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A Study on 3D RTLS at Port Container Yards Using the Extended Kalman Filter

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Abstract

The main purpose of this paper is to manage the container property effectively at the container yard by applying the RTLS technology to the field of port logistics. Yet, many kinds of noises happen to be inputted with the distance value (between the reader and the tag) which is to be inputted into the location identification algorithm, which makes the distance value jumped due to the system noise of the ultrasonic sensor module and the measurement noise. The Kalman Filter is widely used to prevent this jump occurrence; the noises are eliminated by using the EKF(Extended Kalman Filter) while considering that the distance information of the ultrasonic sensor is non-linear. Also, the 3D RTLS system at the port container yard suggested in this research is designed not to be interrupted for its ultrasonic transmission by positioning the antenna at the front of each sector of the container where the active tags are installed. We positioned the readers, which function as antennas for location identification, to four places randomly in the absolute coordinate and let the positions of the active tags identified by using the distance data delivered from the active tags. For the location identification algorithm used in this paper, the triangulation measurement that is most used in general is applied and newly reorganized to calculate the position of the container.

In the first experiment, we dealt with the error resulting in the angle and the distance of the ultrasonic sensor module, which is the most important in the hardware performance; in the second, we evaluated the performance of the location identification algorithm, which is the most important in the software performance, and tested the noise cancellation effects for the EKF. According to the experiment result, the ultrasonic sensor showed an average of 3 to 5cm error up to 45° in case of 60°or more, non-reliable linear distances were obtained. In addition, the evaluation of the algorithm performance showed an average of 4°~5° error due to the error of the linear distance – this error is negligible for most container location identifications. Lastly, the experiment results of noise cancellation and jump preservation by using the EKF showed that noises were removed in the distance information which was entered from the input of the ultrasonic sensor and as a result, only signal was extracted; thus, jumps were able to be removed and the exact distance information between the ultrasonic sensors could be obtained.

Key words : RFID, RTLS, Ubiquitous, Extended Kalman Filter

1. Introduction

RFID means the technology identifying the data of an object by attaching an electric tag to the object, recognizing its peculiar ID by means of radio waves and collecting the related data.

RTLS (Real Time Locating System) technology [1][2] that identifies the real-time location of an object to which an active tag is attached has been newly highlighted as a newly originated technology from this RFID field. In other words, the RTLS allows the location or the status of a tag attached to a person or an object to be identified. The RFID technology-related standardization has been performed by SC31 of ISO/IEC JTC1 as of April 2005, it consists of 5 working groups.

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The RFID technology-related standardization has been performed by SC31 of ISO/IEC JTC1 as of April 2005, it consists of 5 working groups. In 2004, WG5 was installed for the RTLS standardization. It is known that RFID technology is available at the frequency of 125KHz, 135KHz, 13.56MHz, 433MHz, 860 ~ 960MHz, 2.45GHz or 5.8GHz among them, RTLS is available at 2.45GHz bandwidth. The RTLS standardization for 2.45GHz air interface, API, GLS and near-field has been progressed by WG5; among them, the standard drafts of 2.45GHz air interface and API are completed. However, the NFER (Near Field Electromagnetic Ranging) RTLS using low-frequency electromagnetic fields to identify or track an object in the near-field region and the GLS (Geo Locating System) using the satellite L-band have not been discussed at all

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for the standardization and no leading company exists for the job.

So far, one of the representative development cases of RTLS is the RTLS(2.45GHz) manufactured by NextID[5]; however, it is hard to apply this product to the port because the locations of its active tags cannot be exactly identified when there are many obstacles (container loads) during the wave transmission or reception. Therefore, it is demanded to design the RTLS system and to study the location identification algorithm [6][7] practically applicable to the port. In this paper, we will provide the paper results about the 3D RTLS design at the port container terminal device. First of all, we positioned the antennas at the front of the container in order to prevent any obstacles which had been the problem in the wave transmission or reception, and we interpreted the triangulation measurement[8] mathematically again and recomposed it for the location identification algorithm.

Also, we used the EKF[9]~[11] in order to remove instant location jumps, system noise and measurement noise of the ultrasonic sensor module used in this paper.

