EKF-based Localization of a Mobile Robot using Pattern Matching

Seokyong Kim and Jihong Lee
Chungnam National University, Mechatronics Engineering, Daejeon, KOR
E-mail: {seokyoung, ijhong}@cnu.ac.kr

***Abstract*—This paper studied a localization problem for a mobile robot, based on chirp spread spectrum (CSS) indoor localization. This problem in localization is caused by the multi-path effect. The multi-path effect error is difficult to correct because the environment cannot be predicted. To solve the multi-path effect error problem, this paper proposes a pattern matching method. The pattern matching method estimates position by using the fact that data measured for nearby positions is highly similar. To gain high localization accuracy we used the extended Kalman filter (EKF) to fuse the results of localization using pattern matching and dead reckoning.**

***Index Terms*—localization, mobile robot, CSS, indoor, multi-path, pattern matching, EKF**

I. Introduction

Localization studies can be divided into outdoor localization and indoor localization. In outdoor localization, GPS is often used, but GPS cannot be used for indoor localization, as the robot usually cannot communicate with satellites. For this reason, many new studies of indoor localization are in progress, but so far, there is no obvious solution for indoor localization. The following table shows some typical approaches:

This paper proposes a CSS-based indoor localization system. It can be used in a wide variety of indoor environments. Typically, CSS-based indoor localization has multi-path effect problems. This was handled in previous studies such as using median filter algorithm or directional antenna to remove errors generated from multi-path effect, but this problem is not solved yet. The contributions of this work include a pattern-matching algorithm, which uses the characteristics of multi-path.

II. System Used For Research

A. CSS-based Localization

1) CSS

The CSS is a signal in which the frequency increases or decreases with time. Due to these characteristics, CSS is robust to noise from interference. CSS is used for localization because of this characteristic. However, CSS has problems that cause errors in measured distance data. Equation 1 is an equation of CSS [8, 9].

$$S_C(t) = R_e[exp[j(\omega_S + \frac{\omega_{BW}}{2T_C}t)t + \theta_0] \times [u(t) - u(t - T_C)] \quad (1)$$

TABLE I. Indoor Localizations [1, 2, 3, 4, 5, 6, 7]

Technology	Advantage
RFID	-Ratio of recognition is excellent -Low cost of a passive tag
WLAN	-An existing installation of stations
IR	-Already solution existed -Host mobile computer is unnecessary
UWB	-Low power -Wide coverage area -Within 0.2m accuracy
Technology	Weakness
RFID	-System needs many tags -Small coverage area
WLAN	-Difficult and expensive to install -Large size of system and high power consumption
IR	-Small coverage area -Cognitive impairment by sunlight -Vulnerable by obstacles
UWB	-Difficult and expensive to install -High production costs

2) Time of Arrival (TOA), Symmetric Double-Sided Two Way Ranging (SDS-TWR)

TOA uses a method of time arrival to calculate the distance. This approach is very important for synchronization between devices because this method uses the speed of light. However, it is technically difficult to synchronize. An alternative method is SDS-TWR, which is a way of measuring communication time accurately between devices. This time includes the flight time of propagation and signal processing time. Since signal-processing time can be measured, the flight time of propagation can be known. Using the speed of light, the distance between devices can be determined by knowing the flight time of propagation. Fig. 1 and equation 2–5 show SDS-TWR [10], [11].

