Research on Maximum Likelihood Estimation Location Method Based on UWB Platform

Qinghua Luo, Sicheng Liu and Jie Wang

May 26, 2019

Research on Maximum Likelihood Estimation Location Method Based on UWB Platform

Qinghua Luo	Sicheng Liu	Jie Wang
1. School of Information Science and Engineering, Harbin Institute of Technology,weihai #1	1. School of Information Science and Engineering, Harbin Institute of Technology,weihai #1	1. School of Information Science and Engineering, Harbin Institute of Technology,weihai #1
2. Shandong Institute of Shipbuilding Technology #2	2. College of Information Science and Engineering #2	2. College of Information Science and Engineering #2
Weihai, China	Weihai, China	Weihai, China
luoqinghua081519@163.com	before_the_dawn@163.com	13280787539.oka@163.com

***Abstract*—UWB platform is a system suiTABLE for high precision ranging and location. A location algorithm suiTABLE for indoor and outdoor scenes is essential to make better use of UWB platform. Maximum likelihood estimation(AML) is a simple and accurate location algorithm, which can meet the requirements of location algorithm based on UWB platform. AML method is studied in this paper. Firstly, we analyze the location principle of AML method. Then, we carried out indoor and outdoor location experiments to verify the effectiveness of AML. Finally, we compare and analyze the mean uncertainty of different location algorithms in different environments, and draw conclusions based on the analysis results. The experimental results show that AML has the highest accuracy in both indoor and outdoor environments, and is the most suiTABLE location algorithm for UWB-based location in the most simple and commonly used LS, AML and trilateral measurement methods.**

Keywords—UWB Platform,AML,Location,Uncertainty

Wireless location could provide crucial position information for various application systems, including PHM (Prognostics and Health Management) system, aerospace, emergency scheduling, rescue and relief, and many other related location-based services system[1]. Location information has certain reference value and decision value, and plays an important role in these systems. However, many uncertainty factors, such as environmental noise, measurement error, non-line-of-sight (NLOS) or multipath propagation of radio signals, have a negative impact on location accuracy, resulting in poor location [1-3].Even worse, it may cause wrong result or wrong action for later deep processing method or decision-making system, because the later processing method or system utilize the localization result as important priori information.

Ultra-wideband(UWB) technology is a sub nanosecond ultra narrow pulse wireless communication technology, which directly modulates impulse pulses with steep rise and fall time, so that the signal has GHz bandwidth. Compared with other location technologies, UWB technology has many advantages, such as high time resolution, good anti-multipath effect, high security, strong penetration, simple hardware structure, etc. It is suiTABLE for high-precision ranging and location, and has a wide application prospect[4-8].

At present, the location algorithms based on UWB platform include Fang algorithm[9], Chan algorithm[10], Taylor algorithm[11], least square method (LS), maximum likelihood estimation (AML), trilateral measurement (Caffery) and so on. AML is a location method based on maximum likelihood principle. It is a location algorithm suiTABLE for UWB platform which is based on TOA information and has good location accuracy as well as low computational complexity. This paper will use LS, AML, Caffery, the three most simple and commonly used algorithms in indoor and outdoor scenes, to carry out location experiments under the set scenarios. By comparing and analyzing mean location uncertainty of different algorithms in the coverage area of the location network, it shows the superiority of AML algorithm in UWB platform location.

The rest of this paper is organized as follows: In part I, we will introduce UWB (mainly introduce its ranging principle); in part II, we will analyze the principle of AML location; in part III, we will illustrate the advantages of AML algorithm over LS and Caffery location methods through simulation; in part IV, we will verify the accuracy advantages of AML over LS and Caffery location methods through experiments; finally, we come to the conclusion of this paper.

I. UWB INTRODUCTION

Ultra-wideband technology is a new communication technology, which differs greatly from traditional communication technology. It does not need the carrier in traditional communication system, but transmits and receives extremely narrow pulses with nanosecond or below to transmit data, so it has GHz bandwidth.

Compared with traditional narrowband system, UWB system has many advantages, such as strong penetration, low power consumption, good anti-multipath effect, high security, low system complexity and accurate location accuracy. Therefore, UWB technology can be applied to indoor static or mobile objects and human location trackingg and navigation, and can provide accurate location accuracy.

