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DESIGN AND PERFORMANCE ANALYSIS OF UWB SHORT RANGE WIRELESS POSITIONING SYSTEM

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Abstract: Many indoor smart application scenarios need to obtain the precise location of indoor moving targets, and the accuracy of indoor positioning depends on the accuracy of the wireless ranging system. The paper introduces the common ranging positioning technology and the basic principles of Symmetric Double-Sided Two-Way Ranging (SDS-TWR), using STM32F103C8T6 as the processor and DecaWave's DWM1000 ultra-wideband wireless ranging module as the measurement module to design hardware system. A Ultra Wide Band (UWB) short-range wireless positioning system is designed by adding the embedded positioning software to the hardware system. The system is tested in a corridor with a length of 31m and a width of 2.4m and a height of 3.4m. The errors calculated by the ranging module designed in this article are all between -0.38m and 0.54m, when the distance between the mobile terminal and the base station is 14m, 20m, 25m, and 28m, respectively. The overall average positioning error is 0.39m calculated by two base stations when a mobile terminal to two base stations within the range of 1m to 30m. Experiments show that the UWB positioning system can meet the requirements of wireless short-range positioning in most indoor scenarios.
Keyword: UWB, indoor positioning, precise location, SDS-TWR, ranging module.

Introduction

Bluetooth, Wifi, ZigBee, RFID and UWB are the commonly used radio frequency ranging and positioning technologies[1-4]. To design a wireless short-range ranging and positioning system in a specific application environment, we need to consider many factors such as the modulation method, the channel capacity, the transmission delay, the data rate, the throughput, the system robustness, the wireless signal attenuation and the factors of environmental interference. The UWB signal usually means that a signal has large relative bandwidth (divided by carrier frequency) or large absolute bandwidth [7-9] . It can transmit the high-speed data with very low power and is widely used in the short-range wireless communication. The UWB positioning system uses shock pulses to transmit data with high time resolution, so we can calculate the arrival time of a UWB signal to receiver from a transmitter accurately. UWB is widely used in ranging and positioning of moving targets in indoor and underground

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environments because of its higher resolution, lower energy consumption, stronger anti-interference and penetration ability and high ranging accuracy. At present, the main UWB point-to-point measurement method is SDS-TWR, which requires four interactive messages to be sent between the transmitter and the receiver and each message contains a transmission time stamp. The transmitter records the receiving time of each message, calculates the time for the signal from the transmitter to reach the receiver, and multiplies the change time by the speed of light to get the distance between them. The transmitter then sends the calculated distance to the receiver through a message. This method eliminates the clock offset and we can improve the ranging accuracy by extending the measurement period.

SDS-TWR Fundamental

SDS-TWR is a ranging algorithm that does not depend on the strict synchronization of the transceiver terminal clock [5-7]. Each node calculates the flight time of the beacon by relying on its own clock and the time information in the received messages. The beacon records the time of sending and receiving a message each time, and then calculates the propagation time to a fixed base station. The clock error caused by clock synchronization is eliminated by multiple handshake messages.

Generally, a ranging process consists of three stages: scanning, ranging and reporting results. In the scanning phase, device A scans and discovers device B, and then applies to establish a connection with B. Device B sends a connection and a response packets to device A to confirm the connection. In the ranging phase, device A sends a request packet and then starts to count and wait. Device B continuously sends multiple response packets to reply to the request after receiving A's message. When the count of A reaches the preset value, it sends a data packet to device B. The data packet includes the signal round-trip time and the time it takes for device A to receive a response signal from device B each time. After device B receives the data packet of device A, it sends another response to device A, indicating the end of the distance measurement between them. In the last stage, device B calculates the propagation time Tp between the two and sends it to the position calculation device. The detailed process of the algorithm is shown in Fig.1.

