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Design and Implementation of Practical Asset Tracking System in Container Terminals

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A container terminal plays an important logistical role in handling transshipping containers. Therefore, location information regarding vehicles that carry containers in a port is critical to cost- and time- efficient management for harbor automation. In terms of scalability, cost, and energy efficiency, an active radio-frequency-identification (RFID) based real-time locating system (RTLS) is an appropriate technology for obtaining location information. In general, an RTLS estimates locations using the transmission time of wireless signals. Accurate distance measurement depends on not only time measurement but also guaranteed line-of-sight (LOS) communication. However, in a container terminal environment, the performance of existing system can be seriously degraded because of densely deployed obstacles, e.g., containers and vehicles. Furthermore, places that readers can be installed in a terminal are limited, and thus a sufficient number of readers cannot be installed to provide reliable communication. To overcome these problems, this paper presents a novel and practical approach to overcoming non-line-of-sight (NLOS) RF propagation problems in asset tracking systems for container terminals. In proposed system, we have considered practicable methods from unit experimentsin real world as well as theoretical methods: the system tries to reducerange estimates obtained under NLOS conditions, and estimate the tag locations using vehicles' range estimates and route information. For evaluation, the proposed method has been implemented at a real container terminal in South Korea, and experimental tests demonstrated its validity.

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1. Introduction

A container terminal serves as a gateway to extend international and intra-regional trade. In a terminal, cargo containers are held temporarily for transshipping between container ships and land vehicles. It is important to complete this task quickly and accurately since the processing time directly affects logistics costs. Therefore, transfer cranes and yard tractors that load, unload, and transport the containers must be managed efficiently and *Real-Time Locating System* (RTLS) is invaluable for this purpose.

Several technologies exist for RTLS in an outdoor environment. Although Global Positioning System (GPS)[1] has been widely used, it has inherent limitations such as cost and energy consumption. Cellular networks are widely available,[2,3] but they require high battery consumption, and their accuracy is low. RTLS based on WiMAX[4] offers long range and low latency, but it also suffers from high power consumption and low accuracy. Wi-Fi RTLS products[5,6] enjoy several advantages, such as low cost and multi-purpose networking, but they are susceptible to interference problems. In contrast, active *Radio-Frequency Identification*- (RFID-) based RTLSs have merits in large outdoor environments, such as a container terminal. These include energy efficiency, good communication range and accuracy, and coexistence with other wireless-communication-based applications.[7-10]

However, following several issues should be considered when RF-based system is applied to a container terminal:

a) Harsh RF propagation environment: Assets (cranes and tractors) shuttle along their pre-defined routes. On their roads, they can be surrounded by many obstacles such as stacked containers or other vehicles made by steel. A locating system measures the transmission time between a RFID tag and a RFID reader and converts it to a distance. Since radio signal travels at the speed of light, precise time measurement is directly related to the accuracy of the system's position estimation. If obstacles exist between a tag and a reader, there is no line-of-sight (NLOS) and thus the signal can be reflected or scattered by surrounding objects. This causes a RFID tag to appear farther away than it actually is and degrades the system's performance.
b) Harsh environment to install RFID readers: In a typical RTLS, a tag

should communicate with three or more adjacent readers. In a container terminal, places that readers can be installed are limited, and thus a sufficient number of readers cannot be installed to provide reliable communication.

In this paper, we suggest a practical locating system that has novel approach considering those problems in a container terminal. First, we designed the system utilizing a signal filtering and candidate location estimation to mitigate NLOS problems. To overcome lack of range estimates derived from insufficient adjacent readers and NLOS filtering, we improved an estimation method of the system. In the method, a location of the object is estimated using just one or two range estimates utilizing pre-defined route information of the target as well as using more than three range estimates.

To evaluate the proposed system, we implemented all of the system components. Before deploying the proposed location system in a real-world situation,we had determined the appropriate threshold values or constants through testing in a real world. The implemented system components are installed on a real environment, and our experiments on tracking assets in a large container terminal show that the proposed location system results in highly accurate location estimation.

This paper is organized as follows: The next section discusses the characteristics of a typical port environment and existing location methods. Section 3 presents the proposed location system. The implementation and evaluation of our system are discussed in Section 4. Finally, Section 5 concludes the paper and discusses future work.

2. Background and Related Works

An active RFID-based RTLS generally consists of tags, readers, and a location engine. Tags are attached to the tracked objects and they communicate with readers installed in the environment. Unlike tags in other wireless-based systems,[11-14] each tag in this environment must communicate with three or more readers for location estimation.[7-9,15] The operation of the location engine generally consists of three phases as illustrated in Fig. 1: the Reader Discovery Phase (RDP), Measurement Phase (MP), and Location Estimation Phase (LEP).