The node P440 for UWB platform uses TW-TOF (two-way-time of flight) to measure distance. The measurement accuracy is 2 cm and the ranging frequency can reach 125 Hz. Each module generates a separate timestamp (a complete, verifiable data that represents a data that already exists at a specific point in time) from the start. As shown in Figure 1, the transmitter of Module A transmits a request-like pulse signal on its timestamp Ta_1, which is received by Module B at its own timestamp Ta_2; Module B transmits a response-like signal at Tb_1 and is received by Module A at its own timestamp Tb_2. From this, the flight time between the two modules of the pulse signal can be calculated, and the flight distance s can be determined:

$$s=c*[(Tb_2-Ta_1)-(Tb_1-Ta_2)] \tag{1}$$

Where c is light speed.

Figure 1. UWB Ranging Diagram

TW-TOF is essentially the same as TOA, but compared with TOA ranging, it does not require strict synchronization of clock time between the two sides, and has lower requirements for ranging equipment than TOA. TOF ranging method has two key constraints: one is that the clock rate of the transmitting device and the receiving device must be equal; the other is the transmission time of the signal provided by the receiving device.

In addition, P440 measures the strength of the first arrival signal to provide a rough range estimation (CRE). Since information from one node can be received by many nodes, CRE is actually broadcast, and each transmission will result in the generation of CRE at each receiving node. CRE updates PRMs regularly to maintain accuracy. The re-calibrated and filtered CRE is presented in the form of filter range estimation (FREs).

II. AML PRINCIPLE

Maximum likelihood estimation location algorithm

As Figure 2 shows, assuming that the unknown node is $P(x,y)$. There are n anchor nodes around. They are A_1, A_2, A_3, $\cdots$, A_n ,and their coordinates are $(x_1,y_1),(x_2,y_2),(x_3,y_3),\cdots,(x_n,y_n)$, The distance from the anchor nodes to the unknown node are $d_1,d_2,d_3,\cdots,d_n$. According to the geometric relationship, we can know the following formula.

$$\begin{cases} (x_1-x)^2+(y_1-y)^2=d_1^2 \\ (x_2-x)^2+(y_2-y)^2=d_2^2 \\ \vdots \\ (x_n-x)^2+(y_n-y)^2=d_n^2 \end{cases} \tag{2}$$

Subtracting the last equation from the first n-1 equations yields the following equation:

$$\begin{cases} x_1^2-x_n^2+y_1^2-y_n^2-2x(x_1-x_n)-2y(y_1-y_n)=d_1^2-d_n^2 \\ x_2^2-x_n^2+y_2^2-y_n^2-2x(x_2-x_n)-2y(y_2-y_n)=d_2^2-d_n^2 \\ \vdots \\ x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2-2x(x_{n-1}-x_n)-2y(y_{n-1}-y_n)=d_{n-1}^2-d_n^2 \end{cases} \tag{3}$$

Written in matrix form as follows:

$$AX=B \tag{4}$$

$$A=\begin{bmatrix} 2(x_1-x_n) & 2(y_1-y_n) \\ 2(x_2-x_n) & 2(y_2-y_n) \\ \vdots & \vdots \\ 2(x_{n-1}-x_n) & 2(y_{n-1}-y_n) \end{bmatrix} \tag{5}$$

$$B=\begin{bmatrix} x_1^2-x_n^2+y_1^2-y_n^2+d_n^2-d_1^2 \\ x_2^2-x_n^2+y_2^2-y_n^2+d_n^2-d_2^2 \\ \vdots \\ x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2+d_n^2-d_{n-1}^2 \end{bmatrix} \tag{6}$$

$$X=[x\ \ y]^T \tag{7}$$

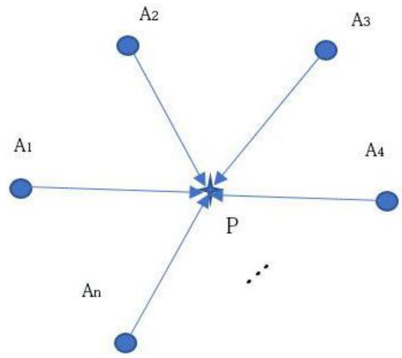

Figure 2. Location schematic map based on ranging

The coordinates of unknown nodes can be obtained by using the method of minimum mean square deviation estimation of standard deviation as shown in the formula.

$$X=(A^TA)^{-1}A^TB \tag{8}$$

AML makes full use of the information of anchor nodes around unknown nodes, and its location accuracy is higher than that of trilateral measurement location algorithm, but its computation is much larger than that of trilateral measurement location algorithm[12].