This paper consists of: Chapter 1. Introduction; Chapter 2. Background of paper; in Chapter 3. we will describe the EKF used in this paper; in Chapter 4. we will mention the port logistics-purpose RTLS to be suggested in this paper; in Chapter 5. the performance experiment and design considerations will be described; and last, in Chapter 6. we will provide the conclusions.

2. Background

2-1. Standardization trend of RTLS

RTLS means the technology monitoring the location of an object in real time by attaching the RFID (active) tag(s) to the object and analyzing the data of the object by means of the tag. Although only detailed contents can be obtained by means of the existing RFID tag data, the location information as well as the object data can be obtained. Currently, the RTLS is called the regional GPS, which means that it gives the location information of the objects within a limited region only. The hardware structure of the RTLS is shown in Figure 1.

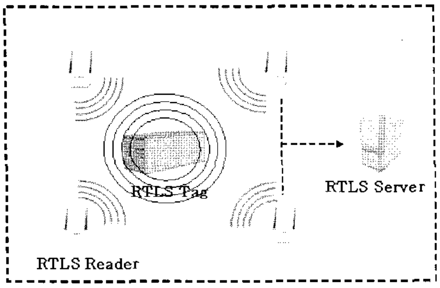


Fig 1. Hardware structure of RTLS

The RTLS reader can receive signals from the RTLS transmitter; the RTLS transmitter is an active radio transmitter and is attached to an object. The RTLS transmitter sends a message to the RTLS reader and provides the information of the transmitter by sending the unique ID. Last, the RTLS server collects the data coming from the RTLS reader and receives the data on the location and the status of the RTLS transmitter. The RTLS standards are established by ISO/IEC 24730 and ANSI/INCITS 371. ISO/IEC 24730 document is largely classified into 24730-1, 24730-2 and 24730-3 first, the API between the RTLS server and the client server is defined in ISO/IEC 24730-1, and communication with the server is made by means of SOAP (Simple Object Access Protocol) 1.1communication protocol. Next, the radio interface protocol between the 2.4GHz or 433MHz tag and the reader is defined in ISO/IEC 24730-2 and ISO/IEC 24730-3.

2-2. Location identification technology trend

The location identification method is classified into time by the radio wave velocity, radio wave strength, radio wave angle, proximity measurement using infrared light or pressure sensor, or scene analysis, depending on the application program. Most measurement technologies use one method, but more than two methods can be mixed for better efficiency. Measuring the radio wave time can be subdivided into ToA(Time of Arrival) and TDoA(Time Difference of Arrival), and the technology measuring the radio wave strength is called RSSI (Received Signal Strength Indicator) in general. In addition, the method measuring the location by measuring the radio wave angle is called AoA(Angle of Arrival) in general. Besides the radio wave used in GPS or mobile communication systems, infrared light or pressure sensor, or image- based scene analysis method is available, as described before, in the wireless sensor network. Figure 2 shows the classified location identification technologies and every developed typical system. The system using the time by the radio wave velocity includes Cricket and Active Bat; the system using the radio wave strength includes RADAR and 3D-iD. The location identification system using the scene analysis was developed in Easy Living project. Ad-hoc Network uses the radio wave strength at reference nodes, and its systems are Centroid, APIT and DV-Hop. In the RTLS, the radio wave time (TDoA) is mainly used to measure the location in real time; in this paper, we used this TDoA method to apply the location identification algorithm, for which the triangulation measurement is most used. More detailed content will be described in following Section 2-3.

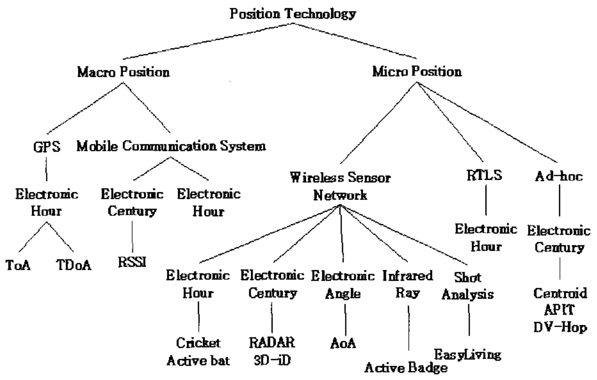
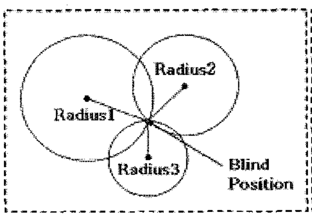


