposed RFID system identifies an object and also assists the estimation of the object's location and orientation. We propose a method for object recognition by using characteristic of the RFID tag which has a close relation to the radiation patterns of an RFID reader-antenna and a tag-antenna. Based on the proposed method, a novel tag named a union tag, its implementations, and experimental results are presented.

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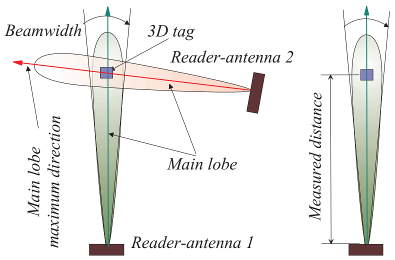
II. Theoretical approach

In developing an RFID system, the optimization of reader power, antenna positioning, and tag design should be considered. Reader-antenna design determines the shape of the field or propagation wave delivered, and the field's strength decreases as the distance between a reader-antenna and a tag increases [4], [5]. When the reader-antenna is set up, the sizes, shapes, and forms of the tags play major roles in determining read range. However, although the tag is within range of the reader, its detection is influenced by the angle subtended between the tag-antenna and the reader-antenna. Thus, the current RFID tags are limited in their universal applicability due to orientation sensitivity issues. The proposed 3D tag eliminates this problem and enhances the use of RFID for a broader range of applications. In this section, the basic concept of this 3D tag is presented.

A. Estimation of location

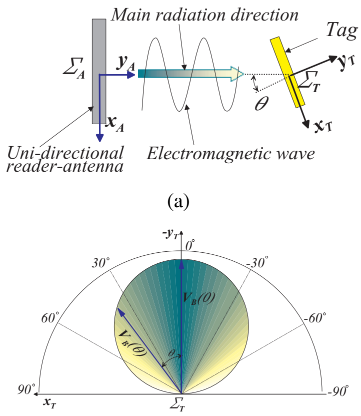
Over the years, many systems have addressed the problem of automatic location-sensing. Triangulation, scene analysis, and proximity are the three principle techniques for automatic location sensing. Because an RFID system is not designed for location sensing, a new method using RFID's characteristics should be investigated. The read range of an RFID system relies on the transmitter power output and in the case of passive tags, on the energizing requirements of the tags. Based on the characteristic of RFID's read range, to estimate object's location, RFID tags are used as artificial landmarks within the environment by placing the tags on the objects of which locations have been already known [6], [7], [8], [9]. Since this method using the tag as landmark provides the roughly presumed range of the object location to the system, the tag itself cannot be applied directly to location-sensing mechanism.

To solve this problem, the characteristic of uni-directional RFID antenna's radiation pattern (or power pattern) can be used. As shown in Fig. 1(a), the location of two RFID reader-antennas and two main lobe directions are determined. Therefore, the location of the object with a tag can be easily computed by using trigonometry. Since the beamwidth and read range of the



(a) (b)

Fig. 1. Estimation of object location using the radiation pattern of a uni-directional RFID antenna. (a) Method using two reader-antennas. (b) Method using the measured distance.



(b)

Fig. 2. Typical tag reading ranges. (a) Electromagnetic backscattering mechanism. (b) Induced voltage according to the tilted angle of the tag.

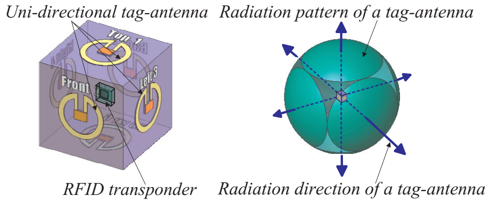
radiation pattern are narrow and long, respectively, this method is a reasonable approach for the estimation of object's location. On the other hand, if the distance between a reader-antenna and a tag can be read by an RFID system as shown in Fig. 1(b), then only one reader-antenna can easily estimate object's location as well as location-sensing system such as ultrasonic sensors because distance and direction can be measured. This approach will be a promising method since the distance measuring method to know which signal level corresponds to what distance has been partially succeeded [10], [11]. Two approaches mentioned above can be undoubtedly applied to typical tags but they have not been applicable so far. This is because they are based on the assumption that the existence of the tag must be detected. Typical tags, however, cannot be detected with respect to tag's orientation. For this reason, the omni-directional 3D tag regardless of tag's orientation is more practical and reliable.