Manuscript received July 1, 2012; revised December 9, 2012.

doi: 10.12720/joace.1.1.40-44

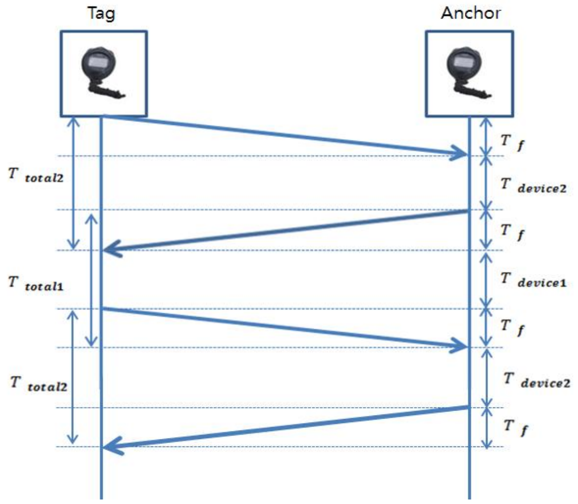


Figure 1. SDS-TWR.

$$T_{total1} = 2T_f + T_{device1} \tag{2}$$

$$T_{total2} = 2T_f + T_{device2} \tag{3}$$

$$4T_f = T_{total1} - T_{device1} + T_{total2} - T_{device2} \tag{4}$$

$$\delta d = c\frac{T_{total1} - T_{device1} + T_{total2} - T_{device2}}{4} = cT_f \tag{5}$$

T_{total1}, T_{total2} Turnaround time of propagation

T_f Flight time of propagation

$T_{device1}, T_{device2}$ Processing time of signal

c Speed of propagation (light)

B. Robot System

One CSS-based indoor localization system is NEXBEE made by Corebell. Maximum distance measurement performance of this system is 70 m. A measured position error is 2m. Fig. 2 shows NEXBEE.

Figure 2. CSS-based localization system, NEXBEE (Corebell).

The mobile robot in this experiment is a skid steering vehicle. A skid steering vehicle is compact, light, requires few parts to assemble and is agile. Skid steering vehicle motion differs from obvious steering motion in the way the skid steering vehicle turns. Fig. 3 is the mobile robot used in the experiment. Table 2 shows the characteristics of the mobile robot. The robot parameters are used to determine the robot motion.

Figure 3. Mobile robot (Corebell)

TABLE Ⅱ. ROBOT PARAMETERS

Wheel size	0.103 m
Robot size	0.237 m
Pulse of encoder	1326 pulse/rotation

III. METHOD

A. Method of Triangulation and a Least- square Method

CSS-based localization provides distances between a tag and anchors. The simplest method of localization is triangulation-calculated position using more than three distances between devices. These distances are between anchors to know position and tag. Fig. 4 represents triangulation.

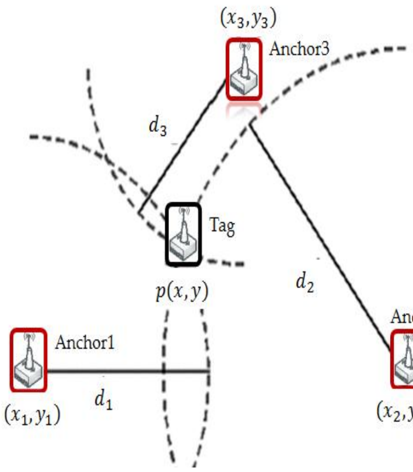


Figure 4. Triangulation method

The distance is not correct since it is influenced by device noise and multi-path errors. For this reason, measured distances are longer than real distances. Calculated results do not converge at a point by inaccurate distance data. We need a least-squares method to overcome this problem.

This algorithm is simple and has a short processing time because the equation for localization is not complicated. The more multi-path errors that are added to the distance, the more inaccurate the positions are.

The following result is from experiments in localization on the rooftop of the fourth engineering building in Chung-Nam National University (Fig. 5).