In the RDP, a tag periodically transmits a short message to search for readers within its range, and the readers reply to the tag. Based on these replies, each tag compiles a list of nearby readers. The time between a reader and a tag is measured in the MP. The measuring method is classified either as a one-way or a two-way depending on the direction of the measurement.[16] A *one-way* method involves unidirectional measurement of communication characteristics between a tag and a reader, such as the received signal strength (RSS), time of arrival (TOA), and time difference of arrival (TDOA). The RSS method simply uses the attenuation of the received signal between a receiver and a sender. Although it is easy to implement, its accuracy is relatively low.[17] The TOA method uses the flight time between a tag and a reader.[15,20] The TDOA method uses the difference in arrival times to obtain the distance difference between readers.[18,19] The TDOA and TOA methods are relatively precise, but they both require nanosecond-level time synchronization. This imposes an additional processing and implementation overhead on the system.[21] In a *two-way* method, a tag and a reader exchange messages in order to measure the

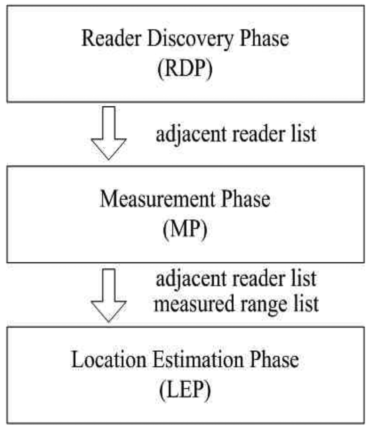


Fig. 1 The general process of the location system

round trip time (RTT). One-half of the RTT indicates the flight time of a signal, and thus the distance between the tag and the reader. Although this method requires more messages for peer-to-peer measuring than the one-way method, it is relatively precise and requires no time synchronization.[22,23] The tag then sends the list of measured distances to one of the readers, and the reader forwards the list to the location engine.

In the LEP, the location engine estimates the location of a tag using the values measured in the MP. The TDOA values can be converted into hyperbolic functions,[24-26] and the RSS or TOA values can be converted into circular functions. The location engine accurately estimates the tag's position using localization methods, such as hyperbolic positioning and tri-lateration.[27]

However, in a real environment, these values from MP can be severely biased in the absence of LOS between two nodes (NLOS errors). Because this problem is critical to the system performance, many researches have been introduced for recent years.[28,29] The researches on the NLOS problem typically categorized into two methods: NLOS identification (detection) and NLOS mitigation.

NLOS identification methods mainly deal with how to distinguish between LOS and NLOS range estimates. Borras et al. tried to identify NLOS range estimates using the variance of range measurements.[30] The method is based on a binary hypothesis test and comparing a likelihood ratio to the measured threshold. It assumes the variance of LOS range estimates should be predefined, and requires numerous sample data from nearly stationary tags. Venkatesh et al.[31] and Shimizu et al.[32] proposed the identification method based on channel statistics.[31] is based on RSS, TOA, and root-mean-square delay spread (RDS) of the received signal. Shimizu et al.[32] used the standard deviation of delay spread. The method is based on their analysis that the delay spread is dependent on distance and the NLOS delay spread is several times larger than that of LOS. Jo et al.[33] suggests ray tracing and map-based identification method. This method is well operated at nearly static environment because it requires pre-defined map of building, and the ray-tracing algorithm relatively takes a long time if the size of environment is big.

NLOS mitigation methods typically use both of NLOS and LOS range estimates. Doherty at el.[34] proposed a semi-definite programming(SDP) approach, and Wang at el.[35] suggested a quadratic programming approach for mitigating NLOS problem. These

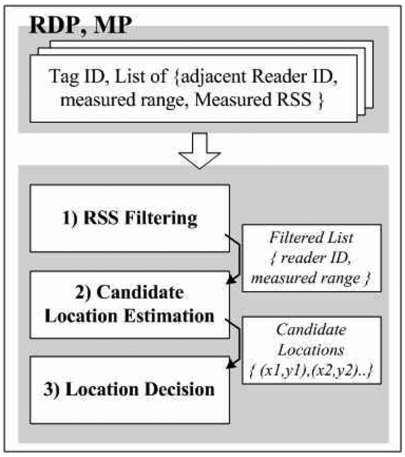


Fig. 2 The Location Estimation Phase of the proposed system.

approaches require high computational overhead. Chen[36] proposed the mitigation algorithm using residual weighting (Rwgh). This method is simple and does not require *a priori*. Venkatesh at el.[29] presented a linear programming approach that incorporates both LOS and NLOS range information. In this method, the method restricts the feasible region to improve location accuracy using the NLOS range estimates.

Generally, the NLOS identification methods require numerous measured values because it tries to filter the NLOS range estimates out. In addition, the threshold value, filtering criteria of identification, can be highly affected to the system performance, and the value is influenced by environmental parameters. On the other hand, in the method of NLOS mitigation, the system performance can be degraded when the values of NLOS range estimates are intensely higher than others. Moreover, the system performance highly depends on the radio of NLOS range estimates in the measured values in these methods.

In this paper, we suggest a hybrid method that includes both features between NLOS identification and mitigation for a real environment. First, the measure values are roughly filtered by received signal strength. After that, the system estimates all possible candidate locations of the asset and determines the location of the asset using various criteria. In order to overcome lack of readers, we suggest a localization method which requires only one or two range estimates utilizing the route of assets which are pre-defined in a container terminal in the procedure of location estimation.