B. Estimation of orientation

Because an RFID tag may be located at various places and orientations around a reader-antenna, the signal path to the reader-antenna varies for each tag, and thus one reader-antenna may see the signal while the other may not. Considering an RFID system which uses electromagnetic backscattering or far-field propagation coupling mechanism, as shown in Fig. 2(a), the voltage $|V_B(\theta)|$ which is induced in the tag-antenna by an electromagnetic wave signal is defined as

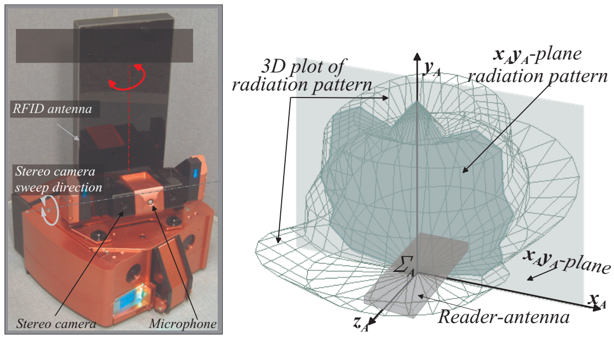
$$|V_B(\theta)| = |V_B(0)| \cos(\theta). \tag{1}$$

where $|V_B(0)|$ is the voltage that is induced when the tag is perpendicular to main radiation direction. Fig. 2(b) shows the induced voltage according to the tilted angle of the tag. The



(a) (b)

Fig. 3. Idea of a 3D tag. (a) Construction of a 3D tag. (b) Radiation patterns of a 3D tag-antennas.



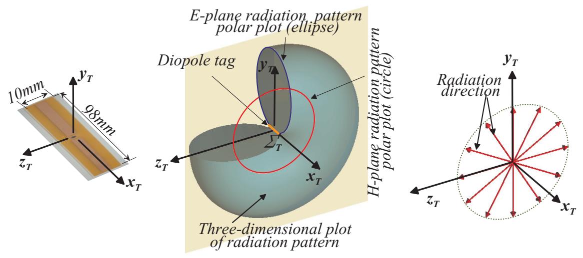
(a) (b)

Fig. 4. 3D RFID system. (a) Construction of 3D RFID system. (b) Simulated radiation pattern of a reader-antenna. Frequency: 910 914Mhz, maximum reading range: 10m, beam width: 3dB 60°, gain: 6dB, manufacturer: KISCOM Co. Ltd.

integration of $V_B(\theta)$ is plotted as a circle and the circle has close relation to the radiation pattern of an reader-antenna. Eq. (1) explain that the induced voltage is various depending on the tag's orientation. This voltage effects on the signal strength which is transmitted to the antenna. The proposed 3D tag uses the difference of this signal strength. As illustrated in Fig. 3(a), the 3D tag consists of several tag-antennas and an RFID transponder. One of the tag-antennas is always detected by the reader-antenna. Each tag-antenna is uni-directional but the integration of radiation patterns of the tag-antennas is omni-directional, as shown in Fig. 3(b). The transponder transmits identification information to the reader through tag-antennas and each tag-antenna has its own directional information. Since the 3D tag's radiation pattern is three dimensional and the different detection signal is read with respect to its orientation, it can be used for the estimation of location and orientation of objects with a built-in 3D tag.

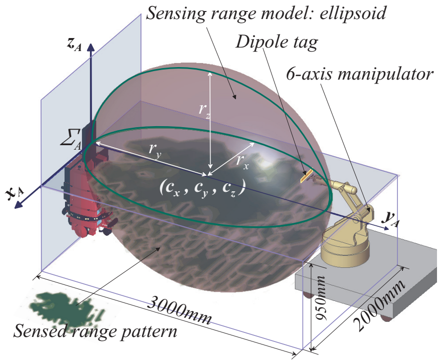
C. Structure of 3D RFID system and sensing model of reader-antenna

The 3D tag-based RFID system (abbreviated as a 3D RFID system hereafter) uses the radiation characteristics of RF antennas. The 3D RFID system is composed of an antenna and a reader to detect a 3D tag. Antenna can be swept by the actuator as shown in Fig. 4(a) and has the uni-directional read range as shown in Fig. 4(b). A 3D tag can be variously designed according to the radiation pattern by a combination of tag-antennas. Since such an RFID transponder with several tag-antennas in Fig. 3 has not been commercially manufactured, the union tag is implemented by using six passive tags as the tag-antennas of the 3D tag. Each transponder chip of the passive tags transmits its directional information to the reader. These passive tags have the dipole antennas as shown in Fig. 5(a). The radiation pattern for the ideal dipole is shown in isometric view with a slice removed in Fig. 5(b). This solid polar radiation pattern resembles a torus with no hole and it is uniform in the $y_T z_T$-plane. This dipole tag has no self-power source, and the required power is obtained through the

