A TOA Cooperate with AOA Location Algorithm Based on IR-UWB

Zhihao Wang, Chong Shen, Gaoang Feng, and Chunhua Long

***Abstract*—IR-UWB applications in indoor localization, to fill the gaps in the indoor high precision localization technology. IR-UWB has a high bandwidth, low power consumption and no carrier. The pulse signal can provide high time resolution, so it can get higher localization accuracy. In this paper, to locate by using TOA synergy AOA based on the IR-UWB signal. This localization algorithm, only need one anchor to complete it. In the case of multipoint localization, the tags distributed in the special position may cause some localization error in TOA. This will be resolved by combining with the AOA. Furthermore, we have tested on the HN-EVK1000 equipment.**

***Index Terms*—AOA, indoor localization, IR-UWB, TOA.**

I. INTRODUCTION

Global Positioning System (GPS) by satellite has been widely used in outdoor localization due to signal attenuation by the building fabric [1], but it does not work well at all in an indoor environment. Wi-Fi, Bluetooth and radio-frequency location system can be used in indoor low precise localization. The application of Impulse Radio-Ultra Wideband (IR-UWB) has some advantages to achieve the indoor high precise localization by sensors [2]. HDR-UWB (High Data Rate UWB) uses MB-OFDM (Multi Band - Orthogonal Frequency Division Multiplexing) to transmit signals, which can reach a data rate of 200 Mbit/s.

Time-of-arrival (TOA) and angle-of-arrival (AOA) measurements play an important role in positioning systems that employ impulse radio IR-UWB signals. TOA or TDOA of ranging frame are widely used because TOA and TDOA provide high accuracy due to the high time resolution with high bandwidth of IR-UWB signal. TOA and TDOA methods localization is through sending and receiving the signals to measure distance. But AOA is different from that which localizes through measuring the angle information of sending and receiving signals. While even relatively simple receivers can measure TOA with high accuracy, it is much more complex to have precise AOA measurements [3].

In this paper, we are concerned with IR-UWB localization in relatively large NLOS environments making use of simultaneous TOA and AOA measurements. TOA using the IR-UWB signal not only offers high precision location information, but also the low calculated amount. It is suitable for sensors to localize. But in multiple targets case, because TOA based on distance, the direction information is not provided. That may cause miss localization in some special situations. Using TOA association with AOA, there are less miss localization and more precision localization.

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II. SIGNAL MODEL

FCC (Federal Communications Commission) had defined the UWB. IR-UWB signal has the properties which are Strong anti-jamming performance, high transmission rate and large capacity of system. These are advantages showing by Fig. 1 while using in indoor localization.

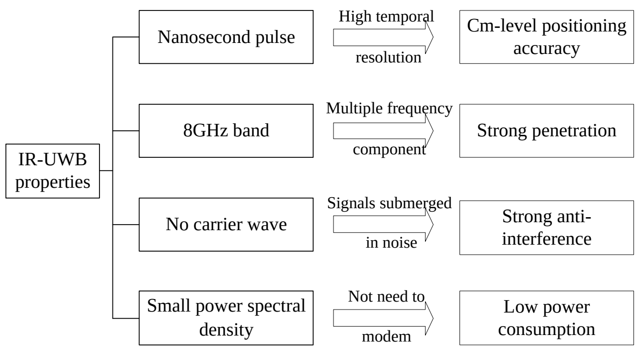

Fig. 1. Advantages of IR-UWB.

High accuracy indoor localization requires the system with a high temporal resolution. That can be realized by using pulse signal. The duration of the pulse signal in time domain is extremely short. Supposing the bandwidth of UWB signal is 0.1ns, then localization accuracy can achieve 3cm in theory. Besides UWB signal belongs high-frequency signal, it is less influence of multipath effect. Smaller distortion rate can ensure the high localization accuracy of measurement. Different from common carrier signal, UWB signal does not have carrier wave. With the addition of the characteristics of low power, it is amazing to found there is small interference between UEB and other signals.