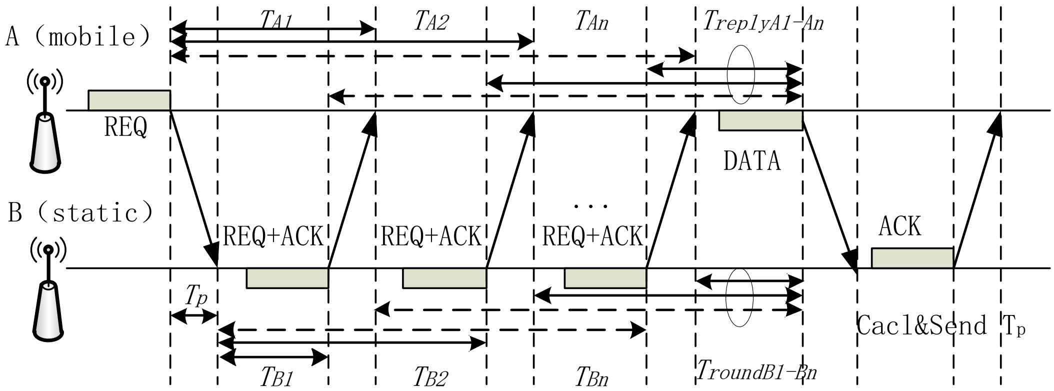


Fig.1. The detailed process of SDS-TWR

As can be seen from Figure 1, the round trip time TA and TB of the signal meet the formula (1) and (2).

$$T_{Ai} = 2T_p + T_{RBi}, \quad 1 \le i \le n \quad (1)$$

$$T_{Bi} = 2T_p + T_{RAi}, \quad 1 \le i \le n \quad (2)$$

T_{Ai} and T_{Bi} represent the ith time round-trip time of signals between A and B devices, and T_{RAi} and T_{RBi} represent the response time of the two devices respectively. Assuming that there is no packet loss between two devices, formula (1) plus formula (2) can get formula (3).

$$T_p = \frac{1}{4n}\sum_{i=1}^{n}\{(T_{Ai} - T_{RAi}) + (T_{Bi} - T_{RBi})\} \quad (3)$$

It can be seen from formula (3) that the signal propagation time between equipment A and B is only related to the clock deviation and drift of the equipment itself, and absolute clock synchronization between equipment A and B is not required. The SDS-TWR ranging algorithm does not need to add a special time synchronization message mechanism, and does not use the absolute time of arrival at the receiver to calculate the distance between receiver and sender. Therefore, the time synchronization requirements for the positioning system are greatly reduced, and the hardware requirements and using costs are both reduced in practical applications.

System Design

The UWB short-distance wireless ranging and positioning system designed in this paper includes hardware system design and software system. Both the base station and the mobile terminal are implemented by the same hardware, and the hardware is used as a base station or as a positioning mobile terminal through a DIP switch. Use STM32F103C8T6 as the processor and DWM1000 ultra-wideband wireless module to form a single positioning module. The hardware schematic diagram is shown in Figure 2.

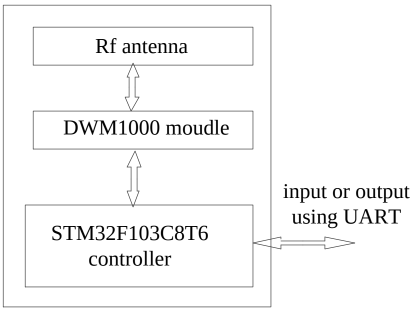


Fig.2. Hardware design block diagram of positioning system

The STM32F103C8T6 controller and the DWM1000 module use SPI communication to control the reset, sleep, and wake-up functions of the DWM1000 module. The PB0 port of the controller is connected to the RSTn pin of the DWM1000 module. when PB0 is low, the ranging module is reset. The PA1 pin of the controller is connected to the WAKEUP pin of the ranging module. When PA1 outputs a high level, the ranging module is waked up from sleep or deep sleep mode to work mode. The GPIO of the module is connected to the GPIOA port of the controller for future expansion. The STM32F103C8T6 controller is configured with a serial port rate of 115200bps, and the solved positioning information is output to the PC through USART3. The pin connection between STM32F103C8T6 controller and DWM1000 module is shown in Fig. 3.

