Indoor Localization by Pattern Matching Method Based On Extended Database

Gyumin Hwang, Jihong Lee

Abstract—This paper studied the CSS-based indoor localization system which is easy to implement, inexpensive to compose the systems, additionally CSS-based indoor localization system covers larger area than other system. However, this system has problem which is affected by reflected distance data. This problem in localization is caused by the multi-path effect. Error caused by multi-path is difficult to be corrected because the indoor environment cannot be described. In this paper, in order to solve the problem by multi-path, we have supplemented the localization system by using pattern matching method based on extended database. Thereby, this method improves precision of estimated. Also this method is verified by experiments in gymnasium. Database was constructed by 1m intervals, and 16 sample data were collected from random position inside the region of DB points. As a result, this paper shows higher accuracy than existing method through graph and table.

Keywords—Chirp Spread Spectrum (CSS), Indoor Localization, Pattern-Matching, Time of Arrival (ToA), Multi-Path, Mahalanobis Distance, Reception Rate, Simultaneous Localization and Mapping (SLAM), Laser Range Finder (LRF).

I. INTRODUCTION

LOCALIZATION technique, one of the important techniques in the field of service industry, is being highlighted. The localization can be divided into outdoor localization and indoor localization. In the outdoor localization, GPS is mostly used, but GPS cannot be used for the indoor localization, as the robot usually cannot communicate with satellites. For this reason, many researches to solve this problem are ongoing, and research about close distance communication is being focused more than ever.

Localization based on the close distance communication used methods such as Time of Arrival (ToA), which measures the distance through radio wave's travel time, and the RSSI method, which measures the distance through the change of radio wave's intensity [1]-[5].

CSS-Based indoor localization system [6], [9], which is suggested in existing research, uses a ToA method to estimate the location with the distance [7], [8]. However, there exists an error in distance due to the multi-path caused by the complicated and narrow indoor, which leads to a large error in localization. Pattern matching method is being studied to solve these problems [10]. This paper proposes the method that

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enhances the accuracy of existing pattern matching.

II. PATTERN MATCHING

A. Pattern Matching Method

The existing trilateration method has a very low accuracy due to the error in distance caused by the multi-path we have mentioned earlier. Therebythe pattern matching method has been studied to solve these problems. Also Filtering of algorithm has been enhanced by using the extended DB (Database), which was to improve the accuracy of existing pattern matching.

First at all, pattern matching method localizes by interpolation through the similarities between data, and it considers the errors caused by the multi-path a characteristic of the data, which is used in the process of localization [10]. For using the method, we constructed database R_{DB} in (1).

$$R_{DB} = \begin{bmatrix} R_{11} & R_{12} & R_{13} & \cdots & R_{1n} \\ R_{21} & R_{22} & R_{23} & \cdots & R_{2n} \\ R_{31} & R_{23} & R_{33} & \cdots & R_{3n} \\ \vdots & \vdots & \vdots & \ddots & \\ R_{m1} & R_{m2} & R_{m3} & & R_{mn} \end{bmatrix} \in R^{m \times n} \quad (1)$$

$$R_{robot} = \begin{bmatrix} R_1 & R_2 & R_3 & \cdots & R_n \end{bmatrix} \in R^{1 \times n} \quad (2)$$

$$R_{gap} = \begin{bmatrix} I \cdot R_{robot} - R_{DB} \end{bmatrix} \in R^{n \times m} \quad (3)$$

$$I = \begin{bmatrix} 1 & 1 & \cdots & 1 \end{bmatrix}^T \in R^{m \times 1} \quad (4)$$

R_{DB} : Range data of database point

R_{robot} : Range data of robot

R_{gap} : Difference between R_{robot} with R_{DB},

where R_{mn} is distance data from anchor to tag. n means number of anchor, and m means number of DB point from(1). Construction of DB (previous DB) about the certain environment is necessary to develop localization method. Also, R_{robot} is range data received at random location from in (2). To calculate R_{gap}, we created vector I to modify size of R_{robot} in (4). DB points with relatively low R_{gap} is extracted by comparing the difference in results, as in (3). Not only that, by considering the difference in distance with DB points that showed high similarities, weighted values are given for each DB points and interpolation is utilized to extract the final

location.