IEEE 802.15.4a has given the power, frequency and channel about UWB. In [4], [5], it has described the IR-UWB signal in Mathematical model. The signal that tag transmits can be expressed as follow:

$$s(t) = \sum_{i=-\infty}^{\infty} a_i \omega(t - iT_s) \tag{1}$$

where $\omega(t)$ is an ultra-short monocycle of duration T_S, $1/T_S$ is the pulse rate, $\{a_i\}$ are the data symbols taking values ±1.

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We use the channel with the standard IEEE 802.15.4a, the received signal at the nth element can be represented as follows:

$$r_n(t) = \sum_{i=0}^{M_S}\sum_{l=0}^{L_n-1} a_i b_{n,l} p(t - iT_s - \tau_{n,l}) + n_n(t) \quad (2)$$

where $p(t)$ is single UWB impulse signal; a_i is the ith transmitted symbol taking values ±1; L_n is the number of multipath at element n; $b_{n,l}$ and $\tau_{n,l}$ is the amplitude and delay of the lth multipath signal at element n respectively; TS is the pulse period; $n_n(t)$ is additive white Gaussian noise(AWGN) at element n with zero-mean and $N_0/2$ double sided power spectral density. $\tau_{n,l}$ represented the direct path signal delay which is the TOA for element n, we set it τ_n for short.

III. Localization Algorithm

A. TOA

TOA localization algorithm as shown in Fig. 2 is based on TOA circumference equation, through the different combination of intersecting lines between circle and circle, construct different positioning equation [6].

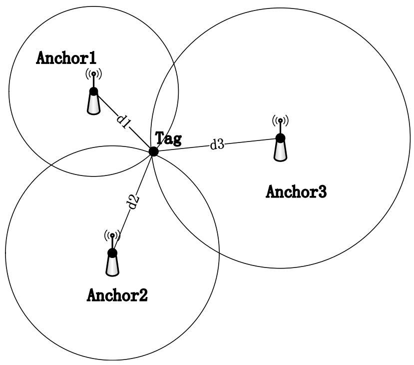


Fig. 2. TOA location principle diagram.

From the geometry model, assumed the signal transmit from tag to anchors. The measured distance is d_i:

$$d_i = \sqrt{(x_i - x_t)^2 + (y_i - y_t)^2}, i = 1,2,3 \quad (3)$$

$(x_i, y_i)$is the *NO. i* anchor's coordinate, (x_t, y_t) is coordinate of tag.

Then the tag must be located on the circumference of a circle with radius *di* centered on the anchor. When there are three anchors' coordinates, TOA measurement equation can be expressed as follow:

$$(x_2 - x_1)x_t + (y_2 - y_1)y_t = \frac{1}{2}[(x_2^2 + y_2^2) - (x_1^2 + y_1^2) + (d_1^2 - d_2^2)] \quad (4)$$

$$(x_3 - x_2)x_t + (y_3 - y_2)y_t = \frac{1}{2}[(x_3^2 + y_3^2) - (x_2^2 + y_2^2) + (d_2^2 - d_3^2)] \quad (5)$$

Simultaneous equations, we can calculate the coordinates of the tags:

$$x_t = \frac{(y_2 - y_1)D_3 - (y_3 - y_2)D_1}{[(x_3 - x_2)(y_2 - y_1) - (x_2 - x_1)(y_3 - y_2)]} \quad (6)$$

$$y_t = \frac{(x_2 - x_1)D_3 - (x_3 - x_2)D_1}{[(y_3 - y_2)(x_2 - x_1) - (y_2 - y_1)(x_3 - x_2)]} \quad (7)$$

where:

$$D_1 = \frac{1}{2}[(x_2^2 + y_2^2) - (x_1^2 + y_1^2) + (d_1^2 - d_2^2)] \quad (8)$$

$$D_3 = \frac{1}{2}[(x_3^2 + y_3^2) - (x_2^2 + y_2^2) + (d_2^2 - d_3^2)] \quad (9)$$

These are direct method using distance information to locate that the precision is limited. To gain the high precision localization information, there are other steps to take. In order to improve the localization performance of the commonly used way is to make full use of redundant information reference node optimize the positioning results, namely, to establish an objective function based on maximum likelihood estimation. Kalman filtering in the dynamic system of Gaussian white noise is a kind of optimal filter. It can effectively suppress noise in the measurement and enhance environmental interference robustness, improve the positioning accuracy [7].