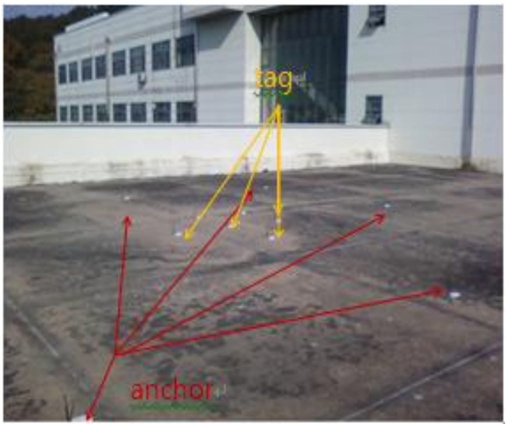


Figure 5. Experiment of localization
(Engineering 4th building of Chung-Nam national university)

The method is as follows: First, we arrange anchors in planned positions. The tag is in a position that we know. Fig. 6 is the position of a tag. Fig. 7 is the result of the experiment.

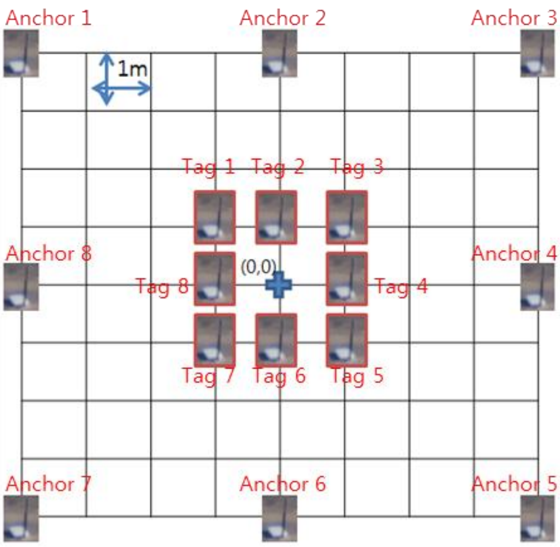


Figure 6. The position of tag and anchor

This result is from 100 experiments. The errors are mostly due to multi-path.

TABLE Ⅲ. Errors of Triangulation

Axis	Error
X	0.73 m
y	0.76 m

B. Pattern Matching Interpolation Method

Localization by triangulation is problematic. This system would lead to multi-path effect errors. Accordingly, it is necessary to develop a new localization method. This paper proposes a new localization method, which is pattern matching. The pattern-matching method is an interpolation to locate the nearest data value, and assign the same value as an interpolation. At this point, used data is eight distances data of between tag and anchors.

This pattern-matching method is a very simple algorithm. As the position is estimated by interpolation, standard data is needed. When standard data is measured, we must know the location of the standard data, and it must be measured in every part evenly (Fig. 8).