Fig 2. Classification of location identification technologies

2-3. Triangulation measurement method

The triangulation measurement method is classified into lateration using distances, as shown in Figure 3, and angulation using angles, as shown in Figure 4. In case of lateration, the location of an object can be obtained by measuring each distance between the object and the three reference points of which locations are already known and then finding the point where the three circles intersect of which radii are the distances from the three points. In this method, measuring the distance from the three reference points is very essential. Various methods are available to calculate this distance such as directly measuring the distance, using the flight time of radio waves, using the time difference of radio wave arrival using ultrasonic waves and using the radio wave strength. In case of AoA(Angle of Arrival) method using the angles to find the location, if the angels among more than two reference points and the object are known, its location can be obtained by means of the linear intersection at that angle. To use this method, the directional antenna must be installed to calculate the direction of radio waves.



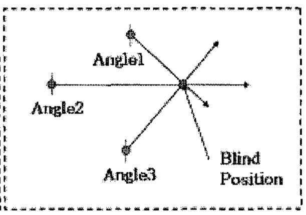


Fig 3. Triangulation measurement using distances (Left fig.)
Fig 4. Triangulation measurement using angles (Right fig.)

3. EKF Algorithm

The EKF applies the Kalman filter to the non-linear system, which gives high performance under non-linear conditions and can be successfully applied. In order to apply it to the non-linearity, it is necessary to modify the formulas that are applicable to the linearity. First of all, the system can be shown in the non-linear difference equation as shown in Equation (1).

$$x_k = f(x_{k-1}, u_{k-1}, w_{k-1}) \\ y_k = c(x_k, v_k) \tag{1}$$

w_k and v_k are the system noise and the measurement noise respectively, and the non-linear function f shows the relation between the previous time phrase k-1 and the current time phrase k. The non-linear function c shows the relation between the state x_k and the measurement y_k. Actually, because we do not know the individual values of w_k and v_k, we can approximate them as Equation (2). Here, $\tilde{x}_k$ is the future measurement obtained from the previous time phrase k.

$$\tilde{x}_k = f(\hat{x}_{k-1}, u_{k-1}, 0) \\ \tilde{y}_k = c(\tilde{x}_k, 0) \tag{2}$$

If the above non-linear difference equation and the measurement equation are linearized and modified again, it can be expressed as Equation (3). In Equation (3), x_k and y_k are the real state and the measurement vector respectively; $\tilde{x}_k$ and $\tilde{y}_k$ are the proximity state and the measurement vector respectively; $\tilde{x}_k$ is the future measurement at the phrase k; the random variables w_k and v_k express the system noise and the measurement noise respectively.

$$x_k \approx \tilde{x}_k + A(x_{k-1} - \hat{x}_{k-1}) + Ww_{k-1} \\ y_k \approx \tilde{z}_k + C(x_k - \tilde{x}_k) + Vv_k \tag{3}$$

A is Jacobian matrix of the partial integration of f for x and is shown in Equation (4). W is Jacobian matrix of the partial integration of f for w and is shown in Equation (5). C is Jacobian matrix of the partial integration of c for x and is shown in Equation (6). V is Jacobian matrix of the partial integration of c for v and is shown in Equation (7).

$$A_{[i,j]} = \frac{\partial f[i]}{\partial x[j]}(\hat{x}_{k-1}, u_{k-1}, 0) \tag{4}$$

$$W_{[i,j]} = \frac{\partial f[i]}{\partial w[j]}(\hat{x}_{k-1}, u_{k-1}, 0) \tag{5}$$

$$C_{[i,j]} = \frac{\partial c[i]}{\partial x[j]}(\tilde{x}_k, 0) \tag{6}$$

$$V_{[i,j]} = \frac{\partial c[i]}{\partial v[j]}(\tilde{x}_k, 0) \tag{7}$$

If the estimation error is arranged in other expressions, it can be Equation (8) and (9).

