Indoor Position System Based on Improved TDOA Algorithm

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Abstract. An indoor position system based on UWB modules is introduced in this paper. The time difference is obtained by the communication between the target node and the source node, and the time difference is sent to the upper computer to calculate the position of the target node with the improved TDOA algorithm and kalman filtering algorithm. The test shows that the system has the advantage of high precision and high stability.

1. Introduction
There are some mature solutions to the outdoor position, such as GPS, Glonass, Beidou, but there are no mature solutions to the indoors position. Two indoor position solutions are proposed at present. One solution is that the target node position is determined by the signal strength received by the signal receiver from the signal transmitter, which is called RSS [1-2]. In this way Bluetooth, WiFi or infrared equipment are used to transmit signal, which are of short transmission distance, environment influence and high power consumption. The position precision is only within meters. Another solution is that the target node position is determined by the arrival time of the signal, which is called TOA [3]. In this way some signal transmitters are set at the position place and the time stamp is obtained by the signal interaction, such as RFID, ultrasonic waves, UWB. RFID is of short transmission distance, and the ultrasonic waves are influenced by temperature greatly and of high cost. In this paper UWB is adopted for the advantage of strong anti-interference capability, low power consumption and low cost, and the theoretical position decision is within centimeters, which has obvious advantage in the indoor position platform.

2. General Structure of System
There are an upper computer and multiple lower computers in this position system to realize the calculation and display of the target node indoor position. The upper computer communicates with the lower computer by ESP07S, which is a WiFi module. The hardware of the lower computer is a wireless sensor network based on UWB, including four source nodes and one target node, and purpose of the software is to get the time stamp through the signal interaction between the target node and the source node and the time stamp is sent to the upper computer by ESP07S. The upper computer receives the time stamp to calculate the target node position with the improved TDOA algorithm and kalman filtering algorithm, and display the position on the screen. The general structure of the system is shown in figure 1.
3. Position Principle

The position system is based on TDOA [4-5] (Time Difference of Arrival). Clock synchronization is needed when all the source nodes begin to work in the traditional TDOA. Aiming at the demerit, the improved TDOA algorithm is adopted. In this method, the clock synchronization is not needed to realize the position easily. However, there is no escape from occurrence of error because of the non-line-of-sight obstructions to the transmitting signal in the complex indoor environment. Thus the kalman filtering algorithm is used to reduce the error and increase the precision.

The difference between the improved TDOA algorithm and the traditional TDOA algorithm is that clock synchronization is not realized by cables to solve the puzzle of clock synchronization. The position system is shown in figure 2. The source node stands for the base station, and the target node stands for the point whose position is measured. $R_{S1T1}$, $R_{S2T1}$, $R_{S3T1}$, $R_{S4T1}$ mean the distance between the four source node and the target node, and $R_{S1S2}$, $R_{S1S3}$, $R_{S1S4}$ mean the distance from the source node 1 to source node 2, source node 3 and source node 4.

Firstly, the source node 1 sends a signal to the whole network. The target node records the time $t_1$ when receiving the signal. Other source nodes send signals to the target node when receiving the signal form the source node 1. $t_n$ stands for the time of the target node receiving the signal from the source node n. Then the time difference of the source node signal arriving at the target node $(t_2-t_1)$, $(t_3-t_1)$, $(t_4-t_1)$ can be calculated. The target node position is obtained combined with the source node coordinate.

During the above process, the source node 1 sends the signal to the whole network, and the target node records the arrival time of the entire source node, which means that the signal of the source node 1 arrives at the target node from different paths to realize the clock synchronization of the source node.
The improved TDOA algorithm realizes the clock synchronization in the algorithm to make the wireless sensor arranged to solve the clock synchronization [6]. The improved TDOA algorithm is shown as below.

\[
\begin{align*}
R_{A1A2} + \hat{R}_{A2T1} - \hat{R}_{A1T1} &= c \cdot (t_2 - t_1) \\
R_{A1A3} + \hat{R}_{A3T1} - \hat{R}_{A1T1} &= c \cdot (t_3 - t_1) \\
R_{A1A4} + \hat{R}_{A4T1} - \hat{R}_{A1T1} &= c \cdot (t_4 - t_1)
\end{align*}
\]

\(t_n\) stands for the time of the target node receiving the signal from the source node \(n\). \(\hat{R}_{A1T1}\) is the distance between the source node \(n\) and the target node.

\[
R_{A1T1} = \sqrt{(x - x_n)^2 + (y - y_n)^2}
\]

\((x, y)\) is the coordinate of the target node, which is unknown parameter, and \((x_n, y_n)\) is the coordinate of the source node, which is the known quality[7]. \(c\), the signal transmission speed, defaults to 299 792 458 m/s.

There is no escape from occurrence of error because of the non-line-of-sight obstructions to the transmitting signal in the complex indoor environment. So, the Kalman filtering algorithm is used to reduce the error. The Kalman filtering algorithm is based on the assumption that all the measuring result is composed of real signals and additive Gaussian noise. If the assumption is valid, the Kalman filtering algorithm can effectively obtain the real signal from the measuring result [8-9].

4. Hardware Design

The target node and the source node use the same PCB board. The working mode (the target node or the source node) and the address can be set by dial switch. The hardware is composed of power module, controller module, position module and communication module. The power module supplies the whole board, position module transmits and receives signal to position, and the communication module transmits the time stamp to the upper computer. The diagram of the board is shown in figure 3, and the main module is analyzed as below.

