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Error Correction Method for 2D Ultra-Wideband Indoor Wireless Positioning System Using Logarithmic Error Model

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***Abstract*—**Indoor positioning technologies have been evolved rapidly. They augment the Global Positioning System (GPS) which requires line-of-sight to the sky to track the location of people or objects. In this study, we developed an error correction method for an indoor real-time location system (RTLS) based on an ultra-wideband (UWB) sensor from Decawave. Multiple stationary nodes (anchor) were installed throughout the workspace. The distance between stationary and moving nodes (tag) can be measured using a two-way-ranging (TWR) scheme. The result has shown that the uncorrected ranging error from the sensor system can be as large as 1 m. To reduce ranging error and thus increase positioning accuracy, we present an online correction algorithm using the Kalman filter. The results from experiments have shown that the system can reduce ranging error down to 5 cm.

***Keywords*—**Indoor positioning, ultra-wideband, error correction, Kalman filter.

I. Introduction

IN the 21st century people mostly stay in houses and buildings. More than 86% of the surveyed population spent their time indoor beside of staying outdoor [1]. A 2016 Global Research Report on The Indoor Positioning Market shows Indoor Positioning System (IPS) growth over 72% [2]. Outdoor positioning such as GPS requires line-of-sight (LOS) between satellites and receivers on the ground to track the position of people or object. This means that the receiver needs to be located outside the buildings or near building openings. An advantage of IPS is ability for user to locate their position within large building. However, there is a challenge for IPS that the indoor environments tend to be non-line of sight (NLOS) environments.

There are many kinds of indoor positioning technologies that use a variety of sensors such as ultrasonic, infrared, camera, radio frequency, magnetic technology and many more [3]. In this research, we mainly focus on using UWB technology to measure distance of an object. Advantages of UWB are high precision ranging distance, high data rates and low power signal transmission. It is also insusceptible to multipath loss which can be found in the NLOS environment [4].

In this research, we aimed to improve the accuracy of an IPS using UWB sensors from Decawave. To measure distances between sensors, real-time location algorithm with TWR scheme was used. The sensors can be considered into two types: fixed position sensors (Anchor) and moveable sensor (Tag).

Our experiments have shown that the ranging error of the sensor can be as large as 1 meter which would affected the positioning performance. To reduce this ranging error, we used a least square method to combine ranging measurements from multiple pairs of sensors to gain better estimation. Later, we extended this to an online estimation method using Kalman filter.

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II. Related Works

To improve range estimate from the Decawave sensor, the drift of the internal clock of the sensor can be calibrated [5] to remove the clock discrepancy between two sensors. Hindermann et al. [6] show the simulation of 100 tags of UWB sensor provided by Decawave with constrained Gauss-Newton algorithm to correction error in a 2-Dimensional area and showed that they can reduce error to less than 0.5 m. Poulose et al. [7] have proposed a sensor fusion framework which has shown to be able to reduce positioning error in two of their experiments to 0.42 m and 0.22 m. Haggenmiller et al. [8] provide an optimization framework that recovers both positions and antenna delays. Their result has shown that errors after correction are 3 cm in LOS and 30 cm in NLOS.

III. Methods

A. Least Square Method

The distance between a pair of sensors can be measured from TWR method. For a measurement between anchor A and a Tag, the distance is defined as d_{AT} with the actual distance $\bar{d}_{AT}$.

To improve ranging estimation, we can combine distances from a Tag to three or more anchors and find the estimated position of the tag using linear least square method. Suppose that we know the locations of each anchor $(x_i, y_i); i \in \{A, B, C\}$ and distances to the tag (d_{AT}, d_{BT}, d_{CT}), we can estimate the position of the tag $(\hat{x}_T, \hat{y}_T)$ using least square method in the following:

$$A = 2\begin{bmatrix} x_C - x_A & y_C - y_A \\ x_C - x_B & y_C - y_B \end{bmatrix} \quad (1)$$

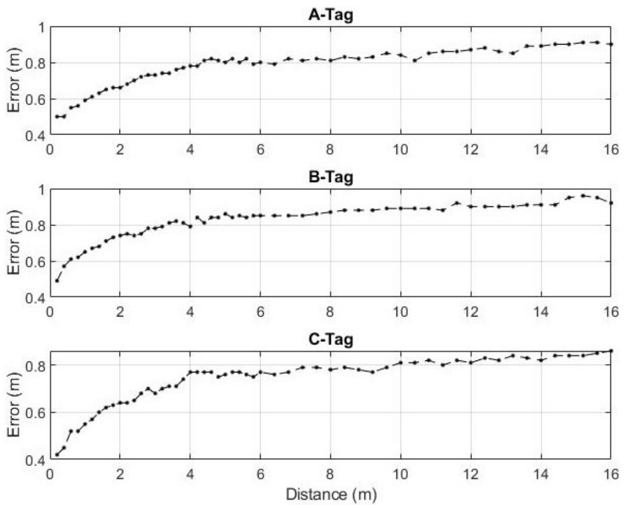

Fig. 1 Ranging error from 3 sensors as a function of measured ranges. The error follows a logarithmic trend