3. The Proposed Asset Locating System in Container Terminals

Fig. 2 shows the operations of the proposed location system. In RDP, RFID readers that appear within the range of a RFID tag are added to an in-range list. Then, the in-range list containing readers' IDs, measured distances, and radio signal strength indicator (RSSI)values are sent to the location engine. The location engine estimates each tag's location, using 1) *RSS Filtering* module, 2) *Candidate Location Estimator* module, and 3) *Location Decision* module. The Location Decision module also contains the locations of readers as well as pathway information of the tags. The following subsections discuss the details of these three modules.

3.1 RSS Filtering

After measuring between tags and readers, the measured values are transmitted to a location engine. The values are filtered in RSS Filter module based on RSS provided by an RF module. Because these values are roughly approximated, this module tries to filter only a portion of NLOS range estimates.

Eq. (1) shows the relation between *RSS* and *RSSI*, which is provided by the RF module.[22] Eq. (2) shows the relationship between *distance* and *RSS*.[39,40]

$$RSS(dBm) \cong k_1 - k_2 \cdot RSSI \tag{1}$$

$$RSS(dBm) \cong 10 \cdot \log\left(\frac{k_3}{distance^2}\right) + 30 \tag{2}$$

where k_1, k_2, and k_3 are constants that are defined by manufacturers of RF modules.

The following equation shows the relationship between distance and RSSI obtained by simultaneously solving Eqs. (1) and (2).

$$RSSI \cong \frac{20}{k_2} \cdot \log(distance) + \frac{k_1 - 30 - 10logk_3}{k_2}$$
$$= A \cdot \log(distance) + B \tag{3}$$

Eq. (3) can also be simplified by using constants *A* and *B*, which can be calculated using a least square method by substituting the measured distance values and the typical RSSI value in a LOS environment.

Our proposed location system can determine whether the measured values are affected by NLOS communication by comparing them with the RSS model. The following equation calculates the maximum *RSSI* value, $RSSI_e$, using the ranging data, including measurement errors:

$$RSSI_e = A \cdot log(R - \bar{\varepsilon} + \delta) + B \tag{4}$$

where R is the measured distance, $\bar{\varepsilon}$ is the average measurement error, and δ is the standard deviation of the measurement error. If RSSI obtained from the RF module during ranging is greater than the RSSI threshold, $RSSI_{th}$, the value is highly likely to be an NLOS value. Since RSSI can include errors arising from the measurement or the environment, the error constant γ is added to the RSS model as defined below

$$RSSI_{th} = RSSI_e + \gamma \tag{5}$$

3.2 Candidate Location Estimator

The Candidate Location Estimator module finds the locations of tags using the procedure shown in Fig. 3. In this module, the location engine tries to find all the possible locations of a tag using readers' locations and filtered range estimates as well as the routeinformation of the tracked target. Location Estimation functions LE_1, LE_2, and LE_3 perform location estimation based on the number of available range estimates. If the location engine receives three or more range estimates, the LE_3 function is called to obtain the candidate locations. The LE_3 function uses tri-lateration to estimate the location of tag t, (x_t, y_t), based on the following equation:[21]

```
R = { Set of measured distances }
|R| = { The number of elements in R }
r_i = { All possible combinations of R } ( r_i ∈ R, |r_i| = i )

procedure LOCATION ESTIMATOR(R, r_i)
    if |R| ≥ 3: then
        call LE_3 with r_3 returns LIST_cand
    else if |R| = 2: then
        call LE_2 with R returns LIST_cand
    end if
    if |LIST_cand| equal to 0 then
        call LE_1 with r_1
    end if
end procedure
```

Fig. 3 Procedure for candidate location estimation

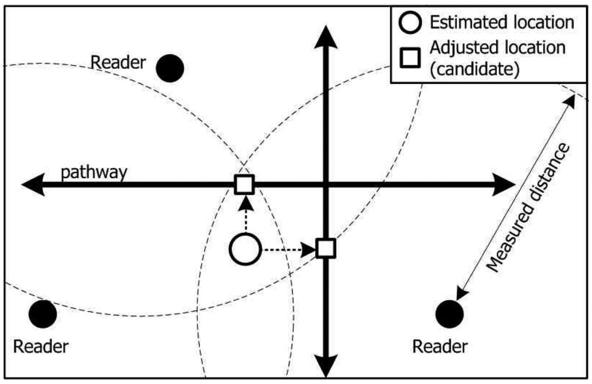


Fig. 4 Example of error correction using pathway information: ***LE*$_3$**

$$x_t = \frac{(y_b-y_a)C_2-(y_c-y_b)C_1}{[(x_c-x_b)(y_b-y_a)-(x_b-x_a)(y_c-y_b)]}$$
$$y_t = \frac{(x_b-x_a)C_2-(x_c-x_b)C_1}{[(y_c-y_b)(x_b-x_a)-(y_b-y_a)(x_c-x_b)]}, \quad (6)$$