$$\tilde{e}_{x_k} \equiv x_k - \tilde{x}_k \tag{8}$$

$$\tilde{e}_{y_k} \equiv y_k - \tilde{y}_k \tag{9}$$

Using the error system, it can be expressed as Equation (10).

$$\tilde{e}_{x_k} \approx A(x_{k-1} - \hat{x}_{k-1}) + \epsilon_k \\ \tilde{e}_{x_k} \approx C\tilde{e}_{x_k} + \eta_k \tag{10}$$

Here, ε_k and η_k are new independent random variables and zero mean; the covariance matrices are WQW^T and VRV^T respectively. The above expression is similar to the discrete Kalman filter; if the above two errors are combined and new $\tilde{e}_k$ is used to apply it to the non-linear system, it can be expressed as Equation (11).

The above random variables and Equation (12) have similar probability distribution. If they are approximated and the estimated value $\tilde{e}_k$ is 0, the Kalman filter equation for assuming $\tilde{e}_k$ will be Equation (13). Using the above equation, Equation (14) can be obtained.

$$\tilde{x}_k = \tilde{x}_k + \tilde{e}_k \quad (11)$$

$$\begin{aligned} P(\tilde{e}_{x_k}) &\sim N(0, E[\tilde{e}_{x_k}, \tilde{e}_{x_k}^T]) \\ P(\epsilon_k) &\sim N(0, WQ_k W^T) \\ P(\eta_k) &\sim N(0, VR_k V^T) \end{aligned} \quad (12)$$

$$\tilde{e}_k = K_k \tilde{e}_{z_k} \quad (13)$$

$$\tilde{x}_k = \tilde{x}_k + K_k \tilde{e}_{z_k} = \tilde{x}_k + K_k(z_k - \tilde{z}_k) \quad (14)$$

The execution of the EKF described so far can be diagramed in Figure 5.

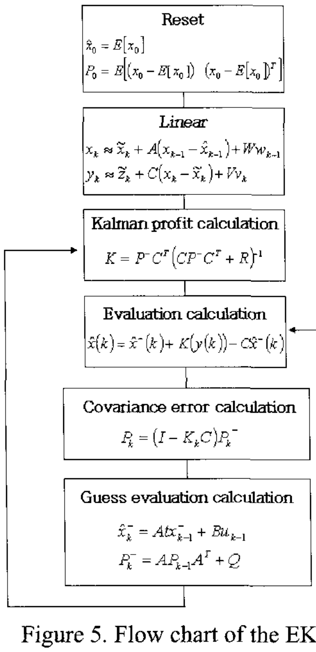


Figure 5. Flow chart of the EKF

4. Proposed port logistics-purpose RTLS

4-1. Design of the port logistics-purpose RTLS

Since containers are made of steel, which generally reflects radio waves, it is very important to select the proper positions at which the ultrasonic transmitters/receivers are installed, to minimize the reflection. In this research, we proposed to position the readers at the front of the containers, as shown in Figure 6, for the RTLS port so that radio waves can be transmitted/received properly between the readers and the tags, without obstacles. The enlargement of a part of Figure 6 is Figure 7; the radio wave transmitters are attached at the front of the container in order to deliver the data on the distance between the container and the antenna; four fixed radio wave receivers are attached to the antenna position in order to receive the Euclidean distance value sent by the radio wave transmitter. We produced a simulated port model based on the above description, as shown in Figure 8.

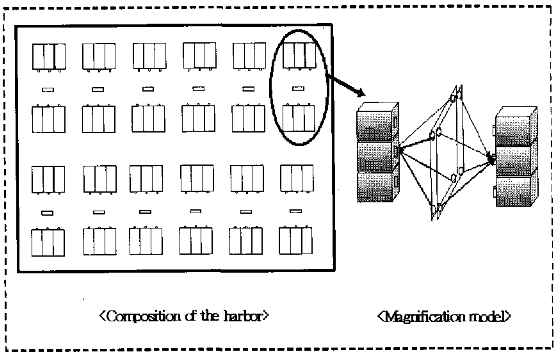


Figure 6 Arrangement plan of active tags and readers at the container terminal yard