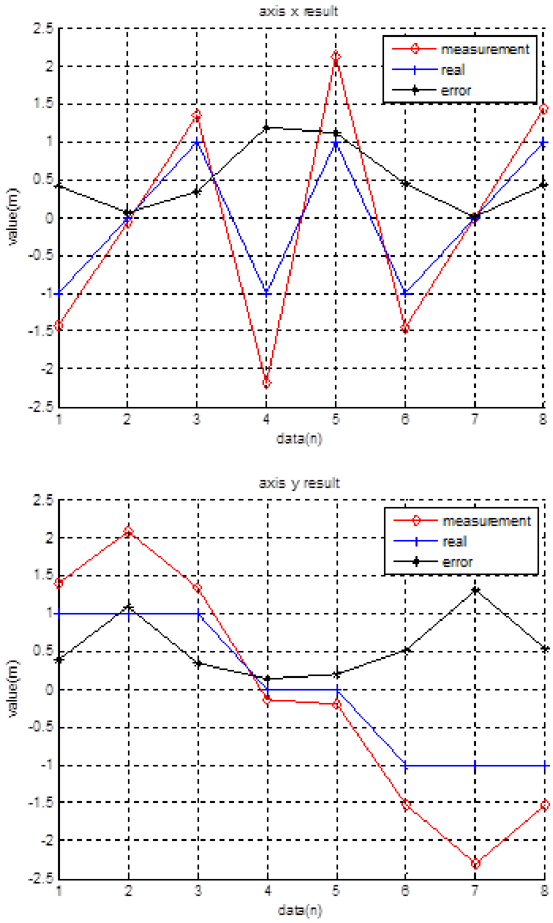


Figure 7. Result of experiment

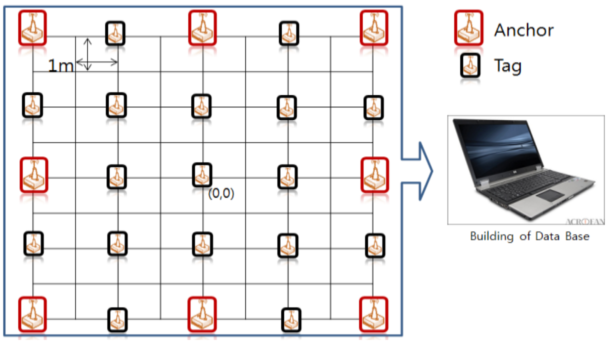


Figure 8. Building of Data Base

The following step compares standard data with measured data in the coordinates where you want to know position of a tag. A method to compare two kinds of data such as standard data and measured data is to use matrix norm. The value by norm shows similarity between standard data and measured data. This similarity is used for interpolation. Fig. 9 is the results of the experiment in the same environment as Fig. 6.

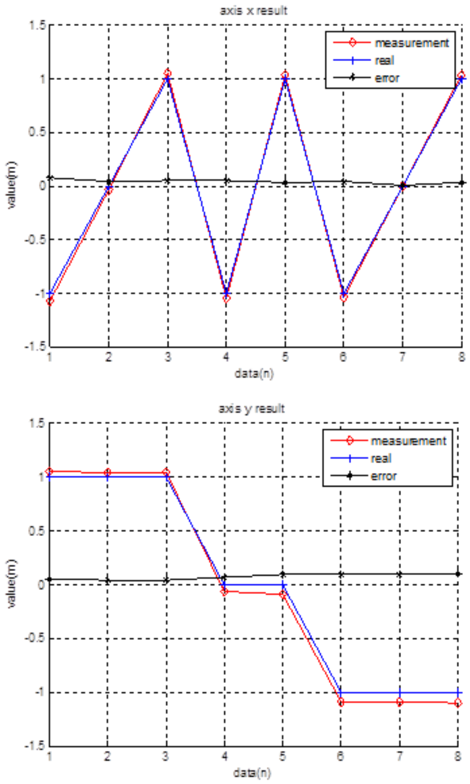


Figure 9. Results of pattern matching.

TABLE IV. ERROR OF TRIANGULATION

Axis	Error
X	0.04 m
y	0.07 m

This result is the mean of 100 experiments. While the error of triangulation is about 0.7 m, the error of pattern matching is about 0.05 m. It confirms that pattern matching has better performance than triangulation. This performance is determined by multi-path errors. The multi-path effect is affected by a spatial structure where a mobile robot is moving in an indoor environment. Pattern matching is advantageous in localization.

IV. EKF-BASED MOBILE ROBOT LOCALIZATON

A. Explain of Localization Experiment

This paper proposes a localization method for a mobile robot. We planned an experiment to demonstrate the performance of the localization method. First, we needed to compare data from the true path of the mobile robot. We determined true path using a laser tracker. Fig. 10 is a laser tracker.

Figure 10. Laser tracker (T3-60, API Inc.)

We chose a typical office environment for the experiment. Fig. 11 shows the actual experiment.

Figure 11. Experimental scene

B. Compare Triangulation and Pattern Matching

Fig. 12 is the result of mobile robot localization by dead reckoning.