where C_1 and C_2 are defined by

$$C_1 = \frac{1}{2}\left(\sqrt{(x_a^2+y_b^2)^2}-\sqrt{(x_a^2+y_a^2)^2}+\hat{R}_{at}^2-\hat{R}_{bt}^2\right)$$
$$C_2 = \frac{1}{2}\left(\sqrt{(x_c^2+y_c^2)^2}-\sqrt{(x_b^2+y_b^2)^2}+\hat{R}_{bt}^2-\hat{R}_{ct}^2\right) \quad (7)$$

where (x_r, y_r) is the location of reader r, and a, b, and c are readers' IDs. Since the heights of readers and tags can be different, $\hat{R}_{rt}$ represents the *height adjusted* distance between a reader r and a tag t given by the following equation:

$$\hat{R}_{at}^2 = \sqrt{\left|R_{at}^2-(h_a-h_r)^2\right|}$$
$$\hat{R}_{bt}^2 = \sqrt{\left|R_{bt}^2-(h_b-h_r)^2\right|}$$
$$\hat{R}_{ct}^2 = \sqrt{\left|R_{ct}^2-(h_c-h_r)^2\right|} \quad (8)$$

where R_{rt} represents the distance between a reader r and a tag t, and h_x is the height of each component.

After estimation, the Candidate Location Estimator adjusts the location to compensate for errors in measured distances. If the estimated location is not on the pathway of a tracked object due to errors, it is moved to the nearest point on the pathway as shown in Fig. 4.

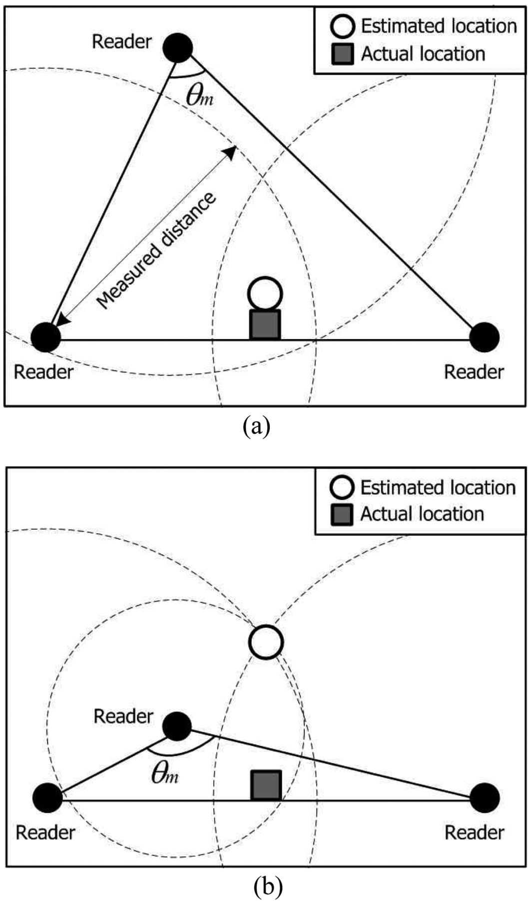


Fig. 5 Comparison of location accuracy based on the size of θ_m

The location engine also considers the *geometric dilution of precision* (GDOP) of readers derived from GPS[37] to minimize errors. The GDOP can be a criterion in a location system for determining the precision of the result. As shown in Fig. 5, the GDOP is determined using the largest angle θ_m between readers during estimation. As can be seen from Fig. 5(a), the error between the estimated and the actual location is minimal when θ_m is of normal size. However, when θ_m is too large as shown in Figure 5(b), the error can be significant. Therefore, a candidate location is dropped if θ_m is bigger than a threshold θ_{th}.

As mentioned above, the location engine cannot always obtain three or more range estimates required for estimation because of NLOS range filtering or shadow areas. If there are less than three range estimates, the location engine cannot apply tri- or multi-lateration methods. Therefore, the proposed method uses not only range estimates but also vehicle route information.

If there are two range estimates, the ***LE*$_2$** function illustrated in Fig. 6(a) uses both the range estimates and route information as follows: First, two circles are drawn using the range estimates and their intersection points are calculated. Then, the candidate locations are the crossing points between the designated pathway and the line that connects the intersection points. If there is only one range estimate, the system operates as ***LE*$_1$** illustrated in Fig. 6(b). Because the target should be on the circle which has a diameter of measured distance, the system determines candidate points as intersection points with the route of the asset.