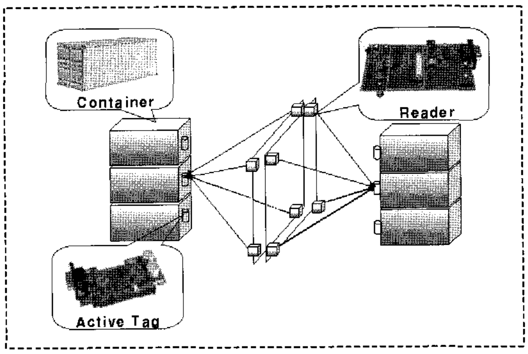


Figure 7. Device configuration

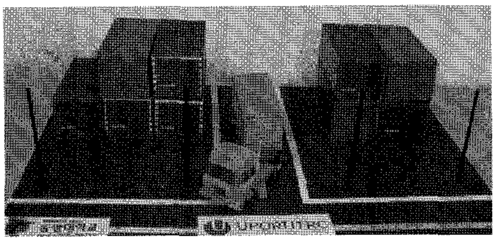


Figure 8. Design of the RTLS model

4-2. Location identification algorithm

The location identification algorithm using the radio wave uses four fixed readers as shown in Figure 9. If those four readers are place on the same x axis, no inverse function can exist, and accordingly the location of the active tags cannot be computed. Therefore, we moved one reader to x axis and fixed the absolute coordinate of every reader. The distance can be expressed as Equation (15) to (18) by means of the triangulation measurement.

$$\begin{aligned} (x-x_1)^2+y^2+z^2&=d_1^2 \\ x^2+(y-y_2)^2+z^2&=d_2^2 \\ x^2+y^2+(z-z_3)^2&=d_3^2 \\ x^2+(y-y_2)^2+(z-z_3)^2&=d_4^2 \end{aligned} \qquad (15)\sim(18)$$

Once eliminating x-, y- and z-second orders of the above equation and expressing it as a matrix, it can be Equation (19). The central server computes the location of the active tags by means of Equation (19) and saves it.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} -\frac{1}{x_1} & \frac{1}{x_1} & 0 \\ 0 & \frac{1}{y_2} & 0 \\ 0 & 0 & \frac{1}{z_3} \end{bmatrix} \begin{bmatrix} \frac{1}{2}(d_1^2-d_2^2+y_2^2-x_1^2) \\ \frac{1}{2}(d_3^2-d_4^2+y_2^2) \\ \frac{1}{2}(d_2^2-d_4^2+z_3^2) \end{bmatrix} \qquad (19)$$

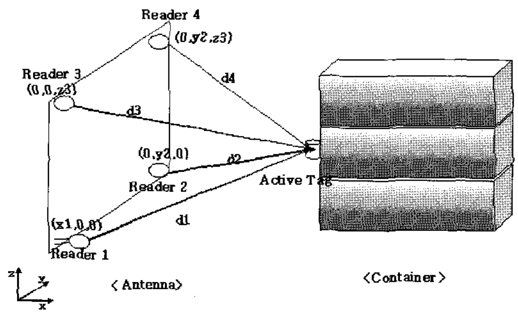


Figure 9. Location identification system

4-3. Flow chart of the suggested RTLS S/W

Figure 10 shows the sequence of the location identification algorithm of the RTLS software, which uses the location identification algorithm and the EKF described in the previous section. The signals d1', d2', d3', d4' inputted from the four receivers are modified into d1, d2, d3, d4 by means of elimination of noises with the EKF, and then the location of the transmitter tag is computed by the location identification algorithm. Then, the location data is sent to the RTLS server.

