Structural Design of High-precision Positioning System in Weak Signal Environment Based on UWB and IMU Fusion

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Abstract: Aiming at the problem that indoor positioning technology based on wireless ultra-wideband pulse technology is susceptible to non-line-of-sight effects and multipath effects in confined spaces and weak signal environments, a high-precision positioning system based on UWB and IMU in a confined environment is designed. The STM32 chip is used as the main control, and the data information of IMU and UWB is fused by the fusion filtering algorithm. Finally, the real-time information of the positioning is transmitted to the host computer and the cloud. The experimental results show that the positioning accuracy and positioning stability of the system have been improved in the non-line-of-sight case of closed environment. The system has high positioning accuracy in a closed environment, and the components used are consumer-grade, which has strong practicability.

Keywords: Ultra-wideband, Inertial Sensor, Weak Signal Environment, Non-line-of-sight

1 Introduction

Global Navigation Satellite System (GNSS) has the characteristics of global coverage, high precision and all-weather[1]. It has been widely used in all walks of life[2]. People all over the world use GNSS to carry out various work on electronic equipment. However, it is undeniable that due to the obstruction of obstacles and the limitation of satellite space load, GNSS signals cannot provide better positioning services in indoor and closed environments. With the further acceleration of urbanization, people's daily life and industrial production have gradually shifted to indoors, which poses a challenge to how to achieve high-precision positioning in indoors and confined spaces. With the further acceleration of urbanization, people's daily life and industrial production are gradually transferred to indoors, which poses a challenge to how to achieve high-precision positioning in indoors and confined spaces. In recent years, with the development of radio technology, more and more indoor positioning methods are known[3]. For example, the use of wireless network (Wireless Fidelity, WIFI), wireless ultra-wideband pulse technology (Ultra-Wide Band, UWB), radio frequency identification (Radio Frequency Identification, RFID), Bluetooth and other wireless communication technologies to achieve indoor positioning, and the use of inertial navigation system (Inertial Navigation System, INS) and pseudo-satellites to achieve indoor positioning. However, among these methods, the most widely used and most applied scenarios are mainly indoor positioning methods based on inertial navigation systems and indoor positioning methods based on wireless ultra-wideband pulse technology.

Inertial navigation is an independent navigation technology. It does not need to arrange the environment in advance. It mainly uses the measured values provided by the inertial measurement unit (IMU), namely acceleration and angular velocity. The position, velocity and attitude (direction) of the carrier can be obtained when the initial position is known. However, because the positioning information is obtained by integral and the system itself has accelerometer and gyroscope deviations, the system error will accumulate over time. In order to solve the problem that the cumulative positioning error of inertial navigation system increases gradually with time in the positioning process, IMU equipment is applied to the field of indoor positioning. Domestic and foreign scholars have made a lot of research. Z.G. Wang and others[4] proposed the method of using binocular camera and IMU fusion to achieve high-precision positioning of indoor environment. Firstly, the attitude information of IMU and binocular camera is measured as the state quantity, and then the two are used to construct the motion equation to obtain the position estimation. M.Y. Nie et al. proposed the method of combining lidar and IMU to achieve indoor positioning. The speed of the positioning tag is obtained by radar plane registration, which is used as the observation of EKF, so as to correct the error of IMU, and finally achieve indoor high-precision positioning[5]. M.J. Gao and others proposed the method of integrated navigation and adaptive fading Kalman filter to fuse the attitude information of Xtion sensor and IMU, so as to improve the accuracy of indoor mobile robot trajectory[6]. Y.F. Shi et al. proposed the method of preprocessing TDOA and IMU by Kalman filter and then data fusion by extended Kalman filter. Compared with the traditional TDOA positioning method, the positioning accuracy has been greatly improved[7].

UWB technology originated in the 1960 s. Different from traditional carrier-based communication technologies, UWB uses short-energy pulse sequences instead of carriers to increase pulse frequency by direct sorting or orthogonal frequency division modulation. UWB signal only needs a nanosecond pulse can be transmitted through the antenna, by changing the pulse amplitude, time or phase to load the required transmission information. From the perspective of communication system, UWB realizes wireless transmission by receiving and sending ultra-narrow pulses at the microsecond or nanosecond level. The time width of the pulse is very short, and the proportion of the spectrum area is very large, so that the bandwidth is more than 50MHz. UWB positioning not only has high positioning accuracy and strong penetration, but also does not interfere with other devices in the same environment. UWB technology uses ultra-narrow pulses to accurately measure the time from the signal to the receiving position, calculate the distance from the base station to the receiver, and complete the indoor positioning requirements through the position solution equation. In recent years, the use of UWB has been rapidly promoted in the field of data transmission and indoor positioning[8]. Especially, the UWB-based spatial positioning scheme is widely used in underground parking lots, large warehouses, exhibition halls and other confined spaces. Its positioning accuracy can reach centimeter level[9].