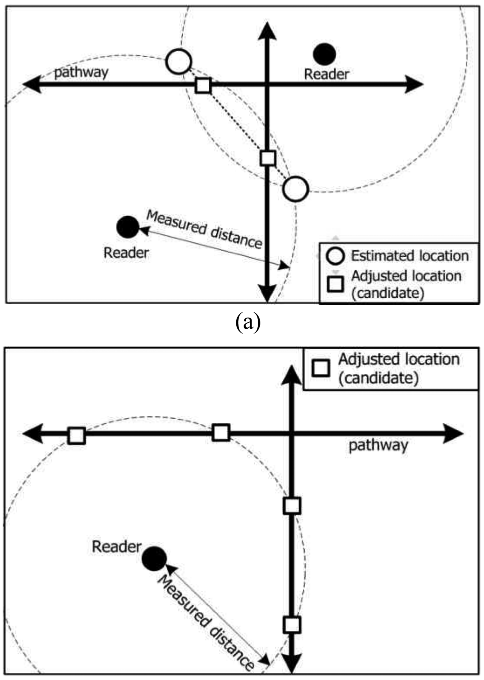


Fig. 6 Operations of (a) $\boldsymbol{LE_2}$ and (b) $\boldsymbol{LE_1}$

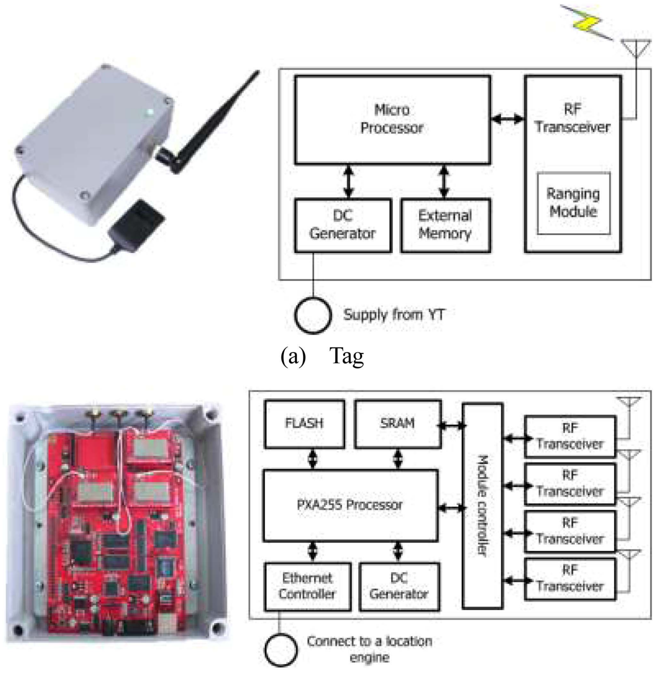


Fig. 7 Components of implemented system

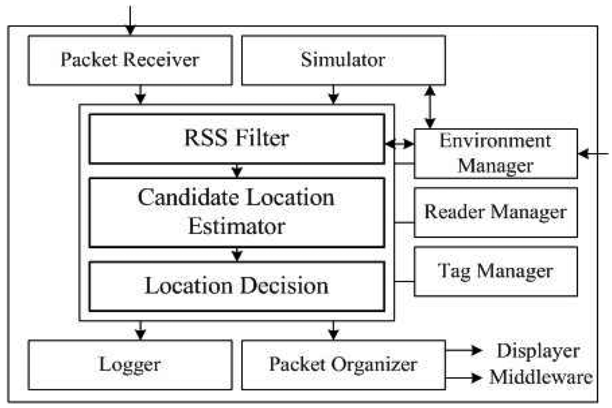


Fig. 8 Structure of the location engine

3.3 Location Decision

The location engine considers the amount of error from measurement and adjustment in choosing the optimal location of a tag. The error is calculated using a weight function G given by the following equation:

$$G = \alpha \cdot G_p + \beta \cdot G_d \quad (9)$$

where G_p is the *pathway adjustment error* and G_d is the *distance measurement error*. G_p represents how much candidate coordinate is adjusted with the pathway. G_d is the sum of the difference between measured distance from each reader to the tag and the arithmetical distance from a candidate coordinate to each reader's coordinate. G_p and G_d can be obtained by the following two equations:

$$G_p = \sqrt{(\hat{x}_t - x_t)^2 + (\hat{y}_t - y_t)^2} \quad (10)$$

$$\begin{aligned} G_d = & \left(\sqrt{(\hat{x}_t - x_a)^2 + (\hat{y}_t - y_a)^2} - \hat{R}_{at}\right) \\ & + \left(\sqrt{(\hat{x}_t - x_b)^2 + (\hat{y}_t - y_b)^2} - \hat{R}_{bt}\right) \\ & + \left(\sqrt{(\hat{x}_t - x_b)^2 + (\hat{y}_t - y_b)^2} - \hat{R}_{ct}\right) \end{aligned} \quad (11)$$

where $\hat{x}_t$ and $\hat{y}_t$ represent the coordinate for a candidate location after adjustment with pathway information, and x_t and y_t are given by Eq. (6). Finally, the location engine choose the optimal location of the tag, which has the minimal value of G.

4. Evaluation

4.1 System Implementation

To evaluate the proposed method, all of the system components, i.e., RFID tags, RFID readers, and the location engine, were implemented. Fig. 7 shows photographs and schematic diagrams of the implemented RFID tag and RFID reader. Each tag consists of a low-power microprocessor and a 2.4 GHz RF module from NanoLOC for TWR-based ranging.[22] Each reader consists of an ARM-based PXA255 core running Embedded Linux. The system also includes up to four RF modules with directional antennas for efficient communication and an Ethernet controller for communication with tags and the location engine. The proposed localization method was implemented on a multi-core server using Python and C languages. Fig. 8 shows the structure of the location engine.