State equation model is following:

$$x_{i+1} = \Phi_i x_i + w_i \quad (10)$$

where $x_i=(x_i, y_i)T$ is the localization of tag which the NO.i-1 anchor calculated after filtering. w_i is the system noise, obey Gaussian distribution. φ_i is the system matrix, in the process of tag localization, thought the position of the tag is fixed. Therefore, φ_i is the second order unit matrix, the system noise variance $Qi=0$.

Measurement equation model is following:

$$d_i = \sqrt{(X_i - x)^2 + (Y_i - y)^2} + v_i = H_i x_i + v_i \quad (11)$$

where d_i is tag to the distance of the *NO.i* anchor, it is according to the measured distance measuring method, (X_i, Y_i) are the coordinates of the *NO.i* anchor, coordinates (x, y) is a label. v_i is the measurement noise, obey the mean is zero, the variance of Gaussian distribution of R. By expanding Taylor series for measuring equation linearization, take the coordinates of the tag after the last filtering vector, the measurement equation is this:

$$d_i = d_0 + h_i \delta_{x_i} + v_i,$$

$$d_0 = \begin{bmatrix} \sqrt{(X_1 - x_i)^2 + (Y_1 - y_i)^2} \\ \vdots \\ \sqrt{(X_N - x_i)^2 + (Y_N - y_i)^2} \end{bmatrix},$$

$$H_i = \begin{bmatrix} h_x^1 & h_y^1 \\ \vdots & \vdots \\ h_x^N & h_y^N \end{bmatrix} (h_x^i = \frac{x_0 - X_i}{d_{i0}}, h_y^i = \frac{y_0 - Y_i}{d_{i0}}) \quad (12)$$

Extended Kalman localization of the flow diagram as shown in Fig. 3, mainly includes the state variables and the error variance matrix initialization, state equation and measurement equation is linearized, computing the Kalman gain, update the status variables, forecasts and other five steps.

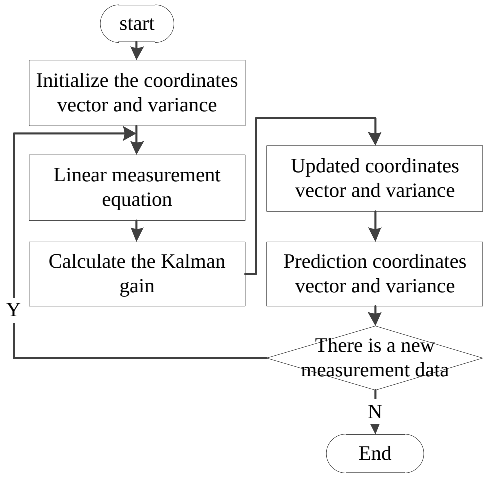
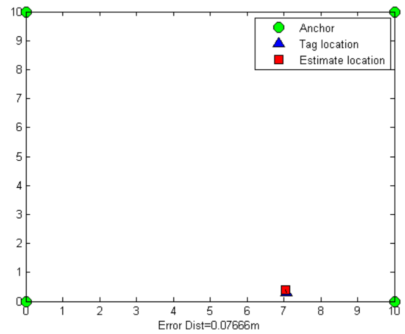
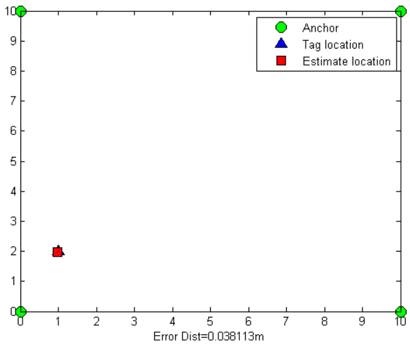


Fig. 3. The flow chart of Kalman filter.

Localization data through Kalman filter is more accurate than the data that is direct measured. Fig. 4 shows us the effect of the Kalman filter directly by a set of contrasting the simulation data on MATLAB.



a). The data through Kalman filter.



b). Direct measured localization data.

Fig. 4. TOA simulation results.

