An Improved Localization System with RFID Technology for a Mobile Robot

Byoung-Suk Choi*, *Student Member*, *IEEE*, Joon-Woo Lee, and Ju-Jang Lee, *Fellow*, *IEEE*
Division of Electrical Engineering
KAIST
Daejeon, Republic of Korea
E-mail: bs_choi@kaist.ac.kr*, good791@kaist.ac.kr, jjlee@ee.kaist.ac.kr

Abstract- This paper proposes an improved localization scheme for self-localization of an mobile robot by fusing RFID localization system and ultrasonic measurements. The novel localization system for an indoor mobile robot is proposed to improve the efficiency of mobile robot system. The proposed system is based on previous RFID localization system, which removes the uncertainty of robot location using the distance measurements by ultra-sonic sensors. We address more efficient localization algorithm than the previous system for the mobile robot in the given environment. 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

Localization problem is a fundamental and complex problem in the field of mobile robotics. The capability of localization is extremely important for path-planning, motion control and navigation in any given environment. Therefore, many researchers have proposed the several localization systems and 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.

Among a lots of presented technical methods, the localization scheme, which uses a distance information by ultra-sonic range sensor, has been widely used for mobile robots in indoor environments and proved to very useful, economical external sensing systems. We use this localization by the ultra-sonic measurement in order to remove the uncertainty of the previous RFID localization system based on tag-floor. 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 using the measurements of the ultra-sonic range sensor, as the last expansion of research results which are announced in the *IEEE International Conference on Industrial Informatics, INDIN 2008,* recently[17]. In this paper, we assume the same RFID system with passive tag based on tag-floor mode, which was used in [17]. In order to remove the uncertainty that appears in RFID system, we use the ultra-sonic localization method and organize combination localization system with RFID localization system together.

This paper is organized as follows. In Section II, we first formulate the problem as a search problem in previous research. In Section III, we describe the uncertainty modeling using error function for RFID system. In Section IV, volatilization scheme to estimate the each uncertainly 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. PROBLEM FORMULATION

In this section, we formulate the problems and consider how to solve the problem shown in the previous research.

As shown in [17], we assume that proposed RFID system has the same environmental-structure based on tag-floor using passive tag(fig. 1). Passive RFID tags are arranged in a fixed pattern on the floor. Absolute coordinates of the location has

978-1-4244-1766-7/08/$25.00 ©2008 IEEE

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.

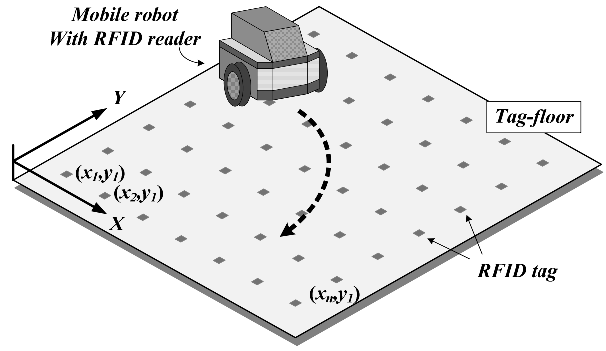


Fig. 1. Localization system based on tag-floor for an indoor mobile robot.

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 [12-16]. In the last research [17], encoder sensor system was used to compensate the limitation of RFID localization system. However, it is subject to major accumulation errors caused by wheel slippage, therefore the robot may fail to keep track of its true location over long distances.

To solve a problem, the additional localization system is required to compensate the limitation and uncertainty in RFID system. In this paper, we propose absolute-localization based on ultra-sonic range sensor system as additional system.

The ultra-sonic localization systems based on distance between the robot and environment can provide precise location, therefore they are widely used for mobile robot localization system with geometric algorithm.

III. System Modeling

A. Kinematics of Mobile Robot

The proposed scheme is developed with reference to a differential-drive mobile robot. The two wheels of the robot are independently controlled by each motor. v_L and v_R represent the velocities of the left and right wheels, respectively. The modeling and relevant variables of a mobile robot are shown in fig. 2.

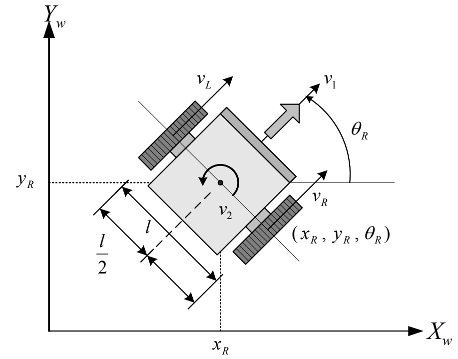


Fig. 2. Kinematics model of a mobile robot.