We implemented various functions such as RSS Filter, Candidate Location Estimator and Location Decision that mentioned before in the location engine, and parameters required for implementation are determined through experiments in Section 4.2. The Packet Receiver receives and analyses packets from readers and tags, and the Simulator generates packets for experiments with environment variables from the Environment Manager. The Environment Manager

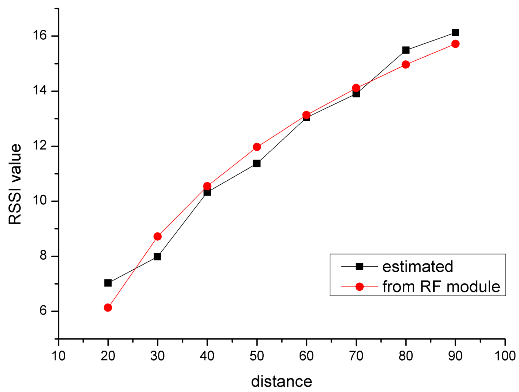


Fig. 9 Comparison of experimental data and the RSS model (distance = 12.4 meters)

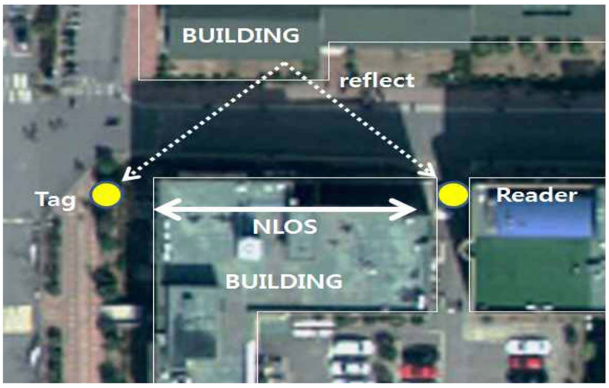


Fig. 10 Experiment for determining γ in a NLOS nvironmrnt

manages position information of readers, pathway information, and other environment variables defined by the operator. The Reader Manager and the Tag Manager monitor status of tags and readers. After location estimation, the Logger module logs all of results for debugging, and the Packet Organizer arranges result packets in order to send them to a middleware or a displayer that provides results to the user interface.

4.2 Determination of System Parameters

Before deploying the proposed location system in a real-world situation, we need to determine the error constant of the NLOS filtering model γ (see Eq. (5)), the GDOP threshold θ_{th}, and the α and β values used by the weight function (see Eq. (9)). To determine constants A and B in Eq. (3), data was collected using the implemented readers and tags in an open field. Based on the experimental data, the following equation was obtained with $A = 14.7$ and $B = -42.3$:

$$RSSI = 14.7 \cdot \log(distance) - 42.3 \tag{12}$$

Fig. 9 shows that the result of Eq. (12) and experimental data are very close.

In order to determine γ in Eq. (5), we experimented with a tag and a reader in a NLOS environment as shown in Fig. 10. The tag was positioned 12.4, 17.2, 46, and 56 meters from the reader. The ranging process was repeated 100 times for each position, and RSSI and distance were measured. Fig. 11 shows the *success rate of filtering*, which represents how many locations are successfully filtered out

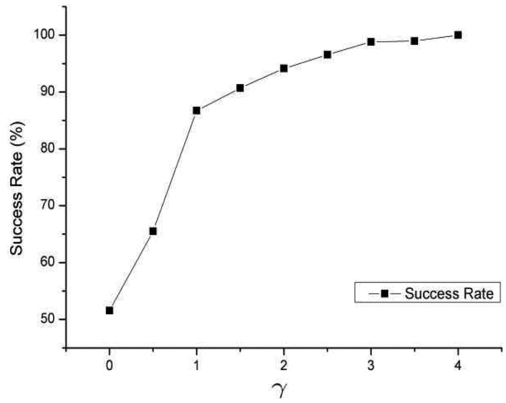


Fig. 11 Sucess rate of filtering versus error constant γ in a NLOS environment

Table 1 Success rate of filtering in a NLOS environment (γ = 3.5)

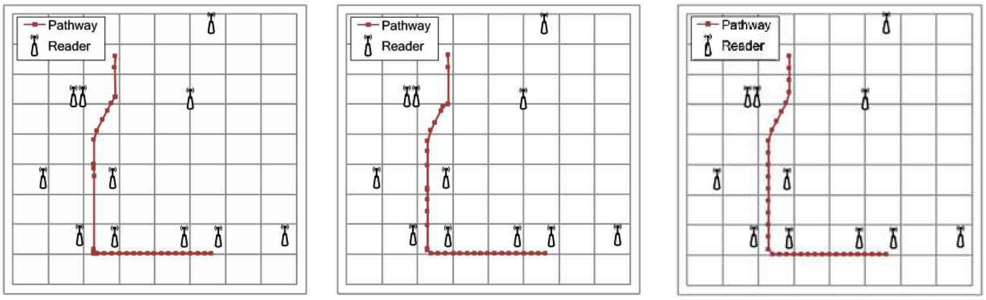
Actual Distance (m)	Measured Distance (m)	RSSI from RF Module	RSSI from RSS Module	Sucess Rate Of Filtering (%)
12.4	35.9	10.7	5.9	96.5
17.2	37.5	11.4	6.4	72.0
46.0	76.3	17.4	13.4	64.5
56.0	89.6	18.9	14.4	80.3

compared with the number of range estimates obtained in the RDP, as function of when the actual distance between the tag and the reader was 12.4 meters. As can be seen, the percentage of correct answers increases as γ increases, and almost all NLOS values are removed when γ = 3.5. However, LOS range estimates may also be removed if the threshold increases. Table 1 shows RSSI values and the success rate of filtering with γ = 3.5.