![Figure 3. Diagram of PCB board](image)

4.1 Position Module

The main chip of the position module is DWM1000, which is produced by DecaWave and installed on both target node and source node. It can work at the state of transmission or receiving controlled by flag bits in the relevant register. DWM1000 is equipped with the standard SPI slave interface with the speed up to 20MHz and the small physical size. And the module is easy to be integrated in the real-time position system and wireless sensor network. The signal from the module is of persistent short time, wide bandwidth and good time resolution, so the module is of strong anti-interference capability and appropriate for the complex indoor environment.

4.2 Controller Module

Since DWM1000 doesn’t integrate microcontroller, the module can only work passively and
controlled by the external microcontroller through SPI interface. The position system adopts STM32F103CBT6 as the microcontroller. The core of the mcu is Cortex-M3, equipped with 128kB flash and 20kB RAM, the package of LQFP48, maximum frequency of 72MHz. The mcu has two SPI interfaces and three UART interfaces. One SPI interface is connected to DWM1000, and one UART interface is connected to ESP07S.

The connection between the DWM1000 and MCU is shown in figure 4.

4.3 Communication Module

In order to increase the transmission speed between the target node and the upper computer and increase the number of the target node, the WiFi module, ESP07S, is adopted to realize the wireless communication between the target node and the upper computer. ESP07S is a WiFi SOC module of small size and low consumption with STA/AP/STA+AP work mode. The ESP07S built in the target node is set to the AP mode, and the upper computer works as the server. ESP07S communicates with mcu through UART interface with two wires. The connection between them is shown in figure 5.

5. Software Design

The development software is Keil uVision5 and the programming language is C in this system. The software of mcu is used to realize the measurement of TDOA from the source node to the target node and transmit the information to the upper computer through WiFi.

The real-time multi-task operation system is not used in the software, and serial processing is used. The software includes STM32 reset module, system clock configuration module, timer configuration module, SPI module, UART module, DWM1000 initialization module and interrupt module. When DWM1000 receives signal, it will send interrupt request to mcu, and the interrupt module of mcu software will judge the interrupt type and read the TDOA information and transmit the information to the upper computer through WiFi.

6. Position Test

Four source nodes are place in a 6m×8m room. Source node 1 is chosen as the first transmission node and the ordinate origin, and the coordinates of the other three source nodes are (6, 0), (0, 4) and (6, 4). The target node is placed at ten points at random in the room, and the position of the target node is measured. The result is displayed in table 1, which shows that the system has the error within 20 centimeters.
Table 1. Position test

| Test Point/m | Test Result/m | Error/m |
|--------------|---------------|---------|
| (1.5,1)      | (1.64,1.13)   | 0.19    |
| (2,2.5)      | (1.94,2.64)   | 0.15    |
| (2.5,2)      | (2.35,2.09)   | 0.17    |
| (2.5,2.5)    | (2.53,2.35)   | 0.15    |
| (3,2)        | (2.85,1.94)   | 0.16    |
| (3.5,2.5)    | (3.41,2.65)   | 0.17    |
| (4,3)        | (4.05,2.93)   | 0.09    |
| (4.5,3)      | (4.39,3.06)   | 0.13    |
| (5,3.5)      | (4.94,3.36)   | 0.15    |
| (5.5,4)      | (5.63,3.91)   | 0.16    |

7. Conclusion
A kind of indoors position system based on DWM1000 is designed in this paper, which solves the problem of clock synchronization with the improved TDOA algorithm and reduce the disturbing error with Kalman filtering algorithm. Tests show that the system is of the error within 20cm, low cost and high stability. And, the system has great practical value.

8. Acknowledgments
This research was supported by the Shandong Province Higher Educational Science and Technology Program (Grant No.J15LN69).

9. References
[1] Li Yingyu, Chen Gang. Newton Localization Algorithm Based on Artificial Network RSSI Ranging [J]. Instrument Technique and Sensor, 2017(08): 122-126.
[2] Wang Jinglei, Wang Jian. Disambiguation of TDOA Estimates in Multi-path Environments [J]. Eletronic Design Engineering, 2019, 27 (03):142-145.
[3] Xu Yaosong, Tan Liang. A Modified Quasi Newton-KNN Algorithm for TDOA Location [J]. Chinese Journal of Sensor and Actuators, 2018, 31 (10): 1578-1583.
[4] Shi Yunfei, Hao Yongsheng, Liu Deliang, et al. IMU-Assisted TDOA Indoor Location Algorithm [J/OL]. Telecommunication Engineering: 1-10 [2019-04-02]. http://kns.cnki.net/kcms/detail/51.1267.tn.20180910.1529.005.html.
[5] Luo Jianyu, Zhang Weiqiang, Xu Ting. Indoor Positioning System Based on Received Signal Strength Indicator Optimization Model [J]. Wireless Communication Technology, 2018, 27 (03): 25-30.
[6] Zhou Junjie, Shen Liangjie. Design and Implementation of High Precision WLAN Locating system Based in TDOA and PTP [J]. Communication Technology, 2019 (02): 33-38.
[7] Wang Zhen, Guo Jian. UWB Indoor Positioning System Based on Improved TDOA Algorithm [J]. Microcontroller & Embedded Systems, 2017, 17 (05): 34-37+67.
[8] Zhang Jie, Shen Chong. Research on UWB Indoor Positioning in Combination with TDOA Improved Algorithm and Kalman Filtering [J]. Modern Electronics Technique, 2016, 39 (13):1-5.
[9] Wang Lei, Hao Jianxin, Chen Weiwei. Design of Sound Positioning System Based on TDOA and Kalman Filtering [J]. Modern Electronics Technique, 2018, 41 (19): 161-164.