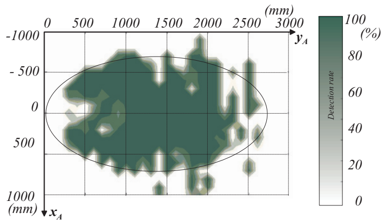


(a) (b) (c)

Fig. 5. RFID tag. (a) Tag with a small dipole antenna (1/4λ). (b)Radial pattern. (c) Radiation direction.



(a)



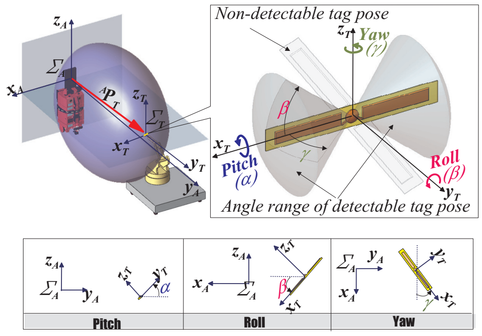
(b)

Fig. 6. Sensing range model of a reader-antenna. (a) Experiment to obtain the sensing model. (b) $x_A y_A$-plane sensing range pattern of the reader-antenna.

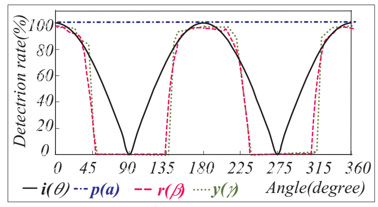
electromagnetic induction. To induce sufficient operating voltage, the tag must be placed within the detectable range (or sensing range) in the magnetic field of the electromagnetic wave from the reader-antenna. To utilize practically this detection characteristic, the authors measured the detectable range of the reader-antenna which can detect the tag in the three dimensional test space, and a 6-axis manipulator was used for taking a accurate measurement, as illustrated in Fig. 6(a). In this experiment, the concept of a detection rate is introduced. The detection rate in this paper means how many times an RFID-reader detects and counts a single tag per 1 second; the detection rate is 100% if the reader detects and counts the tag 20 times per 1 second. Fig. 6(b) shows $x_A y_A$-plane sensing range pattern of the reader-antenna, depending on the detection rate. Based on the experimental results, the three dimensional detectable range of the reader-antenna is modeled as an ellipsoid and the center position of the ellipsoid model (c_x, c_y, c_z) is (0,1350.0) and the radiuses of the ellipsoid r_x, r_y, and r_z are 700, 1350, and 1000, respectively.

D. Detection rate with respect to the tag's orientation

The tag's detection is influenced by the angle subtended between the tag-antenna and the reader-antenna even if it is placed within the detectable range, as mentioned in section II. Similarly, the detection rate of the tag changes with the angle between the

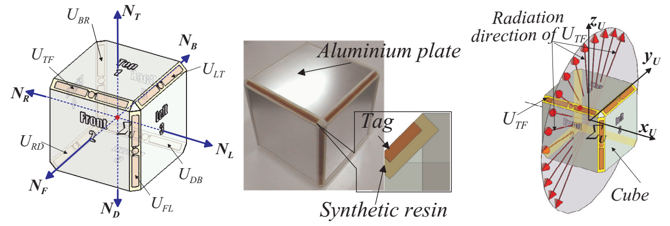


(a)



(b)

Fig. 7. Detectable tag orientation. (a) Rotation of a tag. (b) Angle range of the detectable tag orientation.



(a) (b) (c)

Fig. 8. Union tag range. (a) Notation of a union tag. (b) Prototype of a union tag. (c) Antenna direction capable of detecting the tag unit U_{TF}.

tag in the sensing range and the reader-antenna. When Σ_A and Σ_T are the coordinate frames of the reader-antenna and the tag, the relation between Σ_A and Σ_T is given by the vector ${}^A\boldsymbol{P}_T$ in Fig. 7(a). α, β, and γ are the angles of pitch, roll, and yaw, respectively. $p(\alpha)$, $r(\beta)$, and $y(\gamma)$ are plotted as the detection rate of the tag rotating around x_T, y_T, and z_T ($i(\theta)$ is a ideal detection rate according to the rotation angle θ when the rotation of the tag is roll or yaw, based on Eq. (1)). The experimental results are plotted in Fig. 7(b). Therefore, the dipole tags are always detected without regard to pitch motion, whereas they are detected within the specific angle ranges in roll or yaw motion.