The simulation of the area is 10 × 10m rectangle. From the simulation data, the error of localization data through Kalman filter is 0.0381m, but the data direct measured has 0.0767m error. In TOA, using Kalman filter can make the data more accurate. That improvement should owe to Kalman filter which does not require the assumptions that the signal and noise are stationary processes. For each moment system perturbation and observation error, as long as some appropriate assumptions are made for their statistical properties, through the observation of contain noise signal processing, can be in the average sense, obtained the error to a minimum estimate of the real signal.

But it is still worth noting, simulation does not take into account some factors such as the ability of anchors and tags to send and receive.

B. TOA Cooperate with AOA

TOA does well in terms of location and distance measurement, but failure in the direction of information. AOA use the angle of the received signal to locate. Anchor can calculate receiving labels angle by the received signal. Extension cord at the receiving point of view, two such extension of the coordinates of the intersection is the tag.

From Fig. 5, receiving labels angle can be expressed as following:

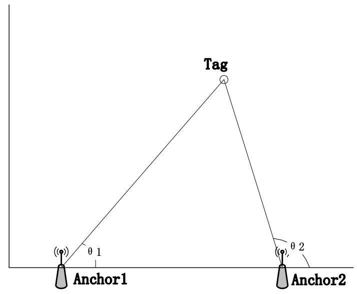


Fig. 5. AOA location principle diagram.

$$\tan(\theta_i) = \frac{x_0 - x_i}{y_0 - y_i}, i = 1, 2 \tag{13}$$

There is a simulation of AOA location. Setting the angle between the tag and the anchor are respectively 37°, 108°, 167°. The result is this:

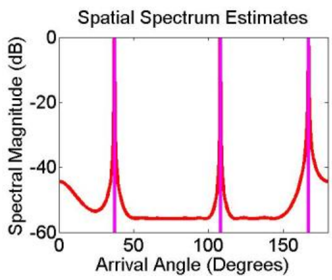


Fig. 6. AOA simulation results.

The calculated angles are 37.0071°, 107.9969° and 166. 9823°.

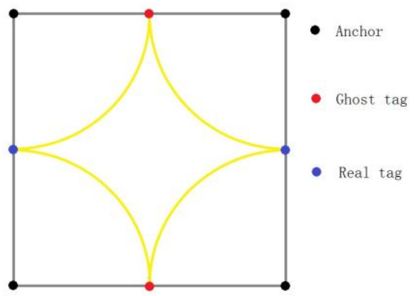


Fig. 7. Ghost tag schematic diagram.

In 2D space, TOA needs three anchors at least to localize. AOA needs two anchors at least to complete it [8]. Combine TOA with AOA, the one anchor can realize localization. In [9], it puts forward "the ghost tags". When two or more tags to locate at the same time, the ghost tags [9] may appear in some special cases as Fig. 7 shows.

IV. The Test Data

Essentially, the followed tests have been done by HN-EVK1000 in a rectangular laboratory which is 6.8m × 12.6m. We can visually observed results of the tests on our system client.

Fist, using only one anchor to locate one tag by TOA cooperate with AOA. The test data are show by Fig. 8.

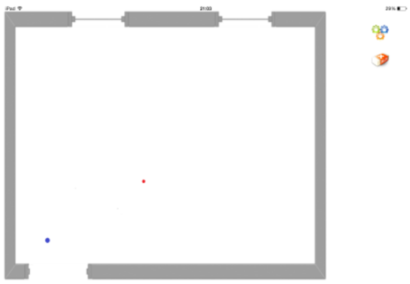


Fig. 8. The data of one anchor and one tag.

In Fig. 8, the blue point stands for anchor, the red one is tag. Compared the located results with the true location, error is 0.0867m.

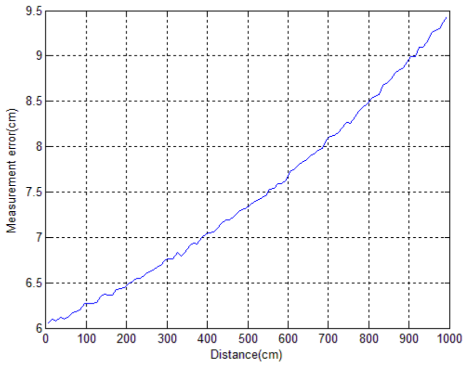


Fig. 9. The data of one anchor and one tag.