On the two dimensional $X-Y$ Cartesian world coordinates, position and orientation of the mobile robot is described by state vector, $\begin{bmatrix} x_R & y_R & \theta_R \end{bmatrix}^T$, as position and orientation. The kinematics model of the mobile robot can be represented as

$$\dot{P}_{robot} = \begin{bmatrix} \dot{x}_R \\ \dot{y}_R \\ \dot{\theta}_R \end{bmatrix} = \begin{bmatrix} \cos\theta_R & 0 \\ \sin\theta_R & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \tag{1}$$

where v_L and v_R represent the linear and angular velocities of the mobile robot.

In Fig. 3, when the mobile robot is moving from A where the robot is located on $P_{robot}^{k} = \begin{bmatrix} x_R & y_R & \theta_R \end{bmatrix}_k^T$ at time $= k$ to C where the position is on $P_{robot}^{k+n} = \begin{bmatrix} x_R & y_R & \theta_R \end{bmatrix}_{k+n}^T$ at time = $k + n$. The state transition of the mobile robot can be described in terms of currents state and inputs as follows [ ]:

$$x_R^{k+1} = x_R^k + T\frac{v_R + v_R}{2}\cos\theta_R^k, \tag{2-a}$$

$$y_R^{k+1} = y_R^k + T\frac{v_R + v_R}{2}\sin\theta_R^k, \tag{2-b}$$

$$\theta_R^{k+1} = \theta_R^k + T\frac{v_R - v_R}{l}. \tag{2-c}$$

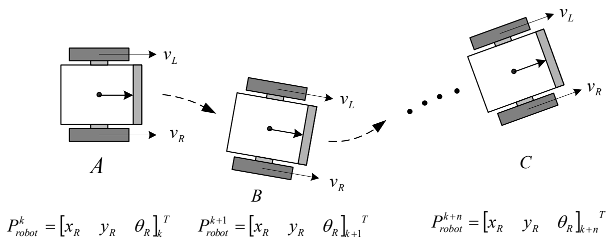


Fig. 3. Position propagation of the mobile robot.

where T is the sampling period.

Note when the position of the mobile robot is estimated, state estimation error is included, and represented as follow:

$$\hat{P}_{robot}^{k+1} = f(P_{robot}^{k}, u(k)) + \nu(k), \tag{3}$$

where $u(k)$ is the current input, $v(k)$ denotes estimation error as a noise term. The estimation error is unexpected components, when position is calculated [6].

B. Uncertainty in RFID System

As shown in fig. 4, 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. 4(a). We assume that recognition area in 2D X-Y coordinates is approximated by a circle form as shown in fig. 4(b). That is, the recognition area is expressed by equation of the circle as follows:

$$(x - x_R)^2 + (y - y_R)^2 = r_R^{\,2}. \tag{4}$$

where, x_R, y_R is center of RFID reader, i.e., the real location of mobile robot, and r_R is radius of reader's recognition area. In the passive RFID localization system, RFD 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. 5 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].

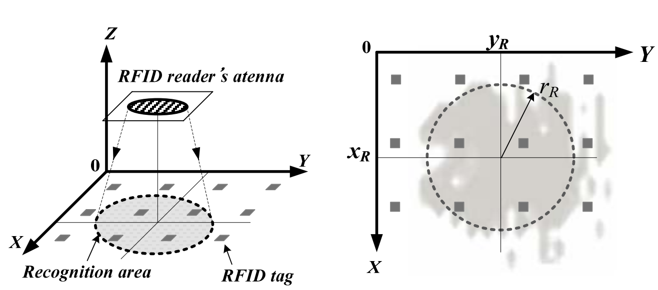
$$x_{est} = \frac{\max\{x_1, \cdots, x_N\} + \min\{x_1, \cdots, x_N\}}{2} \tag{5}$$

$$y_{est} = \frac{\max\{y_1, \cdots, y_N\} + \min\{y_1, \cdots, y_N\}}{2} \tag{6}$$

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 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 $P_E = \{x_E, y_E\}$ as shown in fig. 6. The Estimation error can be represented as follow:

$$e_{est} = |P_R - P_E| = \sqrt{(x_R - x_E)^2 + (y_R - y_E)^2}. \tag{7}$$

Note that the estimation error is determined by the gap between tags and recognition area in [10, 11].