The location accuracy and speed of AML are evaluated by simulation and experiment. Firstly, we compare it with Caffery and LS by simulation. Then, in a specific location environment, the performance of AML location is verified.

III. SIMULATION

A.Comparisons of Algorithms'Running Speed

The three algorithms are positioned and timed at a given location and distance. The average running time of the three algorithms is taken 100 times in a cycle. The operation time of the three algorithms is as follows:

TABLE I. COMPARISON OF RUNNING TIME OF ALGORITHMS

Location method	Caffery	AML	LS
Operation time/s	0.0727	0.0710	0.0690

As TABLE I. knows, there is little difference in the speed of the three location algorithms.

B.Comparison of location accuracy

In order to verify the feasibility and practicability of AML location method, anchor nodes and blind nodes are fixed deployment method, and 11.2m *4.8m location coordinate system is adopted in the simulation.As shown in Figure 3, five fixed anchor nodes are set up, and 15 unknown nodes are selected among the anchor nodes.The trilateral location method chooses the average values of the location coordinates obtained from all three anchor nodes which are not collinear in the coordinate system. AML and LS methods are carried out in this coordinate system.

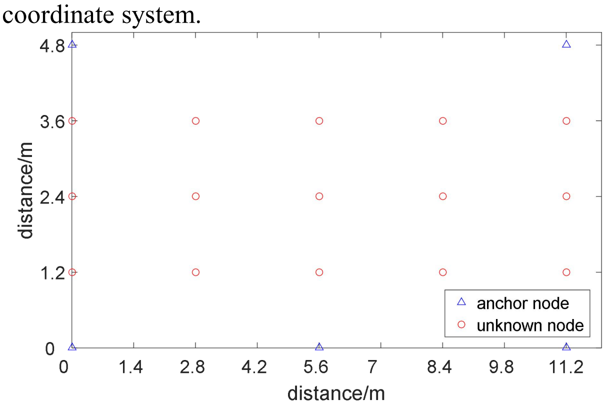

Figure 3. Established location coordinate system

In the presence of ranging error and Gaussian white noise, the absolute error of intermediate point A (5.6, 2.4) is simulated by three methods. For convenience of observation, the Gaussian white noise with standard deviation of 0.001-0.05 is taken.

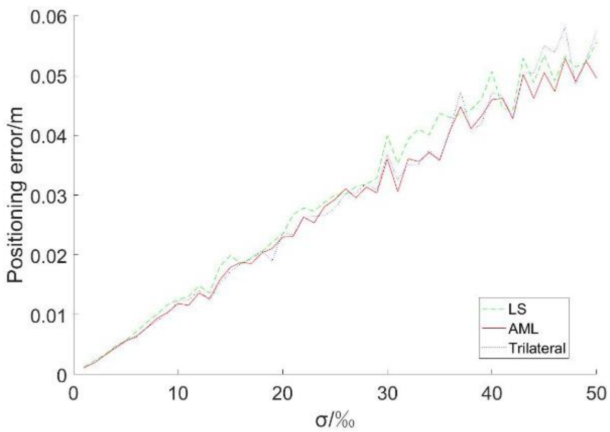

Figure 4. Simulation comparison of three algorithms

By comparing the simulation results of the three methods, it is found that the AML algorithm is better than the other two algorithms in simulation, so the AML method proposed by us is feasible and effective.

IV. EXPERIMENT

A.Indoor location experiment settings

We have set up a 2-D location system of 11.2m x 4.8m in the hall. The anchor nodes and unknown nodes are set as Figure 5. They are deployed on the pallet and the height of the pallet is set to 1.5m. There are five anchor nodes and fifteen unknown nodes.The coordinate information of five anchor nodes is shown in TABLE II. The actual coordinates of unknown nodes are shown in TABLE III. 2-D location is carried out at these points. Statistical information is obtained by repeating distance estimation and location 50 times at each point. The actual layout is shown in Figure 5.