$$b=\begin{bmatrix}\left(d_{AT}^2-d_{AC}^2\right)-\left(x_A^2-x_C^2\right)-\left(y_A^2-y_C^2\right)\\ \left(d_{BT}^2-d_{AC}^2\right)-\left(x_B^2-x_C^2\right)-\left(y_B^2-y_C^2\right)\end{bmatrix} \tag{2}$$

$$\begin{bmatrix}\overline{x}_T\\ \overline{y}_T\end{bmatrix}=\left(A^TA\right)^{-1}A^Tb \tag{3}$$

The estimated tag position is a least square estimate from three ranging measurements. Thus, the corrected ranging using this method can be calculated from:

$$\hat{d}_{iT}=norm\left(\begin{bmatrix}x_i\\ y_i\end{bmatrix}-\begin{bmatrix}\hat{x}_T\\ \hat{y}_T\end{bmatrix}\right);i\in\{A,B,C\} \tag{4}$$

with ranging errors

$$e_{iT}=\hat{d}_{iT}-\overline{d}_{iT} \tag{5}$$

where $\bar{d}_{iT}$ is the actual distance between i[th] anchor and a tag.

B. Log Error Model with Kalman Filter Estimation

To further improve the least square estimation, we conducted many experiments to gain more insight into the source of error and its characteristic. We found that the ranging error between a pair of sensors is a combination of range error of each of the sensor. Suppose that we have a range measurement between an i[th] anchor A and a Tag, the range error of this measurement is:

$$e_{iT}=d_{iT}-\overline{d}_{iT}=e_i+e_T \tag{6}$$

where e_i and e_T are the range error of i[th] anchor and Tag, respectively. Furthermore, we empirically found that the range error is a function of the measured range. Many experiments, in which we compared range measurements with actual distances from a handheld laser range finder, have shown that the function is in a logarithmic trend as shown in Fig. 1. Thus, we can define ranging error of an i[th] sensor as a function of measured distance to the tag in the form:

$$e_i=k_{i1}\ln(d_{iT})+k_{i2} \tag{7}$$

where k_{i1} and k_{i2} are some constants. Thus, we can rewrite (6) as:

$$e_{iT}=k_{i1}\ln(d_{iT})+k_{i2}+k_{T1}\ln(d_{iT})+k_{T2} \tag{8}$$

and,

$$\hat{d}_{iT}=d_{iT}-\left(k_{i1}\ln(d_{iT})+k_{i2}+k_{T1}\ln(d_{iT})+k_{T2}\right) \tag{9}$$

Suppose that we have 3 anchors (A, B, C), we can write (9) in matrix form as:

$$\begin{bmatrix}\hat{d}_{AT}\\ \hat{d}_{BT}\\ \hat{d}_{CT}\end{bmatrix}=\begin{bmatrix}d_{AT}\\ d_{BT}\\ d_{CT}\end{bmatrix}-\begin{bmatrix}\ln(d_{AT}) & 1 & 0 & 0 & 0 & 0 & \ln(d_{AT}) & 1\\ 0 & 0 & \ln(d_{BT}) & 1 & 0 & 0 & \ln(d_{BT}) & 1\\ 0 & 0 & 0 & 0 & \ln(d_{CT}) & 1 & \ln(d_{CT}) & 1\end{bmatrix}\begin{bmatrix}k_{A1}\\ k_{A2}\\ k_{B1}\\ k_{B2}\\ k_{C1}\\ k_{C2}\\ k_{T1}\\ k_{T2}\end{bmatrix} \tag{10}$$

Using this form as a basis for an online estimator, the measured range can be improved by applying Kalman filtering which contains two steps: time update and measurement update. These algorithms are working together and updating each stage in real-time.