Although UWB technology has the advantages of fast transmission speed and long transmission distance, UWB-based indoor positioning technology also has the advantages of high positioning accuracy and wide positioning range. However, it is undeniable that UWB positioning technology also has some shortcomings that cannot be ignored. For example, in the indoor and confined space environment, the indoor environment cannot always remain open, and there will inevitably be some obstacles. Due to the existence of these obstacles, it may cause non-line-of-sight effects and multipath effects in the indoor environment. The non-line-of-sight effect and multipath effect will greatly affect the accuracy of UWB indoor positioning, and even cause signal interruption and signal loss. In order to solve this problem, many methods have been developed. Firstly, Li and others designed a low-cost integrated navigation system of IMU, GPS and magnetic heading meter based on sports car data[10]. Secondly, Zhou designed the corresponding positioning mathematical models for WIFI and IMU respectively, and proposed a combined positioning algorithm in both shallow and deep forms[11]. Thirdly, L.I. Zhang analyzed the basic principle of visual / inertial navigation technology and introduced the landmark achievements of the combination from the perspective of synchronous positioning and composition[12]. Since then, J. Wang, Y.W. Miao et al. proposed a robust EKF algorithm for GNSS / INS tightly integrated navigation, and tested the ability to suppress slow growth errors by simulation[13]. Finally, J.Y. Yu and others designed a 15-dimensional Kalman filter to suppress the error accumulation of IMU through UWB[14]. In addition, J.B. Zhu adopts the UWB / IMU tight combination idea and uses residual chi-square detection to reduce the abnormal measurement values caused by non-line-of-sight[15]. In addition, G.Yang and others designed a double-layer EKF in a loosely coupled manner, and detected the non-line-of-sight error of UWB through the initial position estimation of INS, and adjusted the measurement noise matrix[16]. C.Q. Wang established AUAM and AUM models from the perspective of motion and AUM models from the perspective of motion model to simulate the actual motion[17]. R.B. Li and others introduced LSTM deep neural network to improve MEMS positioning accuracy[18].

It can be seen from the above that the combination of IMU and UWB is the most effective way to solve this problem. The precise positioning method of UWB + IMU combination is an algorithm model to reduce the influence error of NLOS phenomenon in indoor positioning. The algorithm model mainly uses UWB as the positioning and ranging technology, and predicts and corrects the NLOS error probability curve by smoothing with the Inertial Measurement Unit. Finally, the Kalman filter algorithm is used to deal with the influence of NLOS error interference on the accurate positioning calculation of UWB system. In order to achieve high-precision integrated positioning of UWB + IMU, many algorithms and system models have been studied at home and abroad. J.J. Peng and others first proposed the method of support vector machine to realize signal classification and recognition in NLOS environment, and then used Kalman filter to fuse IMU and UWB to achieve high-precision positioning[19]. Then, J. Zhou and others proposed a new algorithm to identify the NLOS environment. They first obtained the probability distribution curve of NLOS error under different obstacles in the offline stage, then fused INS and UWB through Kalman filter, and finally updated the NLOS error to obtain more accurate position estimation[20]. Furthermore, W.L. Hu et al. also proposed an indoor positioning data enhancement method based on the extended Kalman filter (EKF) framework that integrates UWB and IMU sensor information[21]. Since then, K.Y. Yin and others proposed to use the UWB measurement distribution properties in power operation occasions to determine the NLOS conditions, and to mitigate the errors, effectively improving the positioning accuracy under NLOS conditions[22]. B.F. Zhang et al. proposed to use position, velocity, quaternion, accelerometer bias and gyroscope bias as state vectors, and integrate UWB and IMU measurement information through the extended Kalman filter algorithm to enhance the system's ability to resist NLOS errors[23]. However, these methods are in the simulation stage and have not been realized in the physical test stage. There are relatively few experimental platforms that are truly built in kind. In order to truly achieve high-precision positioning in a confined space, this paper designs the following positioning system, which can truly achieve high-precision positioning in a confined environment. Experiments show that the positioning accuracy and positioning stability have been significantly improved, and the UWB and IMU used in the system are consumer-grade devices, which are easy to implement in industrial production and daily life, and have strong practicability.