III. Proposition of 3D Tag: Union Tag

Some kinds of a 3D tag can be developed. In this paper, the 3D tag which is named a union tag is presented. The union tag is comprised of several dipole tags. They are called tag units in the sense that they are the components of the 3D tag. Configuration of the union tag and the estimation of location and orientation using this tag are described in this section.

A. Configuration of union tag

Tag units of a union tag have 1/2 λ dipole antennas. As illustrated in Fig. 8(a), the tag units are attached to the six edges of a cube and the six units are denoted by U_{TF}, U_{FL}, U_{LT}, U_{DB}, U_{BR}, and U_{RD}, respectively. The subscripts $_T$ and $_F$ of U_{TF} denote top and front. Similarly, U_{FL}, U_{LT}, U_{DB}, U_{BR},

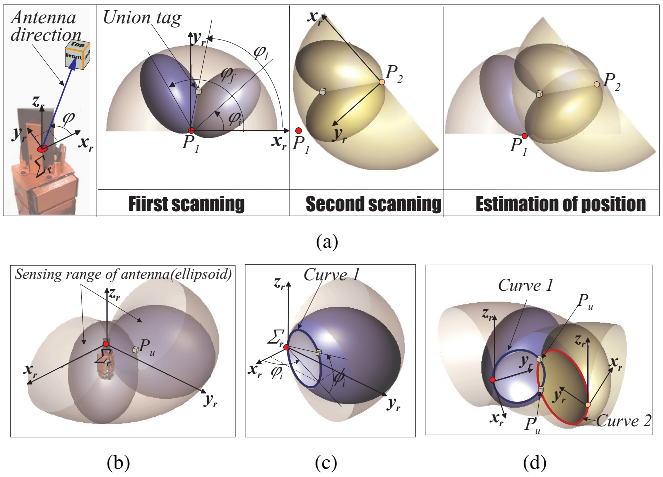


Fig. 9. Location estimation of a union tag. (a) Two dimensional approach. (b) Three dimensional approach. (c) Cross section of two ellipsoids. (d) Estimated location.

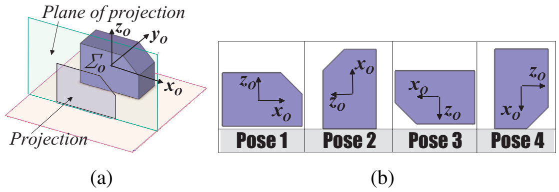


Fig. 10. Orientation relation of an object. (a) 3D view. (b) Posture of an object.

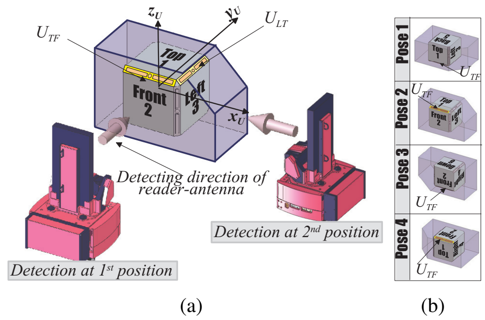


Fig. 11. Orientation estimation of an object with a built-in union tag. (a) Detection of two tag units. (b) Orientation relation of a union tag and an object.

and U_{RD} correspond to front-left, left-top, down-back, back-right, and right-down, respectively. $\boldsymbol{N}_F$ and $\boldsymbol{N}_L$ also denote the direction vectors which are normal to the faces of the front and left, respectively. Owing to the configuration and arrangement of the tag units like this, at least one tag unit of the union tag is always detected at any directions and therefore the union tag has the omnidirectional detection characteristic. For this reason, the location of the object with a built-in union tag can be estimated without regard to its orientation.