In order to evaluate the performance of the NLOS filter, RFID readers were placed in a part of a container terminal as shown in Fig. 12 (about 300 × 300 meters), and a tracked target equipped with an RFID tag moved along the indicated pathway. The tag could not perform ranging with a sufficient number of readers in the middle of the path due to stacked containers, and the measured distances contained arbitrary measurement errors. Dots in Fig. 12 indicate the estimated results. Fig. 12(a) shows that some of the positions are estimated incorrectly without NLOS filtering because NLOS range estimates can be much larger than LOS range estimates, and thus estimated locations can be beyond the experimental area. In contrast, Fig. 12(b) shows that most of NLOS range estimates are filtered out and the route is correctly updated. However, some of locations overlap each other because the range estimates include errors.

As mentioned above, the GDOP can be considered when the location engine estimates candidate tag locations. We performed simulation to determine an appropriate θ_m value using measured range estimates and positions of readers and the tag from the previous experiments in the terminal. Fig. 13 shows the location estimation error versus θ_m, which indicates that the average error increases rapidly when θ_m is greater than 150°.

These determined parameters from experiments have relevance tocomposition of hardware and environmental factors such as temperature or humidity. Especially, a parameter of RSS filtering highly depends on RF module and other hardware.



(a) Without NLOS Filtering (b) With NLOS Filtering (c) Ideal Environment

Fig. 12 Estimated results without and with NLOS ranging value filtering

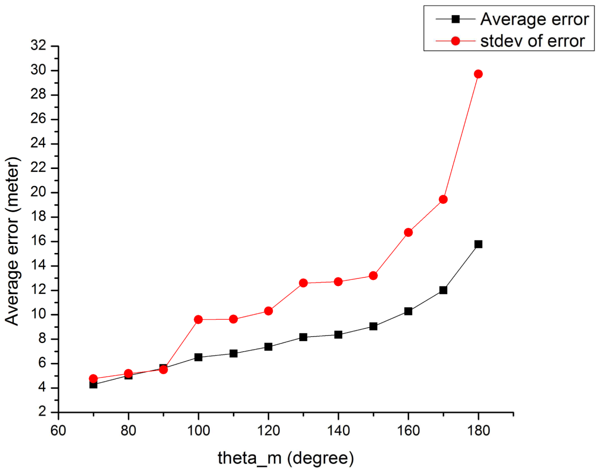


Fig. 13 Estimation error versus θ_m

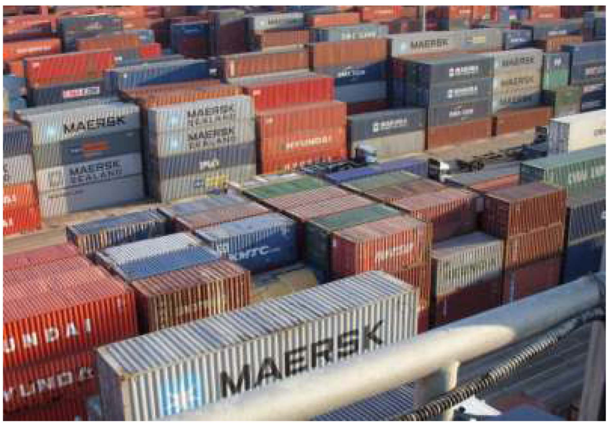


Fig. 14 NLOS environment where many containers are stacked

(a) RFID Tag on a yard tractor


(b) RFID Readers on the top of light tower and transfer crane

Fig. 15 Installed system components

Fig. 16 Target Environment and reader installation

4.3 Evaluation of System Performance in a Real Environment

Our proposed location system was installed in Hutchison Korea Terminals (HKT) in Busan, South Korea for evaluation.[38] As shown in Fig. 14, containers in HKT are typically stacked up to five levels deep, and thus NLOS communications exist between the yard tractors that are being tracked and the readers on light towers and transfer cranes. Fig. 15(a) and 15(b) show pictures of how tags are installed on the yard tractor and readers are installed at the top of the light towers and transfer cranes, respectively.[7,8] We installed 18 readers on the light towers and transfer cranes, and their locations are updated by GPS since transfer cranes move intermittently as shown in Fig. 16. The error constant γ was set to 3, the GDOP threshold θ_{th} to 150°, and the parameters of the weight functi on (α, β) to (1, 1).