2 Closed Space Positioning System Design

The overall framework of the system is shown in Fig.1. The system is mainly divided into positioning part and data uploading part. The function of the positioning part mainly includes the acquisition of IMU measurement data and UWB measurement data and the fusion of the measurement data of the two through the error state Kalman filter, and then transmitted to the host computer through the serial port protocol. The data upload part mainly includes the host computer of the system and the M5310-A chip of China Mobile Internet of Things. The data upload part is mainly responsible for uploading the positioning results to the cloud storage in real time, which is convenient for further data processing.

2.1 System Hardware Structure Design

1) Power Module Design

The system designed in this paper is mainly used in areas with weak GNSS signals such as indoors, canyons and tunnels. These areas cannot maintain the conditions for charging all the time. The hardware module needs to design a rechargeable power module to charge the working process of the system. In this system, TP4054 chip is used to design the power supply module for the system. TP4054 is a complete single-cell lithium-ion battery using a constant current / constant voltage linear charger[24]. The SOT package of TP405 and the small number of external components make it an ideal choice for portable applications. TP4054 has the function of thermal feedback, which can adjust the charging current to adjust the chip temperature under high power operation or high ambient temperature conditions. The power module based on TP405 chip has the characteristics of good portability and high security, which is very suitable for use in this system. The circuit diagram of the power module is shown in Fig.2.

2) UWB Module Design

UWB positioning uses D-DWM-PG module, which is a highly integrated low-power RF transceiver with a radio frequency band of 3.5Ghz-6.5Ghz and a chip rate of 499.2MHz. DW1000 conforms to the IEEE802.15.4-2011 ultra-wideband standard. It has the advantages of low power consumption, bidirectional ranging and positioning, and is suitable for indoor positioning.