B. Pattern Matching Method Based On Extended DB

An existing pattern matching method extracted the final result by pinning 6 DB points that showed high similarities, and each difference in the distance to anchor has been summed and was used as one representative value while finding out the similarity between DB points. Furthermore, according to the circumstance, DB points was not always six, and which can be selected again from 4 to 6 by removing DB point far from the distribution about each DB point. Although existing database only had distance data, we tried to improve the accuracy by using the pattern matching method based on the extended DB, which added the reception rate from anchors.

C. Extended DB Structure

$$R'_{DB} = \begin{bmatrix} R_{11} & R_{12} & \cdots & R_{1n} & P_{11} & P_{12} & \cdots & P_{1n} \\ R_{21} & R_{22} & \cdots & R_{2n} & P_{21} & P_{22} & \cdots & P_{2n} \\ \vdots & \vdots & \ddots & & \vdots & \vdots & \ddots & \\ R_{m1} & R_{m2} & & R_{mn} & P_{m1} & P_{m2} & & P_{mn} \end{bmatrix} \in R^{m \times 2n} \quad (4)$$

R'_{DB} : Range and reception rate of database point

P_{mn} : Reception rate of each anchors

We constructed a new R'_{DB}, and extended DB from(4), by storing the reception rate of each anchors. We stored the reception rate of each anchors in P_{mn}. The reception rate is lowered when an indoors obstacle hinders the propagation from a certain anchor to the tag. And it was considered to distribute the weighted value, in order to lower the reliability of the anchor.

D. Filtering by Using Mahalanobis Distance

The existing pattern matching method extracted 6 DB points that showed high similarities, in other words, that was in close distance to the real robots. However, there were big errors in the final results because DB points that are far from the real location has been chosen, which was caused by the structures of indoor environment.

$$x = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & x_5 & x_6 \end{bmatrix}^T \quad (5)$$

$$y = \begin{bmatrix} y_1 & y_2 & y_3 & y_4 & y_5 & y_6 \end{bmatrix}^T \quad (6)$$

$$D_M(x, y) = \sqrt{(x-y)^T S^{-1} (x-y)} \quad (7)$$

D_M : Mahalanibis distance

S : Covariance matrix of x, y

To lessen these errors, 6 DB points were basically extracted; the average and standard deviation of the 6 DB points were (7) that is threshold to filtering 6 DB points. DB points that have higher value than the threshold were removed; and four to six DB points were filtered case by case.

E. Weighted Index Based On Reception Rate

$$\rho = \begin{bmatrix} \rho_1 & \rho_2 & \rho_3 & \cdots & \rho_6 \end{bmatrix} \quad (8)$$

$$K_n = \frac{\dfrac{1}{\rho_n}}{\dfrac{1}{\rho_1} + \dfrac{1}{\rho_2} + \dfrac{1}{\rho_3} \cdots + \dfrac{1}{\rho_6}} \quad (9)$$

$$K = \begin{bmatrix} K_1 & K_2 & K_3 & \cdots & K_6 \end{bmatrix} \quad (10)$$

ρ : Difference in distance

K : Weighted value

In the existing pattern matching method while finding out the similarity of DB points in(8), was calculated to give weighted values on different DB points. The existing method always fixed 6 DB points, thereby 6 weighted values are calculated from (9) and (10).

$$\rho = \begin{bmatrix} \rho_1 & \rho_2 & \rho_3 & \cdots & \rho_n \end{bmatrix} \quad (11)$$

$$P = \begin{bmatrix} P_1 & P_2 & P_3 & \cdots & P_n \end{bmatrix} \quad (12)$$

$$K'_n = \frac{\dfrac{P_n}{\rho_n}}{\dfrac{P_1}{\rho_1} + \dfrac{P_2}{\rho_2} + \dfrac{P_3}{\rho_3} \cdots + \dfrac{P_n}{\rho_n}} \quad (13)$$

$$K' = \begin{bmatrix} K'_1 & K'_2 & K'_3 & \cdots & K'_n \end{bmatrix} \quad (14)$$