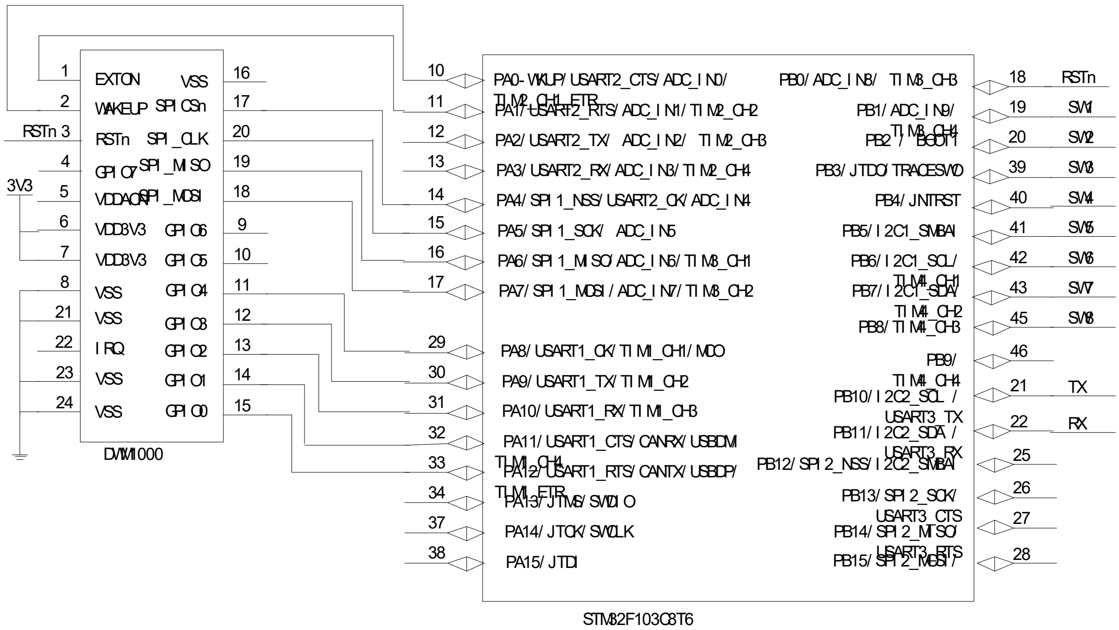


Fig.3. Communication and control schematic diagram

After the positioning system is powered on, the hardware and peripherals are initialized to ensure that the hardware is in the correct work state. To obtain accurate positioning data, the STM32F103C8T6 controller and the DWM1000 module are required to cooperate with each other. For the DWM1000 module, DecaWave compary provides API functions for developers to quickly complete the initialization and data transmission of the DW1000 chip. These codes are saved in the "deca_irq.c", "deca_spi.c" and "deca_device.c" files. The system initialization flow is shown in Fig. 4.

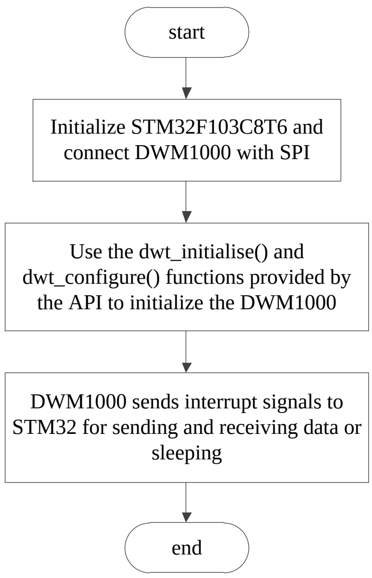
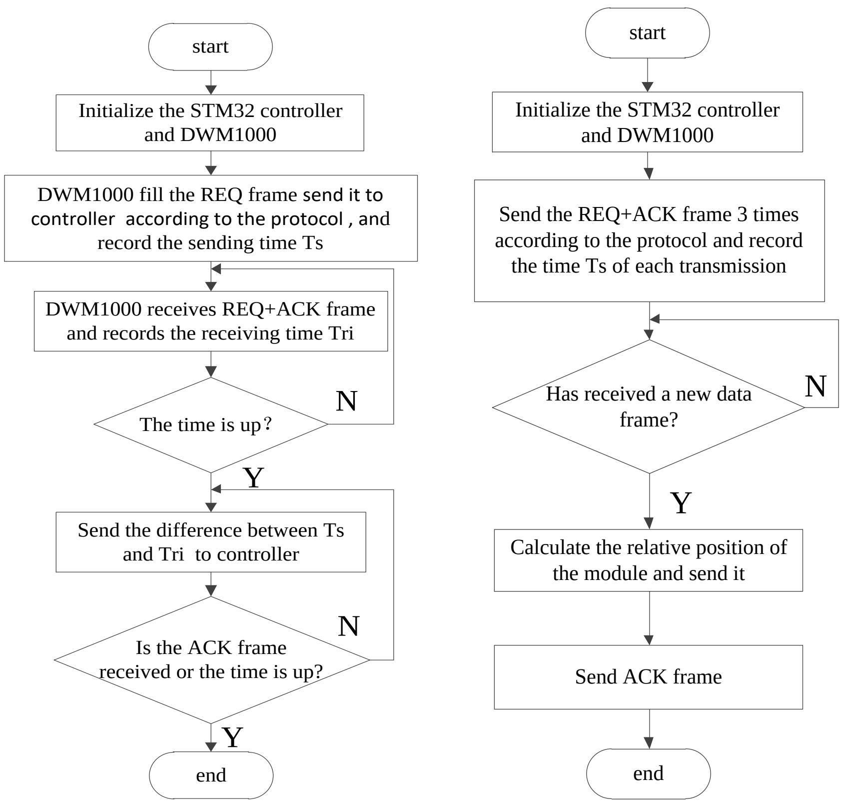