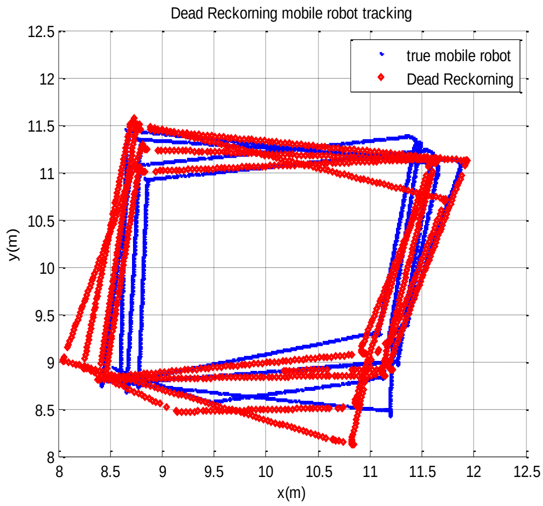


Figure 12. Result of dead reckoning

We found that the true path to follow at the beginning of the localization of dead reckoning. However, due to the characteristics of dead reckoning, errors accrue in localization. As a result, the longer the distance is, the greater the localization deviation from the true path becomes [12].

Fig. 13 shows how we used EKF to fuse the results of triangulation and dead reckoning.

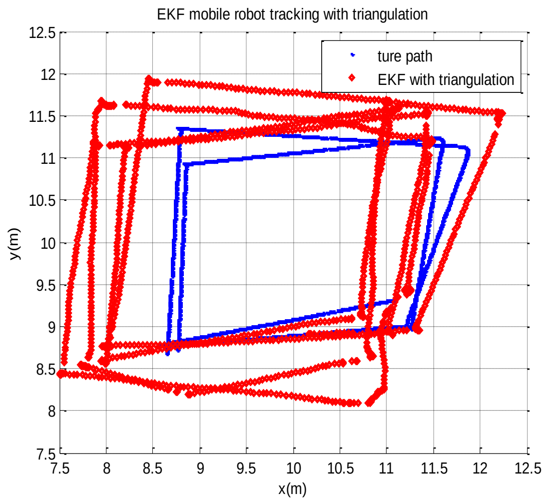


Figure 13. Result of EKF with triangulation

Triangulation results showed lower performance than the result of dead reckoning, because of the localization issues.

Fig. 14 is the result of EKF to fuse the results of pattern matching and dead reckoning.

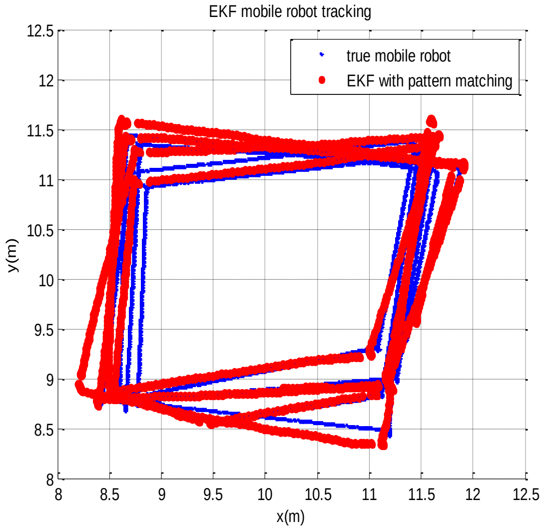


Figure 14. Result of EKF with pattern matching

As a result, the result of EKF with pattern matching is more accurate than dead reckoning. This method has better performance over longer distances.

TABLE V. ERROR OF TRIANGULATION

	Dead reckoning	EKF with pattern matching
Total error	0.2417m	0.1391m
Early part	0.1468m	0.1171m
Last part	0.3212m	0.1524m

(Data is mean of error. Total robot distance moved is 46.31 m. Early part is start to 24 m. Last part is 24 m to finish.)

V. CONCLUSION

Conventional triangulation shows low performance because localization is affected by multi-path effect error. In this paper, we developed a new localization method to improve localization performance. The new method is a pattern-matching method that uses the measured data from the nearest position, which has similar characteristics. We verified which new method was better than conventional method through Experiments using a robot. The pattern-matching method is robust to multi-path error effects.