P : Reception rate of each anchors

K' : Modified weighted values

Not only ρ of the difference in distance as (11), but also P was considered as (12), so that weighted values were lessened when reception rate was low as (13). Through filtering by using Mahalanobis distance, n can be chosen from 4 to 6. Thereby considering reception rate, weighted values were modified as (14).

III. EXPERIMENTAL ENVIRONMENT AND CONSTRUCTION OF ROBOT SYSTEM

A. Experimental Environment

Fig. 1 Gymnasium

Inside the gymnasium, data (distance data, real position data)

about25 DB points (5 by 5) were constructed by 1m intervals. Then 16 sample data (distance data, real position data) were collected from random position inside the region of DB points.
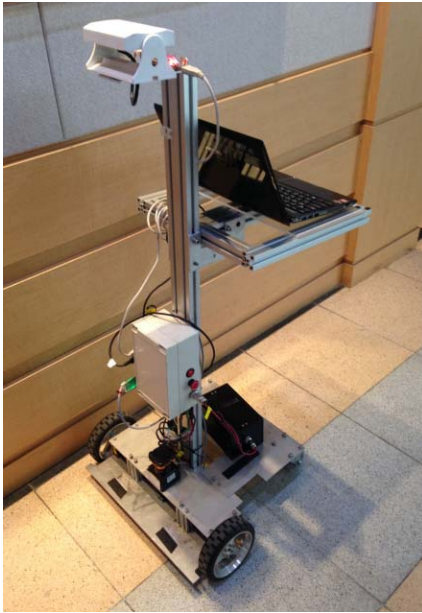
B. Robot System

Fig. 2 The robot

As in Fig. 2, the robot with two wheels was made for a comfortable movement indoors. Under the robot was installed a long distance LRF (Laser Range Finder) Sensor, which helped get the location of the robot through SLAM(Simultaneous Localization and Mapping), and Tag was installed on the upper part, which helped receive distance data from each anchors. Using the portable computer based on Linux through ROS (Robot Operation System), location data of robot and distance data from anchor to tag could be stored at real-time.

Fig. 3 Laser range finder (Hokuyo UTM-30LX)

In order to find out the real position of the robot, which will be used to compare with the estimated position by the pattern matching method, LRF sensor was adhered on the robot, and we used position data through SLAM.

Fig. 4 CSS based module (CorebellNexbee)

CSS based module, which shows the distance data through anchor and tag by ToA method, was used. 8 Anchors were adhered to the antenna on height of 3m during the experiment.In order to receive distance data and store it, the tag was adhered to the upper part of the robot.

IV. ANALYSIS OF EXPERIMENTAL RESULTS
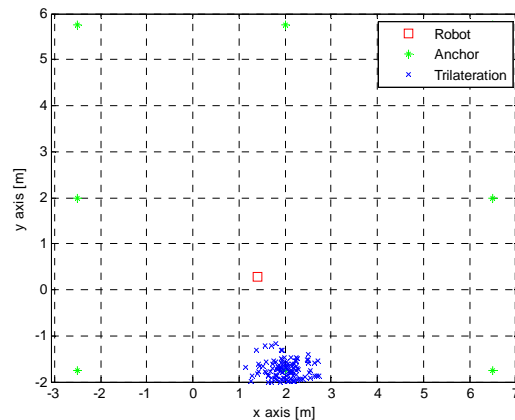
A. Trilateration

Fig. 5 Output of trilateration

Using the trilateration method used in GPS, there exists a big error in Fig. 5. This is because the distance includes the multi-path that is not a real distance from anchor to tag. Estimated position shows the error distance about 2m. As seeing the distribution of the estimated position, the accuracy and precision are also very low.