Fig.4. Software initialization process

Connect the 1-8 pins of the B port of the controller GPIO to a DIP switch during hardware design, and configure the DIP switch to set the ranging module's identity as a base station or a mobile terminal and assign a fixed ID to the module. In the software program, when SW1 is set to ON, it means that the module identity is a base station, and when SW1 is OFF, the module identity is a mobile terminal. SW2, SW3, SW4, SW5 are used as the ID of the module and the maximum number of access is 16. SW7 and SW8 are used to configure radio frequency channels, and only multiple terminals on the same channel can communicate with each other. After the data link between multiple positioning modules is established, the positioning calculation is processed through interrupt events. dwt_ Isr (void) function is an interrupt processing function provided by the API. When a complete data frame has been transmitted or the received data can be submitted to the upper application, it will enter the interrupt function. At this time, the content of the transmitted frame can be obtained by reading the dw1000 chip status register. The work flow of the software program of the base station and the mobile terminal is shown in Figure 5.



(a) (b)

Fig.5. Software flow of the mobile terminal (a) and base station(b)

Result

The trial scenario is a corridor with a length of 31m and a width of 2.4m and a height of 3.4m. Two base stations are placed at both ends of the corridor, and the mobile terminal is placed at the sampling points at center of the cross section of the corridor. This test uses a single mobile terminal, and the positioning results are output to the PC via the serial port at a frequency of 20 Hz. The results of the mobile terminal to the two base stations of 14m, 20m, 25m, 28m is shown in Fig.6 .

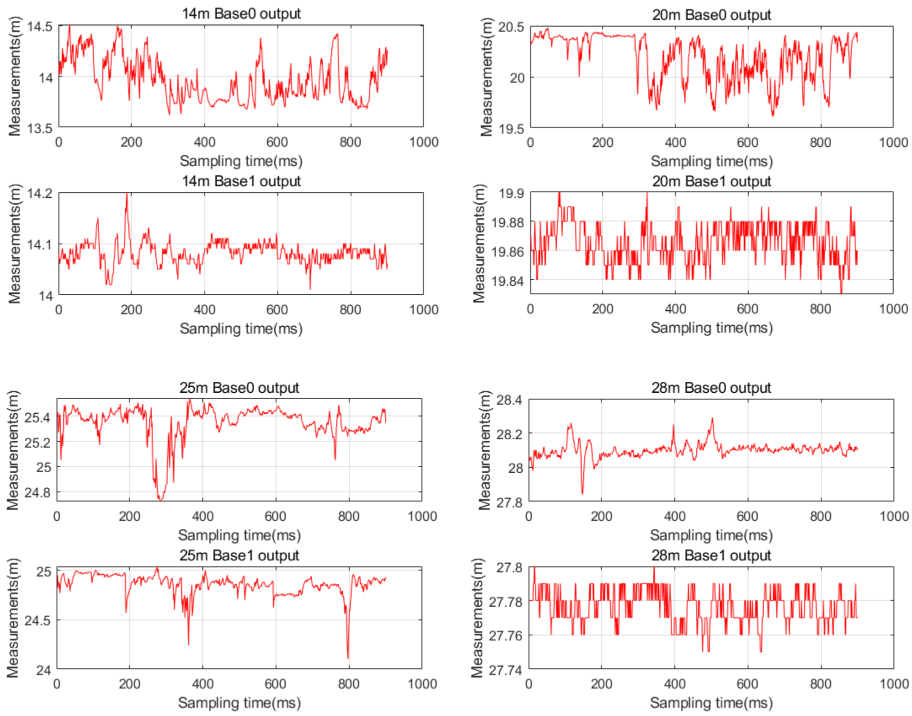


Fig.6. Average error of positioning test in two test scenarios

The average errors between these distances and the standard values are shown in Figure 7. It can be seen from Figure 7 that the errors calculated by the ranging module designed in this article are all between -0.38m and 0.54m, when the distance between the mobile terminal and the base station is 14m, 20m, 25m, and 28m, respectively. The calculated result has no correlation with the distance between the mobile terminal and the base station.