(a) RFID sensing range model (b) RFID recognition area

Fig. 4. RFID recognition area model

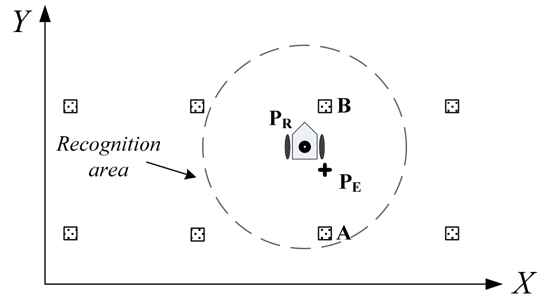


Fig. 5. Uncertainty in RFID localization system

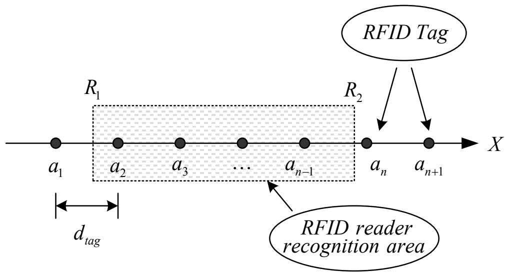


Fig. 6. Position estimation error related to the gap between tags.

$$e_{est\_x} = \left| \frac{(R_1 - a_2) + (R_2 - a_{n-1})}{2} \right| \le \frac{1}{2}\left| d_{tag} \right| \tag{8}$$

The uncertainty of RFID system can be modeled through error function.

IV. Proposed Algorithm

A. RFID localization system

In previous section, kinematics and uncertainty 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.

B. Measurement by ultra-sonic sensor

We assume that a well-structural indoor environment is composed of the combination of a plane, corner, and etc. If the distance between the robot and object in environment can be measured, distance measurement vector for component of environment can be described as shown in fig. 7. In case that distance between the mobile robot and surrounding object by ultra-sonic sensor, note that we cannot measure the precise distance data due to the direction inaccuracy of the sensor and reflection sensitiveness, which is caused by large angle between beam of sensor and surface of object. Therefore, this paper assumes the vector to be vertical at the tangent of the obstacle, which has direction to the center of a mobile robot. And we can obtain the accurate distance data within 30 degree.

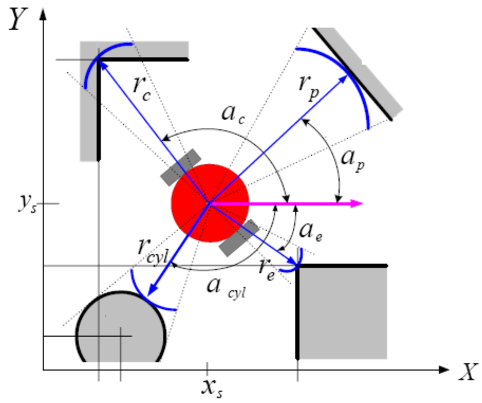


Fig. 7. Localization process using RFID and encoder system

If there are cylindrical objects, we can represent the distance as follows:

$$\mathbf{C} = \mathbf{L}_{\min}. \quad (9)$$

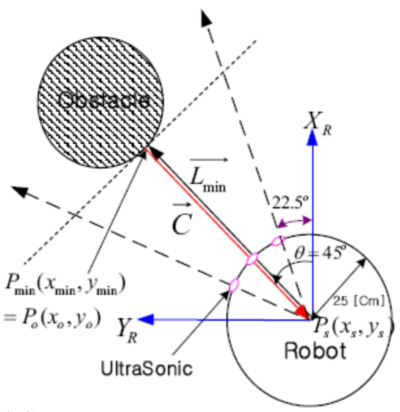
If the distance data is measured by 2 sensors, we define smaller data as $\mathbf{L}_{\min}$ and the other is defined as $\mathbf{L}_L$, or $\mathbf{L}_R$.

$$\begin{bmatrix} P_L \\ P_R \end{bmatrix} = \begin{bmatrix} (x_L, y_L) \\ (x_R, y_R) \end{bmatrix} = \begin{bmatrix} (d_R \cos\theta_R, d_R \sin\theta_R) \\ (d_R \cos\theta_R, d_R \sin\theta_R) \end{bmatrix} \quad (10)$$