TABLE II. COORDINATES OF ANCHOR NODES

Anchor ordinal	1	2	3	4	5
coordinate	(0,0)	(5.6,0)	(11.2,0)	(0,4.8)	(11.2,4.8)

TABLE III. ACTUAL COORDINATES OF UNKNOWN NODES

Unknown Node Ordinal Number	1	2	3	4	5
	6	7	8	9	10
	11	12	13	14	15
Actual coordinate	(0,1.2)	(2.8,1.2)	(5.6,1.2)	(8.4,1.2)	(11.2,1.2)
	(11.2,2.4)	(8.4,2.4)	(5.6,2.4)	(2.8,2.4)	(0,2.4)
	(0,3.6)	(2.8,3.6)	(5.6,3.6)	(8.4,3.6)	(11.2,3.6)

Figure 5. Indoor location scene layout

In order to evaluate the feasibility and validation of the proposed method, we use Caffery, AML and LS to locate, and compare their location accuracy.

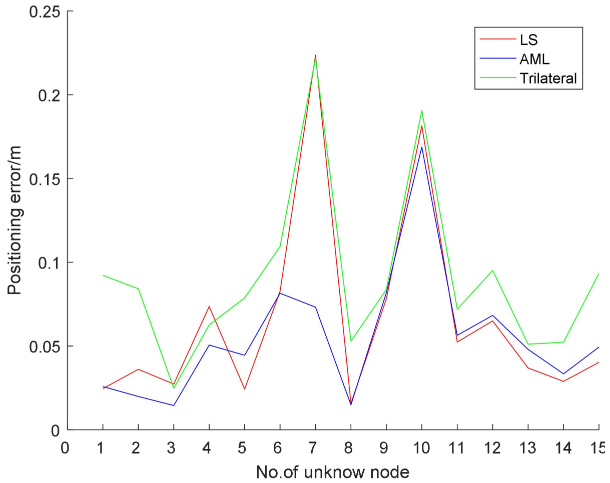

Figure 6. Comparison of three location algorithms for indoor location

According to the data of indoor location experiment, the location performance of AML is better than the other two algorithms in the actual indoor location system.

B.Outdoor location experiment settings

We have set up a 12m×4.8m two-dimensional location system in the square, and deployed them on the tray, the height of the tray is set to 1.5m. There are five anchor nodes and fifteen unknown nodes. The coordinate information of 5 anchor nodes is shown in TABLE IV., and the actual coordinates of unknown nodes are shown in TABLE V. 2-D location is carried out at these points. Statistical information is obtained by repeating distance estimation and location 50 times at each point. The actual layout is shown in Figure 7.

TABLE IV. COORDINATES OF ANCHOR NODES

Anchor ordinal	**1**	**2**	**3**	**4**	**5**
coordinate	(0,0)	(6,0)	(12,0)	(0,4.8)	(12,4.8)

TABLE V. ACTUAL COORDINATES OF UNKNOWN NODES

Unknown Node Ordinal Number	**1**	**2**	**3**	**4**	**5**
	6	**7**	**8**	**9**	**10**
	11	**12**	**13**	**14**	**15**
Actual coordinate	(0,1.2)	(3,1.2)	(6,1.2)	(9,1.2)	(12,1.2)
	(12,2.4)	(9,2.4)	(6,2.4)	(3,2.4)	(0,2.4)
	(0,3.6)	(3,3.6)	(6,3.6)	(9,3.6)	(12,3.6)

Figure 7. Outdoor location scene layout

We use Caffery, AML and LS to locate and compare their locating accuracy in order to evaluate the feasibility and validation of our proposed method.