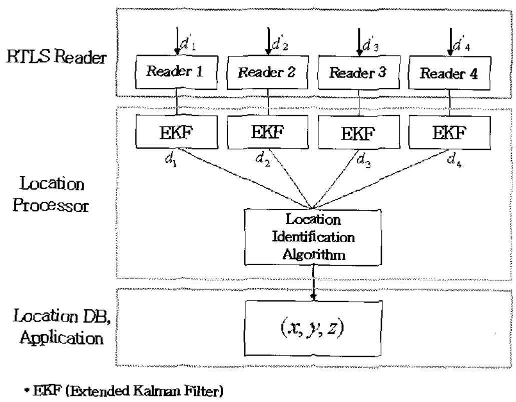


Figure 10. Sequence of the suggested RTLS S/W

5. RTLS design with the performance experiment

We applied Cricket system developed by MIT in 2000 as the ultrasonic sensor module used in this research, and it consists of the ultrasonic receiver, the ultrasonic transmitter and the download board. The hardware of the ultrasonic receiver and that of the ultrasonic transmitter are same type, but different software is installed with the real-time OS (TinyOS). In Section 5-1, we tested the actual distance and the measurement distance by angles for the performance test of the ultrasonic sensor module selected in this research; in Section 5-2 and 5-3, we performed and compared the performance test of the location identification algorithm and that of the EKF.

5-1. Experiment of the actual distance and the measurement distance by angles

In order to understand the accuracy performance of the measurement distance by the angle of the ultrasonic module and the actual distance, we varied the distance and the angle to test the accuracy performance. Figure 11 shows the measurement results at the angle of 0° to 90° on the same plane and the distance of 50cm to 2000cm. it is noticeable that an average of 3 to 5cm error is shown at the angle of 45° or less while unreliable linear distances are obtained at the angle of 60° or more. Based on this test result, the angle between the reader and the active tag can be computed.

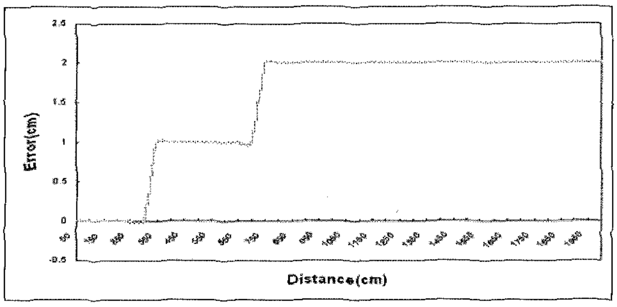


Fig 11-1. 0°

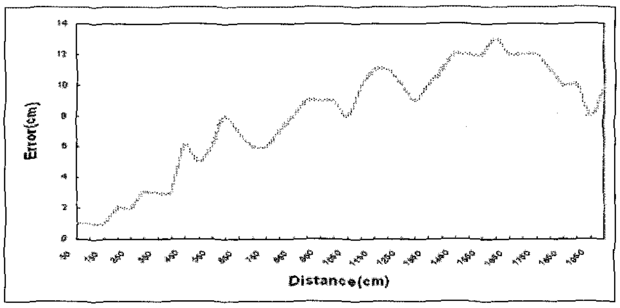


Fig 11-2. 30°

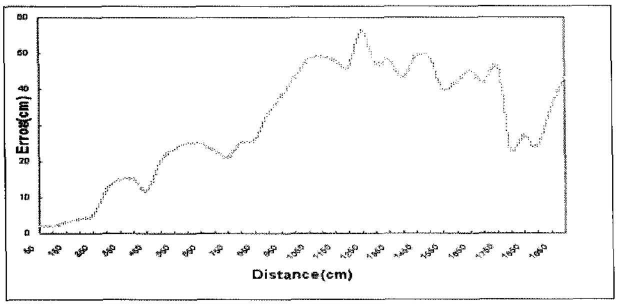


Fig 11-3. 60°

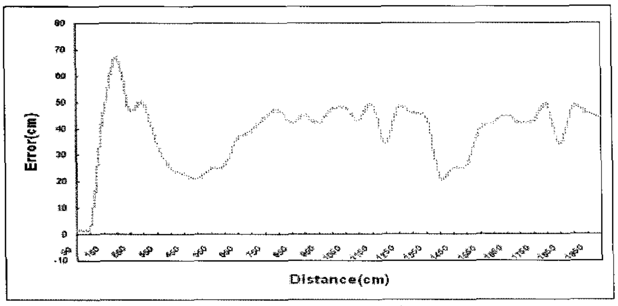


Fig 11-4. above 60°

Figure 11. Distance error of the active tag in the experiment

5-2 Performance experiment of the location identification algorithm

This experiment verifies the accuracy of the location of the active tag through the signals inputted from the four receivers, by means of the ultrasonic location identification algorithm suggested in Section 4, and its results are shown in Figure 12. According to the experiment result, an average of 4 to 5° is shown due to the error of the linear distance, and this error is negligible compared to the container location.