The surface of the cube is covered with aluminium plates as shown in Fig. 8(b). Since the tag units cannot be detected if they are in surface contact with the plate, there are synthetic resin blocks between the plates and the tag units. The plates shield a radio wave partially and the shielding limits the angle range for the detection of the tag unit. For example, the radiation direction of U_{TF} is shown in Fig. 8(c) because of this shielding plate. Without the plate, the radiation direction of U_{TF} is omni-directional in the $y_U z_U$-plane, as described in Fig. 5(c). This detection of U_{TF} by the reader-antenna means that the y-axis of Σ_A in Fig. 7(a) (hereinafter referred to as the antenna direction) faces the side of the top or front or both. In this case, the other tag units are not detected. In other words, the reader-antenna detects the different tag unit in accordance with the antenna direction. With this detectable tag unit, the orientation of the union tag can be estimated. Thus, the orientation of the object fitted with the union tag can be estimated because the union tag is aligned with the orientation of the object.

B. Location Estimation of Union tag

As mentioned in the section II-A, it is possible to estimate the wide scope of the position of a union tag if two RFID readers locating at different places are used. This estimation method is more effectively applied to the proposed system since the system can rotate a reader-antenna to scan objects as shown in Fig. 4. Fig. 9 shows how the proposed system works to estimate the union tag's location. As shown in Fig. 9(a), the system rotates the antenna from the right-hand to the left-hand at the first scanning position P_1. The union tag is initially detected when the direction angle of the antenna is φ_i, and the tag keeps on being detected until the angle is φ_f. Thus, the estimated position of the union tag is a single point because the intersection point of two ellipses is unique except for P_1. This estimation is reasonable only if the level of the union tag is given. For examples, since the objects with a built-in union tag such as shoes and chairs are generally located on the ground, if an RFID reader detects and identifies the object, the heights of them are determined. Thus, the object's position is estimated through the process as shown in Fig. 9(a). On the other hand, as shown in Fig. 9(b) the position P_u of the union tag in three dimensional space is on the *Curve 1* in Fig. 9(c) which is the cross section of two ellipsoids. P_u, therefore, cannot be determined by scanning at only one place even if the system can estimate the azimuth φ_1 of the union tag (where $\varphi_1 = (\varphi_i + \varphi_f)/2$). On the basis of this geometrical approach, the estimated location of the union tag is the intersection point P_u on *Curve 1* or P'_u on *Curve 2*, as shown in Fig. 9(d) if two systems scan the union tag at the different places P_1 and P_2. When using this method, the false location P'_u of the union tag is computed, in addition to P_u which is the real location of the tag. The tilting scanning procedure is also needed so that the system should choose the real location between P_u and P'_u. As the antenna of the current 3D RFID system is not equipped with a tilting sweep device, experimental results using the proposed method in section IV do not present the z coordinate estimation of the union tag but the x and y coordinates estimation of it is discussed when the z coordinate is already known.

C. Orientation Estimation of Union tag

An ordinary object has four postures per one face when the face is rotated in 90° increments as shown in Fig. 10, and there are 24 kinds of poses of the object. The classification like this is useful in that a human being frequently understands the orientation of an object with the base of 90 degree such as top, bottom, front, back, left and right. On the other hand, the orientation of the object with the built-in union tag is also divided into twenty four classes from a different standpoint. In Fig. 11(a), when the 3D RFID system detects the tag unit U_{TF} at the first scanning position, four kinds of object pose allows the U_{TF} of the union tag to be detected, as shown in Fig. 11(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 can be determined. The

TABLE I

ORIENTATION ESTIMATION OF AN OBJECT WITH A BUILT-IN UNION TAG. (A) TABLE OF ORIENTATION ESTIMATION. (B) TRANSLATION OF THE ESTIMATED ORIENTATION.

(a)