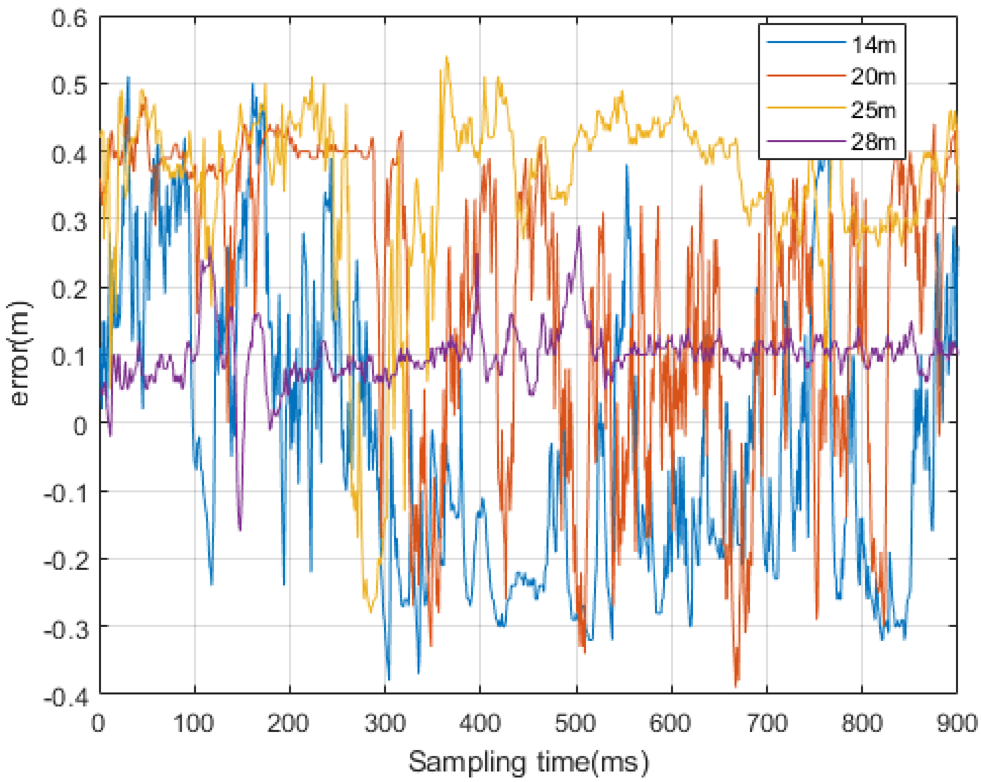


Fig.7. Average error of positioning test in two test scenarios

Figure 8 shows the average positioning error calculated by two base stations when a mobile teminal to two base stations from 1m to 30m. It can be seen from the experimental results that the distance errors calculated by the designed UWB short-distance ranging wireless positioning system of two base stations are basically the same and both are within 0.68m and the overall average positioning error is 0.39m. The fluctuation of positioning error is that the tester carrying the mobile terminal interferes with the ranging signal between the base stations and the mobile terminal.

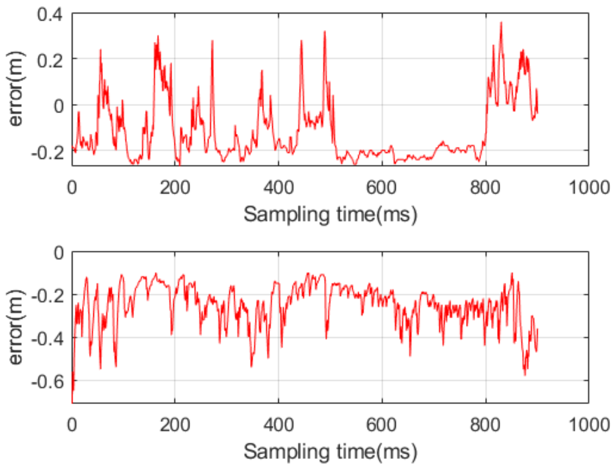


Fig.8. Average error of positioning

Conclusions

This paper studies the problem of precise positioning of UWB wireless ranging, uses the SDS-TWR algorithm to avoid the large measurement error caused by the clock asynchronous problem between the base station and the mobile terminal, and gives the hardware system design method and software system of the wireless positioning system work flow, then using the trilateral measurement positioning method calculate the precise position of the indoor moving target. Experimental results show that the UWB short-range positioning system designed in this paper can be applied to factories, warehouses, museums, hospitals, shopping malls, smart homes and some areas that require high security protection.

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