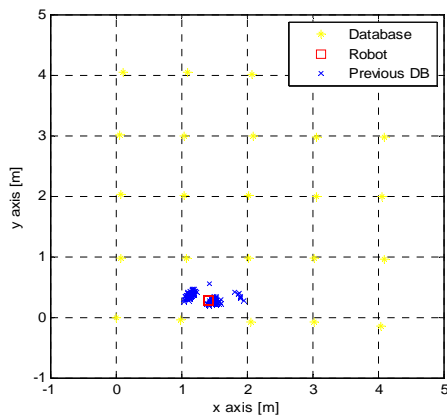*B. Pattern Matching Method Based On Previous DB*

Fig. 6 Output of previous DB

Using the existing pattern matching method based on previous DB, we can get a location value that is very near to the real position of the robot: because, the error is greatly reduced by using the data that includes multi-path as the characteristic of DB point. However, when looking at Fig. 6, we can easily see that accuracy is slightly low. Because incorrect DB points were selected by indoor structure, incorrect position is estimated.

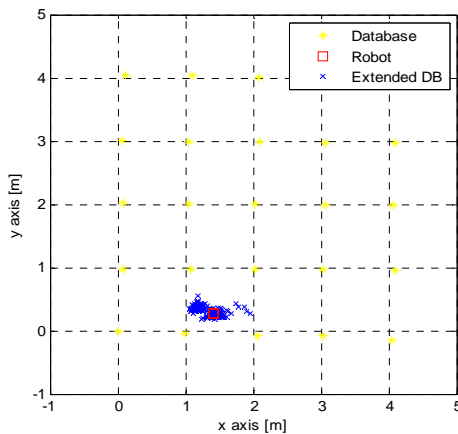*C. Pattern Matching Method Based On Extended DB*

Fig. 7 Output of extended DB

Using the pattern matching method based on extended DB, we can get a result with higher accuracy as Fig. 7, because filtering of DB points and reception rate is considered while distributing the weighted values. Also, the precision and accuracy of estimated position is greatly increased and compared with the trilateration or the existing pattern matching method.
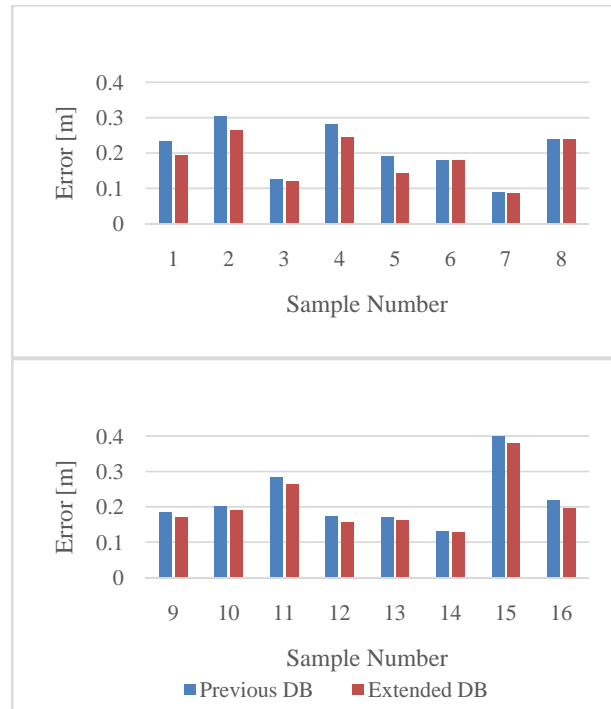