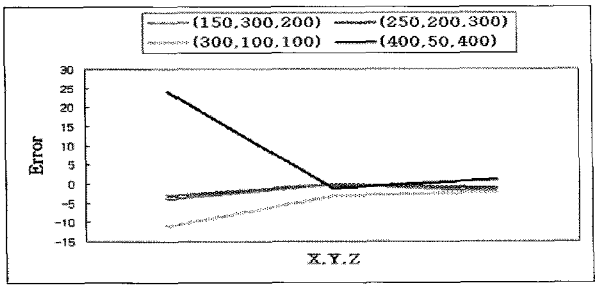


Figure 12. Error of the active tag by the fixed reader

5-3. Distance measurement result by means of the EKF

Figure 13 shows the result of the elimination of jump occurrences of the sensor module, by means of the EKF. Without the Kalman filter, jump occurrences reached about 45%; after passing the EKF to reduce jumps, many noises were cleared, giving less error and reducing jumps as low as about 5%.

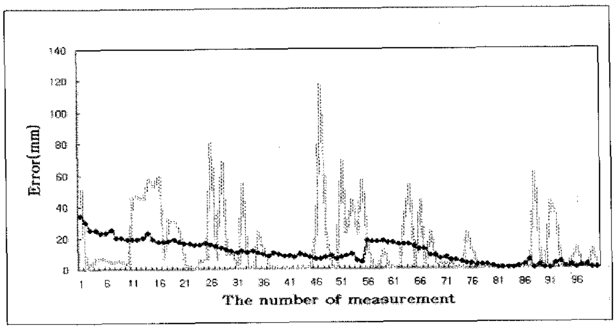


Figure 13. Error – Kalman filter is applied

Figure 14 shows the mean squared error of x, y and z location values.

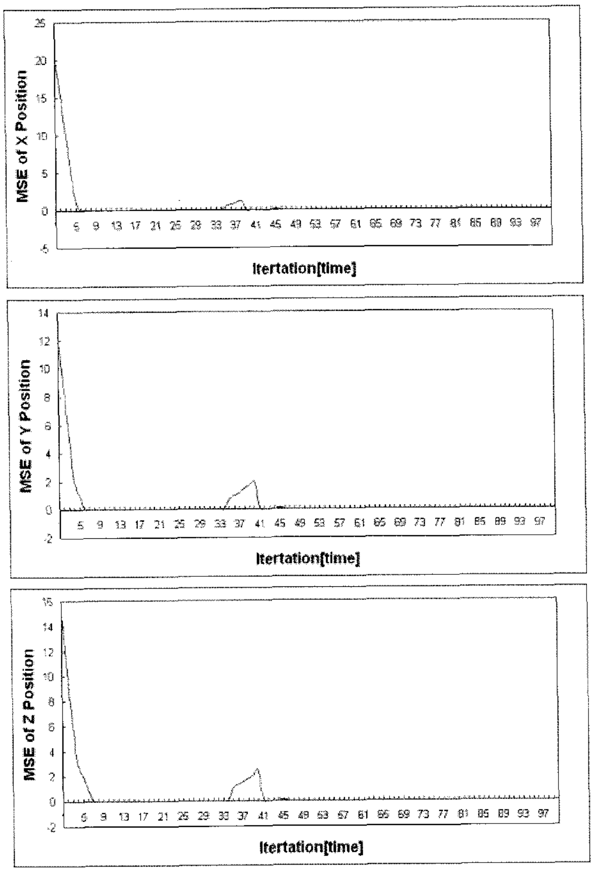


Figure 14. Mean Squared Error

5-4. Design by the experimental result

According to the experimental results shown in Figure 11 to 14, following conditions should be met in order to find the reliable container location.