Time update stage equations:

$$\hat{x}_k^-=A\hat{x}_{k-1}+Bu_k \tag{11}$$

$$P_k^-=AP_{k-1}A^T+Q \tag{12}$$

Measurements update stage equations:

$$K_k=P_k^-H^T\left(HP_k^-H^T+R\right)^{-1} \tag{13}$$

$$\hat{x}_k=\hat{x}_k^-+K_k\left(z_k-H\hat{x}_k^-\right) \tag{14}$$

$$P_k=\left(I-K_kH\right)P_k^- \tag{15}$$

Let the state matrix ($\hat{x}_k^-$) be the state vector. In this case is the vector of the constant's variables.

$$\hat{x}_k^-=\begin{bmatrix}k_{A1} & k_{A2} & k_{B1} & k_{B2} & k_{C1} & k_{C2} & k_{T1} & k_{T2}\end{bmatrix}^T \tag{16}$$

Since we want to estimate these constants, the state propagation matrix A is just an identity matrix.

$$\hat{x}_k^-=\hat{x}_{k-1}+Bu_k \tag{17}$$

As for the observation matrix (H), we can apply (10) as:

$$\hat{z}_k^- = \begin{bmatrix} d_{AT} \\ d_{BT} \\ d_{CT} \end{bmatrix} - \begin{bmatrix} \hat{d}_{AT} \\ \hat{d}_{BT} \\ \hat{d}_{CT} \end{bmatrix} = H\hat{x}_k^- \tag{18}$$

where

$$H = \begin{bmatrix} \ln(d_{AT}) & 1 & 0 & 0 & 0 & 0 & \ln(d_{AT}) & 1 \\ 0 & 0 & \ln(d_{BT}) & 1 & 0 & 0 & \ln(d_{BT}) & 1 \\ 0 & 0 & 0 & 0 & \ln(d_{CT}) & 1 & \ln(d_{CT}) & 1 \end{bmatrix} \tag{19}$$

The estimated range $[\hat{d}_{AT} \quad \hat{d}_{BT} \quad \hat{d}_{CT}]^T$is from the least-square method from (4) with range correction $H\hat{x}_k^-$.

IV. Experiment

The purposed algorithm was tested in simulation using MATLAB. We set 3 anchor nodes in different positions and move the tag node randomly around the workspace. We can inject the range error to the measurement and test how well our correction method works. The ranging error of each of the anchor-tag pair before (black) and after (gray) with a function of distance between the sensors can be shown in Fig. 2. Fig. 3 shows error as a function of the simulation step. The results have shown that our Kalman filter correction method can significantly reduce range error into less than 10 cm.

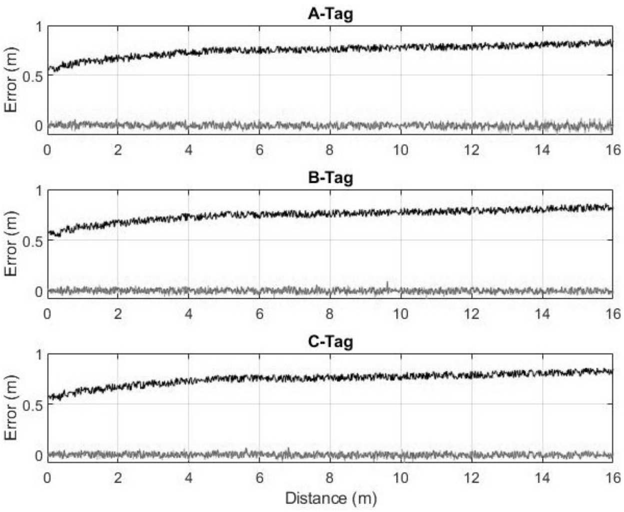

Fig. 2 Ranging Error before (black) and after correction (gray) as a function of distance

We also tested our method using real sensor in real workspace. Our sensor board consisted of a Decawave DWM1000 sensor module and Teensy 3.2 microcontroller installed into a custom PCB board. We used this sensor board for both anchor and tag role but with different firmware. Beacons were installed in the testing area of 132 m^2.

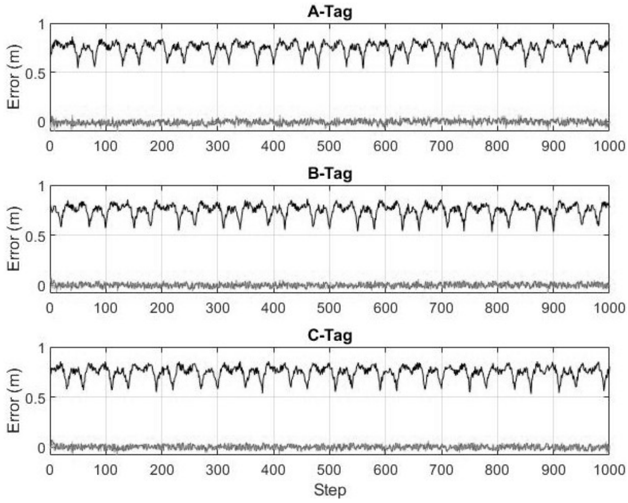

Fig. 3 Ranging Error before (black) and after correction (gray) as a function of simulation step

Anchor nodes were distributed to the corners of the testing area. The tag node was moved around the testing area and data of distances were sent to a laptop. MATLAB is used for computing the same algorithm as we have used in simulation but we replaced the simulation distances with the measured distances from the sensors instead. The raw uncorrected range error between a pair of sensors can be calculated by comparing the distance from the sensors with the actual distance measured using a handheld laser range finder as shown in Fig. 4.