Tags were installed on two stationary yard tractors in different areas in HKT. The accuracy of our system was compared with a common least-square (LS) localization method.[21] Each tag transmits a short signal every one second during the RDP. The system is tested for about one hour in HKT. Table 2 shows the success rate of location estimation. Table 3 shows the error and standard deviations for the

Table 2 Success rate of location estimation

	Yard Tractor #1	Yard Tractor #2
LS	6.3%	59.6%
Proposed Method	75.6%	98.3%

Table 3 Accuracy of location estimation

	Yard Tractor #1		Yard Tractor #2	
	Avg. Err.	Std. Dev.	Avg. Err.	Std. Dev.
LS	55.0 m	37.8 m	153.3 m	80.9 m
Proposed Method	12.1 m	8.0 m	38.9 m	37.3 m

estimated yard tractor locations. These results clearly show that our proposed method is more accurate than the LS method.

Fig. 17 illustrates how a yard tractor is tracked as it moves from area *A* to *F*. Fig. 17(a) shows the result of tracking based on the LS localization method with pathway adjustment, and Fig. 17(b) is for the proposed system. On the pathway from *A* to *C*, the number of obstacles is small but there is insufficient number of installed readers as shown in Fig. 16. Therefore, the success rate of LS is almost zero because it requires three or more range estimates, while the proposed system estimates successfully. On the pathway from *C* to *E*, there is sufficient number of readers but there are a lot of stacked containers that result in NLOS RF propagation. Therefore, the LS method results in lower accuracy than our proposed system. This is because the NLOS range estimates have significant amount of error causing abnormal location readings far away from the actual positions of the tag. On the straight pathway from *E* to *F*, one reader near to area *E* provides highly erroneous distance results due to a problem of its RF module. In spite of this problem, the proposed system successfully tracks the tag.

These results show that our proposed location system has superior update rate and location estimations because of NLOS filtering and utilization of pathway information even when a small number of range estimates are available.

5. Conclusion

This paper proposed a new localization method for NLOS environments. The primary features of the proposed method are a selection strategy to filter out NLOS range estimates and a candidate location estimation method that uses the remaining range estimates together with pathway information of tracked objects. To evaluate our method, all of the system components were implemented and various system parameters were experimentally obtained. The proposed system was also installed and tested in a real container terminal environment containing many shadow areas and verified that it outperforms a least-square-based localization method. The proposed location system is currently being used in container terminals in Korea.

In our future work, we have made plans for improvement of the system as following:

1. Accurate measurement for reference locations of mobile assets: Assets in the proposed system are compared with their attached GPS modules due to high-cost and dangerousness. Accurate positions and time of mobile assets will be accurately measured for obtaining reference points in a container terminal.
2. Long-term testing with various system parameters: For improved analysis and evaluation, the system should be tested for a long time. Relation between environmental factorsand signal strength also will be analyzed.
3. Comparing with off-the-shelf products: Unfortunately, there are only a few locating system for container terminals because of unusual environment. In the future, we plan to compare well-installed off-the-shelf products with our proposed system.
4. Improved system protocols considering scalability and security: The proposed system operates based on range-based localization. In this method, a distance between two nodes is measured usually by message exchanging (Two-Way Ranging), and the system generates a large number of messages that cause transmission delays or failures, and degrades the system performance. Therefore, efficient protocol design should be researched for scalability. In addition, the security can be an important issuefor operating in a real container environment.

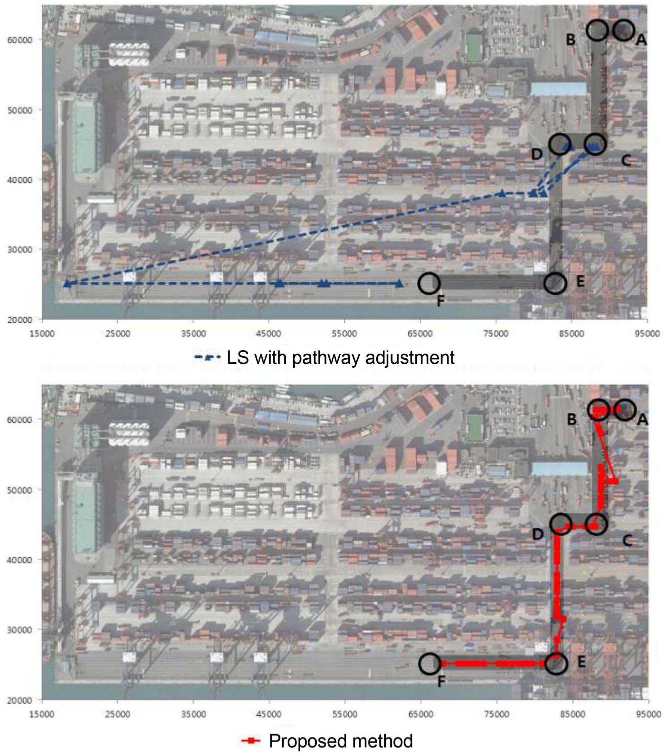


Fig. 17 Tracking of a yard tractor from area *A* to *F*

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