The more tests we do, the data presents a pattern shown by Fig. 9: if tag is further to anchor, the error is bigger. Because of the error which from the calculated angle, the points on the extension will be more and more deviated from the real value. Further, the calculated distance is not completely correct. The located area is limited in indoor localization. Therefore, the four anchors which are setting on the four corners of the region. We use the four localization data to do weighted summation. The algorithm is the anchor that measured distance is smaller, the more weighted it get. The weight used in the test is [0.5, 0.2, 0.2, 0.1]. Test data is as Fig. 10 shows:

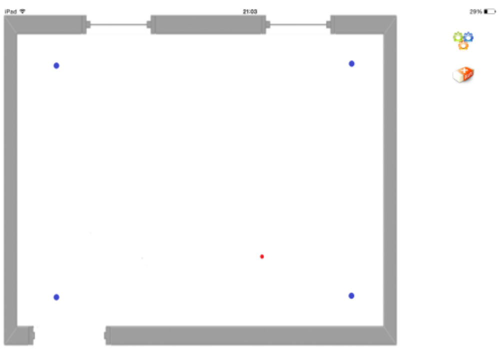


Fig. 10. The data of four anchors and one tag.

Fig. 10 is one of results. We have tested 10 points that each point record data 10 times. The average error is 0.0658m. Each result anchor measured has an error different from others. When calculating the average, different weights to each anchor through the result can improve the accuracy of localization. Assigning weights rule follows the principle that small numerical data has higher weight.

Second, test use four anchor to locate two tags at the same time. The localization of tag is set in the diagonal to test if there will be the ghost tags. The result shown by locating client software is as Fig. 11 shows:

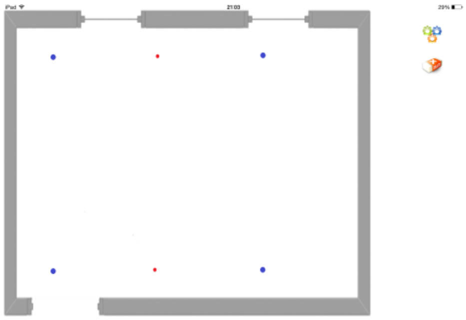


Fig. 11. The data of four anchors and two tags.

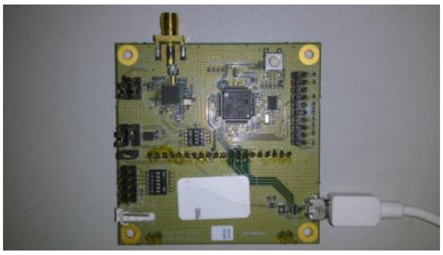


Fig. 12. Anchor of HN-EVK1000.

Fig. 13. Working state of anchor.

This is a tag of HN-EVK1000.

Fig. 14. Tag of HN-EVK1000.

In Fig. 11, there is no ghost tag. It correctly to locate the location of the two tags. The error of the two tags respectively is 0.0712m and 0.0693m.

V. Conclusions

Indoor localization algorithms based on different principle.

AOA algorithm is the measurement of angle for localization. TOA algorithm is based on the measured distance for localization. They each have their own advantages and disadvantages. AOA algorithm needs less resources but accuracy is not high, TOA algorithm with high precision but need more equipment and clock synchronization needs to be done. Combining with two kinds of algorithms, it is possible to locate a tag using one single anchor. And this algorithm does not need strict clock synchronization. But this method is suitable for small range of localization. Once the range of localization become bigger, in order to maintain the higher localization accuracy, it is necessary to set more anchors in other places. In addition, it also does not appear the ghost tags in multipoint localization case. The next step will be to research on how to implement localization network scalability.

ACKNOWLEDGMENT

This work was tested by HN-EVK1000 in the HaiNan University.

This is an anchor of HN-EVK1000 as Fig. 12 and working state as Fig. 13.

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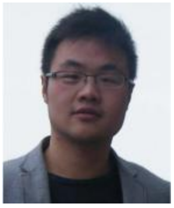

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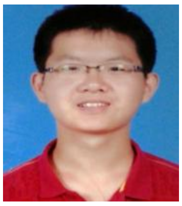

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