Pose	Detected tag unit		Determined pose	
	1st	2nd	1st	2nd
Pose 1	U_{TF}	U_{FL}	$\boldsymbol{N_T}$	$\boldsymbol{N_L}$
Pose 2	U_{TF}	U_{LT}	$\boldsymbol{N_F}$	$\boldsymbol{N_L}$
Pose 3	U_{TF}	U_{RD}	$\boldsymbol{N_F}$	$\boldsymbol{N_R}$
Pose 4	U_{TF}	U_{BR}	$\boldsymbol{N_T}$	$\boldsymbol{N_R}$
Pose 5	U_{FL}	U_{TF}	$\boldsymbol{N_L}$	$\boldsymbol{N_T}$
Pose 6	U_{FL}	U_{LT}	$\boldsymbol{N_F}$	$\boldsymbol{N_T}$
Pose 7	U_{FL}	U_{RD}	$\boldsymbol{N_F}$	$\boldsymbol{N_D}$
Pose 8	U_{FL}	U_{DB}	$\boldsymbol{N_L}$	$\boldsymbol{N_D}$
Pose 9	U_{LT}	U_{TF}	$\boldsymbol{N_L}$	$\boldsymbol{N_F}$
Pose 10	U_{LT}	U_{FL}	$\boldsymbol{N_T}$	$\boldsymbol{N_F}$
Pose 11	U_{LT}	U_{BR}	$\boldsymbol{N_T}$	$\boldsymbol{N_B}$
Pose 12	U_{LT}	U_{DB}	$\boldsymbol{N_L}$	$\boldsymbol{N_B}$
Pose 13	U_{RD}	U_{TF}	$\boldsymbol{N_R}$	$\boldsymbol{N_F}$
Pose 14	U_{RD}	U_{FL}	$\boldsymbol{N_D}$	$\boldsymbol{N_F}$
Pose 15	U_{RD}	U_{BR}	$\boldsymbol{N_D}$	$\boldsymbol{N_B}$
Pose 16	U_{RD}	U_{DB}	$\boldsymbol{N_R}$	$\boldsymbol{N_B}$
Pose 17	U_{BR}	U_{TF}	$\boldsymbol{N_R}$	$\boldsymbol{N_T}$
Pose 18	U_{BR}	U_{LT}	$\boldsymbol{N_B}$	$\boldsymbol{N_T}$
Pose 19	U_{BR}	U_{RD}	$\boldsymbol{N_B}$	$\boldsymbol{N_D}$
Pose 20	U_{BR}	U_{DB}	$\boldsymbol{N_R}$	$\boldsymbol{N_D}$
Pose 21	U_{DB}	U_{FL}	$\boldsymbol{N_D}$	$\boldsymbol{N_L}$
Pose 22	U_{DB}	U_{LT}	$\boldsymbol{N_B}$	$\boldsymbol{N_L}$
Pose 23	U_{DB}	U_{RD}	$\boldsymbol{N_B}$	$\boldsymbol{N_R}$
Pose 24	U_{DB}	U_{BR}	$\boldsymbol{N_D}$	$\boldsymbol{N_R}$

(b)

U_i		U_j		Determined Pose NO.	
i1	i2	j1	j2	n_i	n_j
1	2	2	3	1	3
1	2	3	1	2	3
1	2	4	6	2	4
1	2	5	4	1	4
2	3	1	2	3	1
2	3	3	1	2	1
2	3	4	6	2	6
2	3	6	5	3	6
3	1	1	2	3	2
3	1	2	3	1	2
3	1	5	4	1	5
3	1	6	5	3	5
4	6	1	2	4	2
4	6	2	3	6	2
4	6	5	4	6	5
4	6	6	5	4	5
5	4	1	2	4	1
5	4	3	1	5	1
5	4	4	6	5	6
5	4	6	5	4	6
6	5	2	3	6	3
6	5	3	1	5	3
6	5	4	6	5	4
6	5	5	4	6	4

most effective method is to detect two neighboring tag units as shown in Fig. 11(a). In this case, the RFID system reads U_{TF} and U_{LT} in order. This means that the system detects the front side denoted by $\boldsymbol{N}_F$, and then the left side by $\boldsymbol{N}_L$. The detection case like this is only one. There are a total of 24 cases to determine all pose of the union tag as shown in Table. I(a), and each case determines the orientation of the object with the built-in union tag. To generalize these cases, we define that $\boldsymbol{U}_i$ is the first detected tag unit and $\boldsymbol{U}_j$ the second, where $\boldsymbol{U}_i$=($i1$ $i2$) and $\boldsymbol{U}_j$=($j1$ $j2$). $i1$ and $i2$ or $j1$ and $j2$ mean the subscripts of the tag unit. For example, when U_{TF} is detected first, $i1$ and $i2$ mean T and F, respectively. T, F, L, R, B and D are represented by 1, 2, 3, 4, 5 and 6, respectively. Consequently, $[\boldsymbol{n}_i\ \boldsymbol{n}_j]$, which means the first and second face are detected, is shown in Table. I(b). The basic idea behind orientation estimation is quite simple; the proposed system uses the different signal responses from the individual tag units. However, this system cannot determine the orientation close to the real orientation even if theoretically possible. This is because an RFID reader is not designed to obtain continuous signal strength. Moreover, such an RFID system should operate in the environment which contains electro-magnetic noise, metal, and so on. Though such a sensor noise model can be considered for the more refine orientation estimation, only the RFID system is not equal to the estimation task. For these reasons, the proposed method provide the system with the discrete set of orientation and other sensors, if necessary, compensate the orientation. This method is the reasonable approach to estimate the orientation without regard to sensor noises so far though RFID technology shows rapid growth.