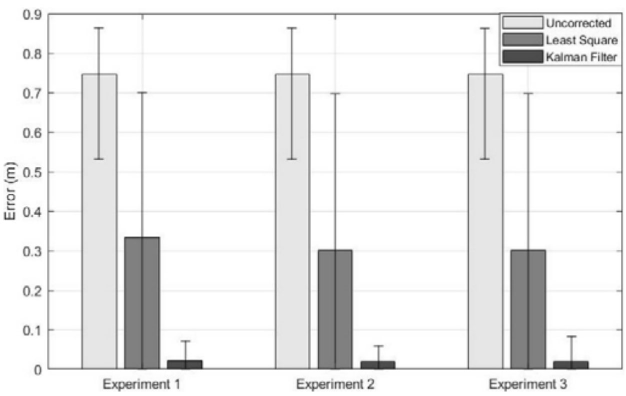

Fig. 4 Ranging error without any correction, least-square method and Kalman filter.

The results in Fig. 5 show that error from each beacon can be reduced by using error correction. Uncorrected ranges measured by sensors had more than 80 cm of error compared with the actual distance. We found that by using only least-square estimation method, the error can be reduced to around 30 cm level. Our error correction method with Kalman filter has shown that it can reduce the ranging error approximately 5 cm which is almost 20 folds of improvement from the uncorrected measurement.

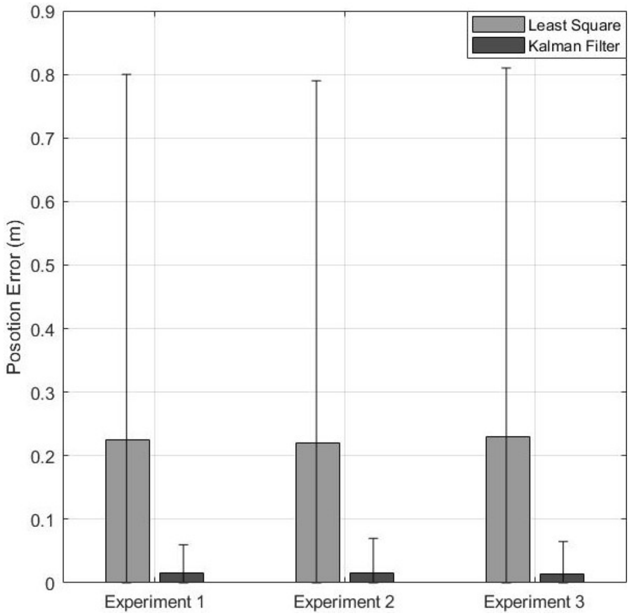

Fig. 5 Positioning error using only least-square method and with Kalman filter

V. CONCLUSION

In this research, we propose an error correction method for indoor wireless positioning system using UWB technology. Our method can significantly reduce ranging error by 85.7% from uncorrected measurement. Even though this method is tested in 2D environment, it can be easily expanded to 3D environment. Furthermore, this high-performance IPS can be used in any autonomous robot that needs precision and accuracy in the working area.

REFERENCES

[1] Klepeis, N.E., et al., The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. 2001. 11(3): p. 231-252.
[2] Indooratlas. A 2016 Global Research Report on the Indoor Positioning Market, 2016.
[3] Mautz, R., Indoor positioning technologies. 2012.
[4] Allen, B., et al. Ultra wideband: Applications, technology and future perspectives. 2005. international workshop on convergent technologies (IWCT).
[5] Decawave APS013 Application Note, The implementation of two way ranging with the DW1000, 2018.
[6] Hindermann, P., et al., High precision real-time location estimates in a real-life barn environment using a commercial ultra wideband chip. 2020. 170: p. 105250.
[7] Poulose, A., J. Kim, and D.S.J.A.S. Han, A sensor fusion framework for indoor localization using smartphone sensors and Wi-Fi RSSI measurements. 2019. 9(20): p. 4379.
[8] Haggenmiller, A., M. Krogius, and E. Olson. Non-parametric error modeling for ultra-wideband localization networks. in 2019 International Conference on Robotics and Automation (ICRA). 2019. IEEE.