First of all, as far as the structural aspect is concerned, the direction of the ultrasonic sensor antenna of the reader should be 0° to 45° and it should be designed to receive ultrasonic signals while facing the active tags. In addition, the ultrasonic sensor of the active tag should be designed in Omni antenna type so that all readers within its sector can receive the signals accurately, and the ultrasonic sensor of the reader should have a directional antennal of which best beam width is 0° to 45°. Considering this, because the structure of the receiver support should include all of the active tags in the sector, it should be designed as shown in Figure 15. In addition, the ultrasonic sensor used in this research can measure distances up to 20m, which is not proper for the actual port situation. In order to apply it to the actual situation, its receiving range should be extended up to 50m; thus, we need high-power ultrasonic sensor for this.

Next, in aspect of software operation, because the reader receives not only clean signals but also various noises including system noise, signal jumps and measurement noise, and we will get very unstable location data if we proceed the location identification algorithm with this information, we have to use a noise reduction algorithm such as EKF.

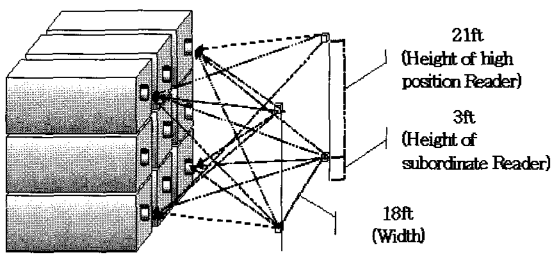


Figure15. The structure of the receiver support in case of 3x3 container yard (1 sector)

6. Conclusion

This research attempted to design the 3D RTLS having no obstacles in sending ultrasonic waves; thus, we suggested the location identification algorithm by applying the triangulation measurement and then reduced noises by using the EKF. With these, we proved that the location of the active tag can be computed through the performance test of the ultrasonic module needed. According to the experiment result, the linear distance between the active tag and the reader could be computed accurately based on the angle and distance of the ultrasonic wave when the angle was 45° or less. Moreover, we reduced the system noise and the measurement noise by using the EKF and reduced jump occurrences to 5%, consequently proving better performance through the simulations. Based on the experiment results, we suggested the angle of the reader to compute the location of the active tag accurately, and also suggested the design of the structure of the receiver support. Therefore, it is considered that the location identification system that can manage container properties effectively can be developed.

For future researches, the design suggested in the above has to be produced and installed at the actual port and its performance test must be conducted; various reasons of any location error may occur must be studied, and the location computation algorithm at the server application program must be improved. Finally, the system with the consideration of energy efficiency also must be studied.

References

[1] Kim H., "A Speed-Adaptive Location Estimator for Wireless LAN-based RTLS System." *IEEE Asia-Pacific Conference on Communications*, 2006.

[2] Tim, H., "Open RTLS Standards." Auto-ID showcase, 2004.

[3] http://www.iso.org/iso/en/ISOOnline.frontpage

[4] http://www.ansi.org

[5] http://www.nextid.co.kr

[6] Jeffrey Hightower and Gaetano Borriello, "Location System for Ubiquitous Computing," *IEEE Computer*, vol. 34, no. 8, pp. 57-66, 2001.

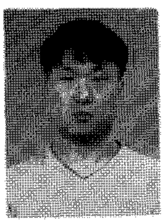
[7] Han-Soo Kim, "Study on range expansion of ultrasonic local positioning system", a mater's thesis of Pusan university, 2006.

[8] Doo-Il Hong, "Design and Implement of 3-Dimensional Real Time Disparity Estimator using Stereo Camera", mater's thesis of Dong-A university, 2002.

[9] Jerry M. Mendel, "*Lessons in Digital Estimation Theory*", Prentice-Hall, 1987.

[10] Juan B. Garcia-Velo, "Parameter Estimation of an Unstable Aircraft Using an Extended Kalman Filter", MS Univ. of Cincinnati, 1991.

[11] Jung-doo Lee, "Study on Tracking of a Moving Object using Extended Kalman Filter", a mater's thesis of Kumoh National Institude Technology, 2006. 2004.



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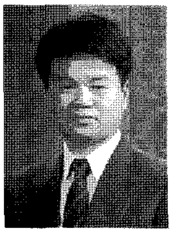

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