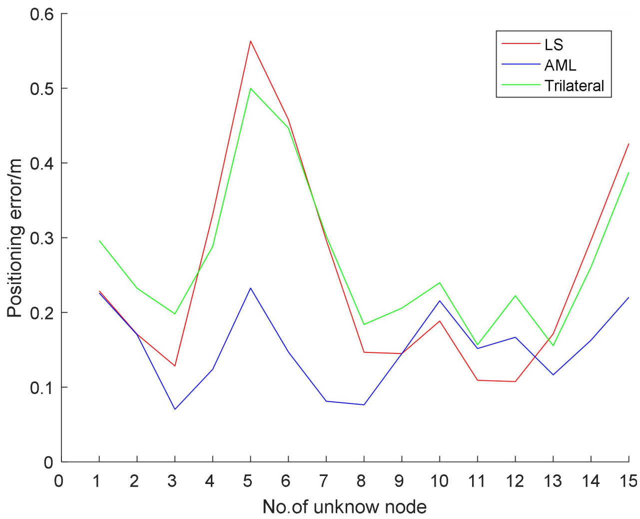

Figure 8. Comparison of three location algorithms for outdoor location

According to the data of outdoor location experiment and Figure 8, AML has better location performance than the other two algorithms in the actual outdoor location system.

Lateral comparison shows that the accuracy of outdoor location is higher than that of indoor location, which is due to the multi-path effect of indoor location. UWB location signal will be reflected and refracted by the surrounding environment such as walls, glass and desktop in the process of transmission, resulting in multi-path effect. The change of signal in delay, amplitude and phase results in energy attenuation and signal-to-noise ratio decrease, which results in the first arrival signal being not a direct signal, and the ranging error and location accuracy are also reduced.

V. CONCLUSION

Through the simulation and experimental comparison of AML and other two commonly used algorithms, this paper finds out the most suiTABLE location algorithm for UWB platform. In this paper, the location principle of AML algorithm is analyzed, and simulation and physical experiments are carried out to verify the advantages of AML over LS and trilateral measurement. The results of simulation and indoor and outdoor experiments show that AML algorithm has the advantages of computational complexity and accuracy compared with the other two location algorithms. It is more suiTABLE for UWB platform location algorithm and provides suiTABLE location algorithm for various systems based on location information.

REFERENCES

[1] Q. Luo, Y. Peng, X. Peng, et al, “Uncertain data clustering-based distance estimation in Wireless Sensor Networks”, Sensor, vol. 14, no. 4, pp. 6584-6605, 2014.

[2] P. Moravek, K. Dan, M. Simek, et al, “Investigation of radio channel uncertainty in distance estimation in wireless sensor networks”, Telecommunication Systems, vol. 52, no. 3, pp.1549-1558, 2016.

[3] C. Lu, G. Liu, B. Liu, et al, “Absolute distance measurement system with micron-grade measurement uncertainty and 24 m range using frequency scanning interferometry with compensation of environmental vibration”, Optics Express, vol. 24, no. 26, pp.30215-30224,2016.

[4] FONTANA R J.Recent system application of short-pulse ultra-wide-band technology[J].IEEE "trans. Microw, 2004 , 52(9) :2007-2014.

[5] MAHFOUG M R , ZHANU C M, MERKL. B C, et al.investigation of high 一 accuracy indoor 3-D position using UWB technology[J].Microwave Theory and Techniques,2008，56(6):1316-1330.

[6] Yang Xiaodong, Chen Jun, Ding Qinhua, et al. UWB wireless communication and SAW broadband signal processing technology [J]. Piezoelectricity and acoustooptic, 2009 31 (3): 299-301.

[7] PORClNO D, HlRT W. Ultra 一 wideband radio technology:Potential and challenges ahead[J].Communicanons Magazincs, IEEE, 2003 ,41(7):66-74.

[8] YANG L, GIANNAKIS G B. Ultra 一 widchand communications;an idea whose time has come[J].SignalProcessing Magazine,lEEE,2004，21(6):26-54.

[9] FANG B T.Simple solution for hyperbolic and related position fixed[J].IEEE Transactions on Aerospaceand Electronic Systems,1990,26(5):748-753.

[10] CHAN Y T , HO K C. A Simple and efficient estimator for hyperbolic location[J].IEEE Transactions on Signal Processing, 1994，42(8):1905-1915

[11] FOY W H. Position 一 location solutions by Taylor series estimation[J].IEEE Transactions on Aerospace and Electronic Systems,1976，12(2):187-194.

[12] Che Zhiping. Research on location technology of wireless sensor networks based on TOF ranging [D]. Dalian University of Technology, 2016.