IV. EXPERIMENTAL RESULTS

The 3D RFID system is a sub-system of the module called a recognition module and the module is a part of a DRP I (*Dynamically Reconfigurable Personal robot I*) which is modularized, as shown in Fig. 12 [12]. The major function of the recognition module is to recognize an object and to judge its state. The 3D RFID system needs scanning process first to estimate the position and orientation of the object with a built-in union tag. To evaluate the performance in estimating the location and orientation of a union tag by scanning process, the authors fix

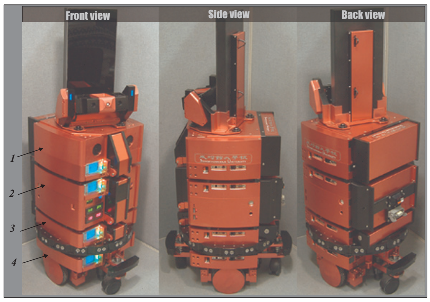


Fig. 12. Experimental system setup. 1, 2, 3, and 4 represent a recognition, an arbiter, a sensor, and a mobile module, respectively.

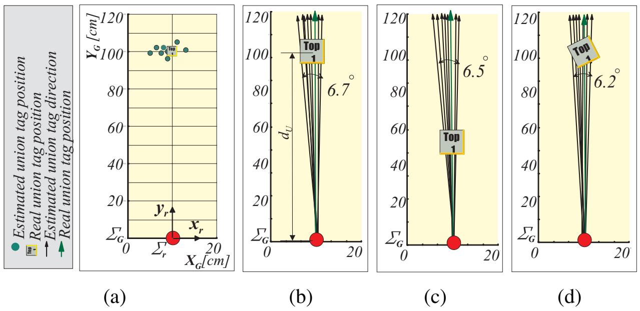


Fig. 13. Experimental results f the single scanning process. (a) Experiment 1: Position estimation error. (b) Experiment 2: Azimuth error when $\boldsymbol{d}_U$ is 1m. (c) Experiment 3: Azimuth error when $\boldsymbol{d}_U$ is 0.5m. (d) Experiment 4: Azimuth error according the tag orientation.

the union tag and the 3D RFID system on the given position and execute scanning process in the several times without location change. Fig. 13 shows experimental results in case that the angular velocity of the antenna is 90°/sec. As mentioned in section III-B, if the z coordinate of the union tag is already known, the position of the tag is estimated through a single scanning process. Fig. 13(a) depicts the results of the repeated position estimation test (experiment 1). the position of the union tag is estimated about within ±5cm from the real position when the tag is scanned at the distance 1m from the antenna. Figs. 13(b), (c), and (d) show experimental results when the tag is placed at the unknown height; in this case, the tag azimuth is estimated instead of the position of it, as mentioned in III-B. In Fig. 13(b), the azimuth error is about 6.7° when the distance d_U between the tag and the antenna is 1m (experiment 2). The azimuth error is about 6.5° when d_U is 0.5m as shown in Fig. 13(c) (experiment 3). Hence, the distance between the tag and the reader does not seems to have much effect on the azimuth estimation of the union tag only if the tag is detected by the reader. This is because the detection rate of the union tag with the same pose is not almost changed even if d_U is changed. Fig. 13(d) depicts the azimuth estimation error when tag's face is not normal to the antenna direction. In Fig. 13(d), the position estimation performance of the 3D tag is not so related to the tag's pose. The reason is found in the characteristic of the detection rate depending on the tag's pose, as shown in Fig. 14. In Fig. 14(a), the orientation of the union tag means θ_U which is the angle between the vectors N_F and the antenna direction, where N_F denotes the front side of the union tag. Fig. 14(b) depicts that the detection rate is decreased as θ_U increases. However, since the sensing range of antenna is uniform regardless of the tag's pose, even if detection rate is low, the azimuth error of the tag is similar to the experiment 2 and 3. In the previous section, the method using scanning process at the two places is presented to estimate the location and orientation of

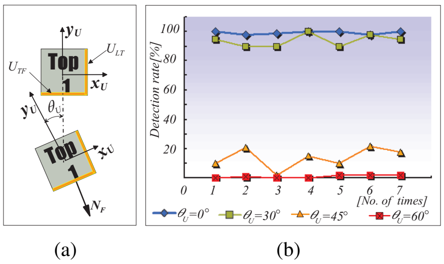


Fig. 14. Detection rate depending on the tag's pose. (a) Tag pose θ_U. (b) Detection rate at $\theta_U = 0°, 30°, 45°$, and $60°$.