Fig. 8 Comparison of error

In Fig. 8, we collected 16 sample data and compared the errors between the existing pattern matching method based on previous DB and the pattern matching method based on extended DB. There were not dramatic reduction in the errors in few of the sample data, but in most of them, we could see reduction in the error about sample data.
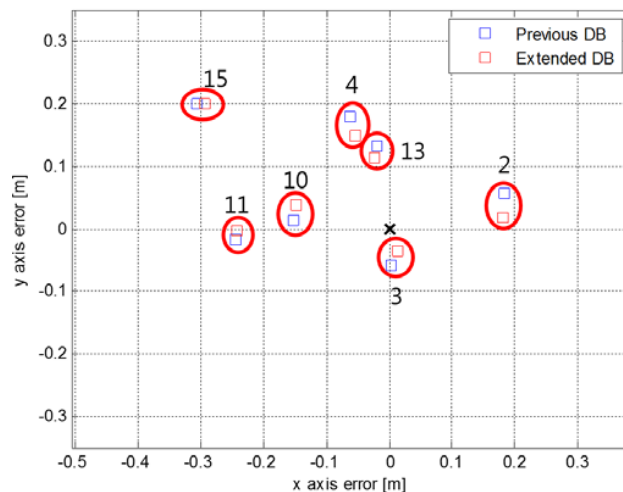

Fig. 9 Error in both axes

From 16 sample data, some sample data is chosen and is compared the error in the x-axis and y-axis. Error rate is lower than existing method when it is closer to the X-mark (0, 0).The errors is reduced by using pattern matching method based on extended DB in Fig. 9.
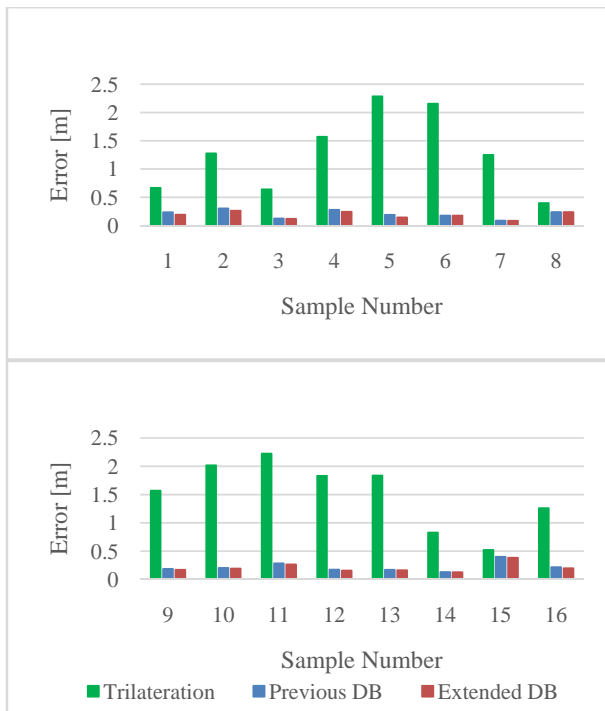
D.Total Comparison of Error

Fig. 10 Total comparison of error

In Fig. 10, we compared the real position of the robot with the estimated position extracted from trilateration method, existing pattern matching method, pattern matching method based on extended DB. All the sample data showed less error when using pattern matching, compared to the trilateration method. Also, through Table I, we can see that higher accuracy and lower error rate was found when using the pattern matching method based on extended DB.

TABLE I
TOTAL COMPARISON OF ERROR

Method	Average of Error [m]
Trilateration Method	1.3958
Pattern Matching Method Based on Previous DB	0.2131
Pattern Matching Method Based on Extended DB	0.1955

V.CONCLUSION

Indoor localization research is ongoing thanks to ever increasing attention on this area. However, there are not any stable methods like GPS. And GPS cannot be used for indoor environment. The existing trilateration method shows low performance because localization is affected by multi-path effect. This paper aimed for an indoor localization method with the inexpensive sensor by overcoming the multi-path caused by the barriers of indoor, which was done by using the pattern matching method based on extended DB. Even though this method need database about certain indoor environment, this method can overcome effect by the multi-path, which can estimate correct location than the existing method.

For further research, by applying it to a moving robot, a deeper research on moving robot should be done based on dead reckoning and EKF.

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