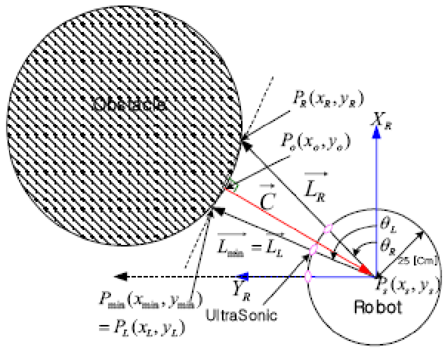
$$P_o = \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} = \begin{bmatrix} \dfrac{V(x_L - y_L)}{V + (1/V)} \\ \dfrac{-x_L + (1/V) y_L)}{V + (1/V)} \end{bmatrix} \quad (11)$$

$$\mathbf{C} = \mathbf{P}_o \mathbf{P}_S \quad (12)$$

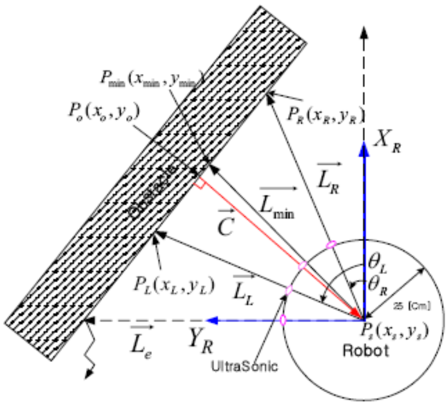
In the case of the distance data by 3 sensors, we define the smallest data as the $\mathbf{L}_{\min}$ and $\mathbf{L}_L$ and $\mathbf{L}_R$ are relatively defined by the their location. Data value is taken using from (10) to (12).



(a) Case I.



(a) Case II



(a) Case III

Fig. 8. Distance between mobile robot and object by ultra-sonic sensors.

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 verify 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 I
SIMULATION PARAMETER

Parameter list	Value
Gap between tags	0.3m
Recognition area	0.44 m
Number of total tags	101

The initial position and goal position of the mobile robot were set as (0.25, 1, 0°) and (0.3, 0.75, -90°), respectively. Fig. 9 shows the path of the mobile robot.

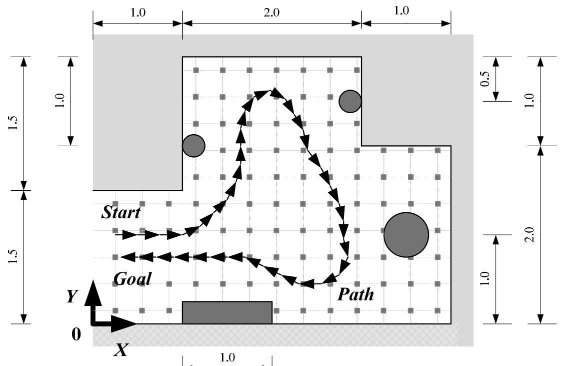


Fig. 9. The path of mobile robot in Simulation

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 ultra-sonic sensor. The experiments results show that estimation error of robot position decreases when the proposed algorithm is applied as shown in fig. 10.

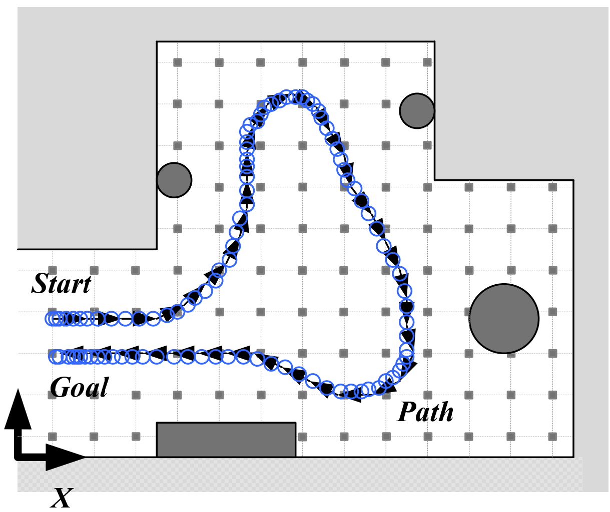


Fig. 10. The experiment result of estimation error of robot position

VI. Conclusion

In this paper, we have presented a new localization scheme based on the RFID system and ultra-sonic sensor for localization of mobile robot in indoor well-structural environment. This allows a mobile robot to reduce the estimation error. 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. For future work, we will address two possible improvements. First, we can apply the results to the real mobile robot. The second, we can reduce the number of RFID passive tag without increasing of estimation error. Also, we 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.

Acknowledgment

Authors are gratefully acknowledging the financial support by Agency for Defence Development and by UTRC(Unmanned Technology Research Center), Korea Advanced Institute of Science and Technology.