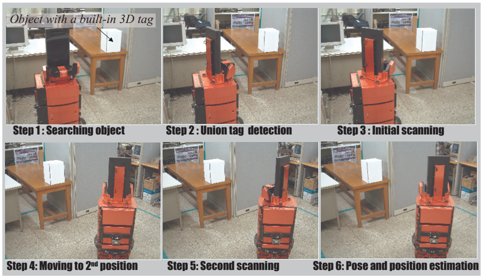


Fig. 15. Experiment of the DRP I.

the object with a built-in union tag. The proposed RFID system is the sub-system of DRP I and the scanning process at the two places is simply materialized since DRP I is a mobile robot as shown in Fig. 12. The target with a built-in union tag is an A4 box and all face color is white so six faces are indistinguishable. Thus, it is difficult for typical recognition systems such as vision to recognize the target. Fig. 15 shows the general procedure of the experiment on the basis of on the proposed method. By using only the 3D RFID system, DRP I searches and detects the target at the first and second location, and then the system estimates the location and orientation of the target. The experimental results for the position and orientation estimation of A4 box at the two position, by using this scanning process are depicted in Fig. 16. A4 box is located on the three dimensional space. The orientation and position estimation of the target is simultaneously executed. The RFID system detects the tag unit U_{BR} and U_{TF} in Fig. 16(a) at the first and second location, respectively. Several position estimation results are plotted in Fig. 16(b). Figs. 16(c) and (d) depict that the detection rates which means the detection of the U_{BR} and U_{TF} according to the scanning angle. The detection rate of U_{TF} is relatively higher than that of U_{BR} because U_{TF} is almost normal to the antenna direction. In addition, the detection period of U_{BR} is longer than that of U_{TF} because the distance between U_{TF} and the system is shorter than the distance between U_{BR} and the system. In this experiment, any other tag units such as U_{LT} are not detected when the system detects U_{BR} at the first location, and then detects U_{TF} at the second location. Therefore, the union tag's pose is easily estimated by using Table. I. The proposed system can estimate 24 kinds of poses of the object as mentioned in section III-C. For the more accurate orientation estimation of an object, other sensors compensate the preliminary orientation (this research will be presented in the next paper).

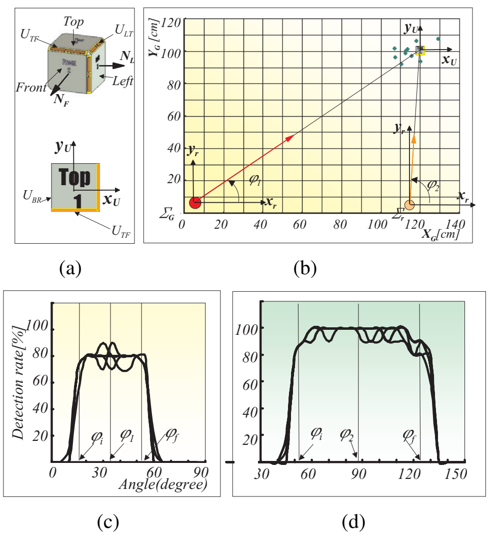


Fig. 16. Position and orientation estimation of an object with a built-in union tag in the three dimensional space (the repeated experiments at the same positions). (a) Union tag notation. (b) Position estimation. (c) Detection rate at the first scanning location. (d) Detection rate at the second scanning location.

V. Conclusions

In this paper, the authors focused on a 3D RFID system using a union tag, analyzed the characteristics of the system, and evaluated the performance of the union tag. The proposed RFID system can support not only to identify the existence of the object, but also to estimate the orientation and location of the object. Thus, the system can reduce considerably dependence on other sensors such as vision which have been typically used for recognizing objects. The current RFID technology does not consider the proposed recognition system so far. Antennas and tags are very large, and the radiation patterns of them do not suit the purpose of the system. However, the sizes and characteristics of the RFID devices are being improved. In addition, it is easy to manufacture a 3D tag since the design modification of the tag-antenna is simple. For that means, our research has the possibility of being used in practical applications though it is still under improvement.

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