For further work, we will solve the problem of multipath effect error referred in this paper by applying a probabilistic method.

ACKNOWLEDGMENT

This work (report, product, ..) was supported(funded) by the leading industry of advanced mechanics and equipments of the Chungcheong Leading Industry Office of the Korean Ministry of Knowledge Economy.

REFERENCES

[1] R. Mautz, "Overview of current indoor positioning system' geodezija ir kartografija, geodesy and cartography," 2009

[2] X. Y. Lu and M. S. Park, "An indoor localization mechanism using active RFID tag," in *Proc. IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing*, 2006.

[3] J. Y. Zhou and J. Shi, "RFID localization algorithms and applications—a review," *Journal of Intelligent Manufacturing* Volume 20, Number 6 pp. 695-707, 2008.

[4] M.H. Francis, P.F. Wilson, T. Kos, L.E. Miller, N.P. Bryner, D.W. Stroup, and L. Klein-Berndt, "RFID-assisted indoor localization and communication for first responders," *IEEE Trans. First European Conference on Antennas and Propagation*, 6-10 Nov. 2006.

[5] M. Kuhn, B. Merkl, A.E. Fathy, and M. Mahfouz, "Accurate UWB indoor localization system utilizing time difference of arrival approach," in *Proc. IEEE Radio and Wireless Symposium*, 2006.

[6] M. A. Stelios, A. D. Nick, M. T. Effie, K. M. Dimitris, and S. C. A. Thomopoulos, "An indoor localization platform for ambient assisted living using UWB," in *MoMM Proceedings 6th International Conference on Advances in Mobile Computing and Multimedia*, 2008, pp. 178-182.

[7] J. S. Bae, S. Y. Lee, J. B. Song, S. Y. Lee, and J. B. Song, "Use of coded infrared light for mobile robot localization," *Journal of Mechanical Science and Technology*, vol. 22 no. 7, pp.1279-1286, July 2008.

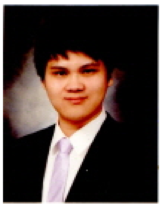
[8] E. S. Kim, "The Ranging Performance of Chirp Spread Spectrum in Indoor Multipath Environment," Seoul National University, 2008.

[9] Q. Spencer, B. Jeffs, M. Jensen, and A. Swindlehurst, "Modelling the Statistical Time and Angle of Arrival Charac-teristics of an Indoor Multipath Channel," *IEEE J. Select. Areas Commun.*, vol. 18, pp. 347–360, March 2000.

[10] K. J. Soo, "A Study on the Location Awareness System using TOA(Time of arrival) algorithm", M.S. thesis, Kangwon University, 2007.

[11] IEEE 802.15.4a 'Part 15.4: Wireless Medium Assess Control (MAC)abd Physical Layer(PHY) Specifications for Low-Rate Wirelees Personal Area Networks(WPANs)' August 31, 2007.

[12] C. C. Tsai, "A localization system of a mobile robot by fusing dead-reckoning and ultrasonic measurements," in *Proc. IEEE Instrumentation and Measurement Technology Conference*, 1998.. 1987, pp. 144-149, 1998, vol.1, pp. 18-21.



Seokyong Kim received the B.S degree in Mechatronics Engineering from ChungNam National University, Daejeon, Korea in 2011. Since 2011, he has been a M.S student at the same university. His research interests include robotics, localization and mobile robot.

Jihong Lee received the B.S degree in Electronics Engineering from Seoul National University, Korea in 1983, and the M.S. and Ph.D. degrees from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea, in 1985 and 1991, respectively, all in Electrical and Electronics Engineering, Since 2004, he has been a Professor in the Mechatronics Engineering Department of Chungnam National University, Daejeon, Korea. His research interests include robotics, intelligent control, multi-robot localization and path planning.