References

[1] Johann Borenstein, "Internal Correction of Dead-reckoning Errors With the Smart Encoder Trailer," *in Proc. IEEE/RSJ/GI Int. Conf. Intelligent Robots and Systems*, Vol. 1, pp. 127-134, Sept. 1994.

[2] Kiyoshi KOMORIYA and Eiinei OYAMA, "Position Estimation of a Mobile Robot Using Optical Fiber Gyroscope (OFG)," *in Proc. IEEE/RSJ/GI Int. Conf. Intelligent Robots and Systems*, Vol. 1, pp. 143-149, Sept. 1994.

[3] Dongheui Lee, and Woojin Chung, "Discrete-Status-Based Localization for Indoor Service Robots," *IEEE trans. Industrial Electronics*, vol. 53, no. 5, pp. 1737-1746, Oct. 2006.

[4] Ohno, K.., Tsubouchi, T., Shigematsu, B., Maeyama, S., Yuta, S, "Outdoor navigation of a mobile robot between buildings based on DGPS and odometry data fusion," Proc. IEEE Int. Conf. on Robotics and Automation, pp. 1978-1984, Sept. 2003.

[5] Sebastian Thrun, Wolfram Burgard, and Dieter Fox, Probabilistic Robotics, , *the MIT Press*, 2005. pp.191-199.

[6] Klaus Finkenzeller, RFID Handbook Fundamentals and Applications in Contactless Smart Cards and Identification, Wiley, 2003.

[7] Kentaro Yamanoi, Kanji Tanaka, Mitsuru Hirayma, Eiji Kondo, Yoshihiko Kimuro, Michito Matsumototi, "Self-localization of Mobile Robots with RFID System by using Support Vector Machine," in *Proc. Int. Conf. Intelligent Robots and Systems*, Sep., 2004, pp. 3758-3761.

[8] D. Hahnel, W. Burgard, D. Fox, K. Fishkin, and M. Philipose, "Mapping and localization with RFID technology," *in Proc. IEEE Int. Conf. Robotics and Automation,* vol. 1, pp. 1015-1020, 2004.

[9] Yu Zhou, Wenfei Liu, and Peisen Huang, "Laser-activated RFID-based Indoor Localization System for Mobile Robots," in *Proc. Int. Conf. Robotics and Automation*, April 2007, pp.4600 – 4605.

[10] Byoung Suk Choi, Jae Mu Yun and Jang Myung Lee, "An Efficient Localization Scheme for an Indoor Mobile Robot", *in Proc. Int. Conf. SICE*, 2005.

[11] HyungSoo Lim, ByoungSuk Choi, and JangMyung Lee, "An Efficient Localization Algorithm for Mobile Robots based on RFID System," *in Proc. Int. Joint Conf. SICE-ICCAS*, Oct. 2006 pp. 5945 - 5950

[12] Jae-il Choe, Jung-wook Choi, Dong-ik Oh, and Seung-Woo Kim, "A Study on the Implementation of RFID-Based Autonomous Navigation System for Robotic Cellular Phone (RCP)" *J. of Control, Automation, and Systems Engineering,* Vol. 12, No. 5, 2006.

[13] Jung-Wook Choi, Dong-Ik Oh, and Seung-Woo Kim, "A Study on the RFID Tag-Floor Based Navigation", *J. of Control, Automation, and Systems Engineering,* Vol. 12, No. 10, 2006.

[14] ByoungSuk Choi and JangMyung Lee, "An Efficient Localization of Mobile Robot in RFID Sensor Space," J. of Control, Automation, and Systems Engineering Vol. 12, No. 1, 2006.

[15] Dae-Sung Seo, Ho-Gil Lee, Hong-Suck Kim, Gwang-Woong Yang, and Dae-Hee Won, "Monte Carlo Localization for Mobile Robots Under RFID Tag Infrastructures," *J. of Control, Automation, and Systems Engineering,* Vol. 12, No. 1, 2006.

[16] K. Komoriya, E. Oyama, and K. Tani, "Planning of landmark measurement for the navigation of a mobile robot," *in Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems*, July 1992.

[17] Byoung-Suk Choi, Joon-woo Lee and Ju-Jang Lee, "Localization and Map-building of Mobile Robot Based on RFID Sensor Fusion System," *in Proc. IEEE International Conference on Industrial Informatics (INDIN 2008)*, Daejeon, Korea, Jul. 2008, pp. 412-417.