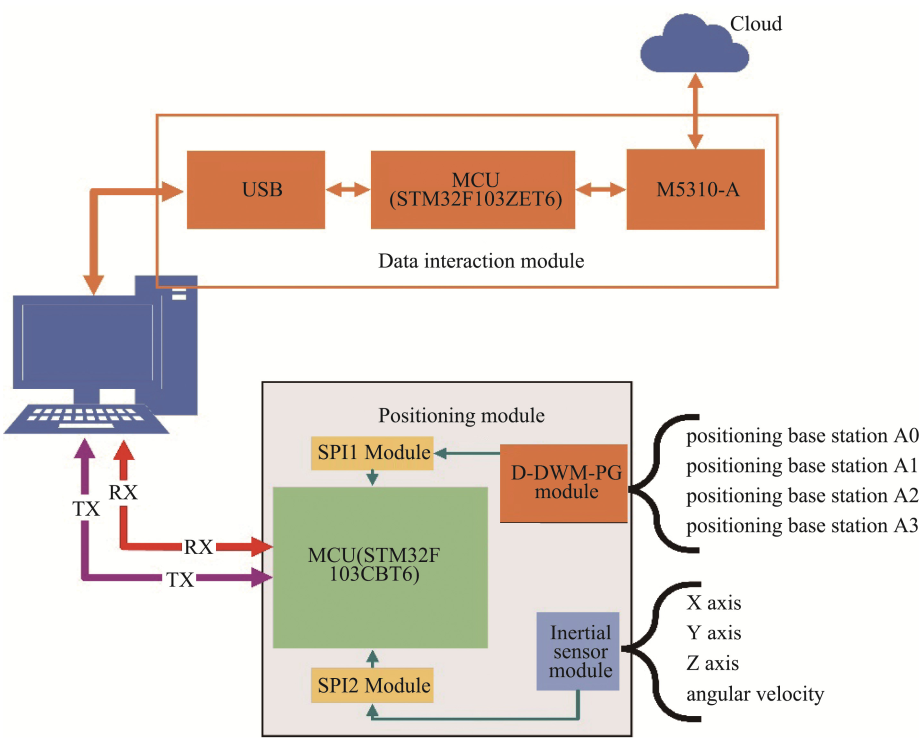


Fig.1 System Structure Diagram

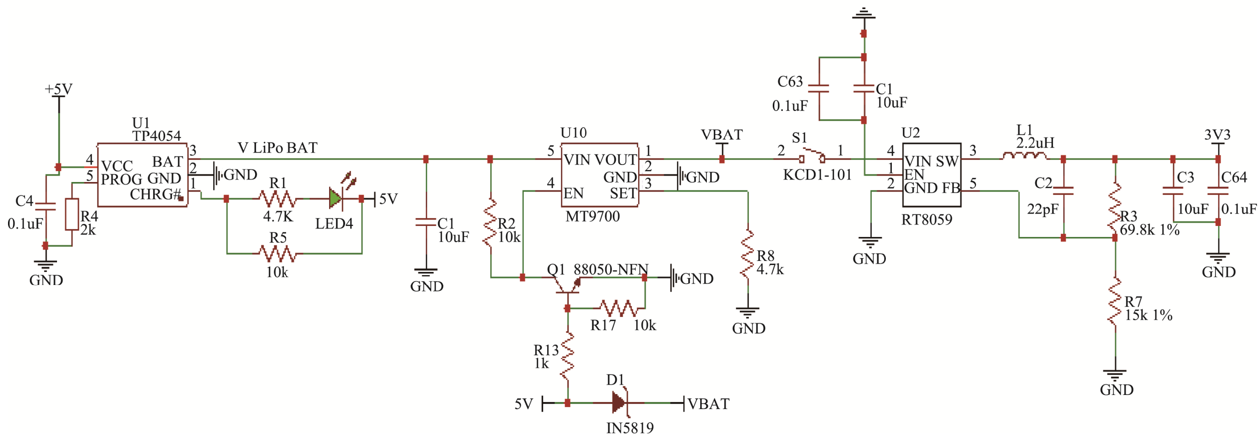


Fig.2 Power Module Circuit Diagram

The UWB chip used in the D-DWM-PG module is DW1000. The DW1000 chip can achieve the purpose of controlling the working state of the chip by controlling the pin level. According to the requirements, the chip switches back and forth between sleep mode and working mode, which can save the battery power in the power module and meet the low power consumption requirements of the system when working outdoors. Moreover, the crystal oscillator of DW1000 is 38.4MHz, and the working voltage is between 2.8V and 3.6V. The DWM1000 module composed of DW1000 chip and peripheral circuit meets the requirements of the main control chip STM32F103CBT6, which can work well with the main control chip[25].

3) IMU Module Design

Inertial Navigation System (INS) is a hardware navigation and positioning system that only relies on its own data and does not rely on external positioning information. It can work independently and output its own speed, acceleration, attitude angle and other information in real time. The core of INS is Inertial Measurement Unit (IMU). An inertial sensor model ICM42605 is used in this system. The IMU consists of a three-axis accelerometer and a gyroscope. The ICM42605 module has the characteristics of low noise, low power consumption and motion wake-up interrupt. It is very suitable for the requirements of low power consumption, high precision and system stability.

4) Host Computer

The positioning results of the system are transmitted to the host computer through the serial port. The host computer is written by LabVIEW. The positioning information can be displayed in real time in the interface of the host computer. The interface diagram of the host computer is shown in Fig.3.

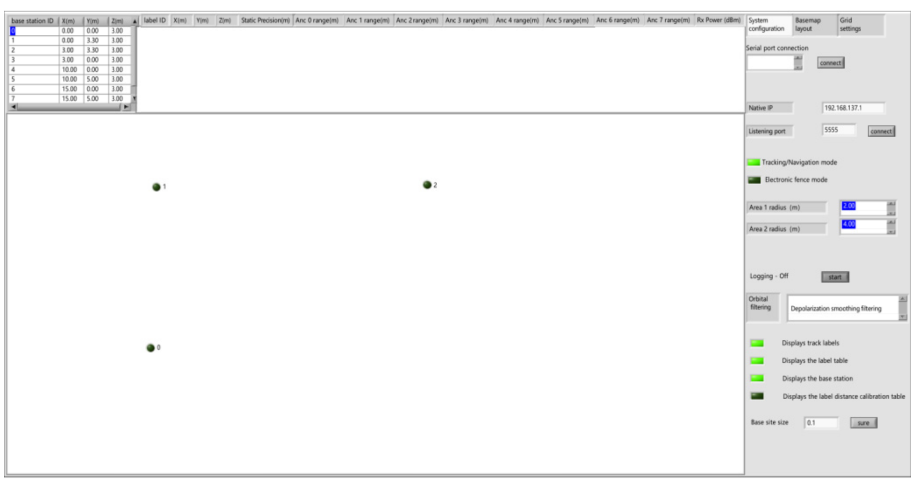


Fig.3 PC Interface Diagram

5) Data Cloud Storage

The M5310-A module is selected as the machine cloud interaction part in the data upload module. M5310-A is an industrial NB-loT module working in Band3 / Band5 / Band8. It supports M2M chip, One-NET cloud platform protocol and the latest Release14 standard, which can realize the function of base station positioning and higher communication rate.

The M5310-A module is connected to OneNET through LMW2W protocol. With the help of serial communication protocol, it communicates with STM32F103ZET6 chip through TXD and RXD pins, and sends relevant data to OneNET. The schematic diagram of the M5310-A is shown in Fig.4.

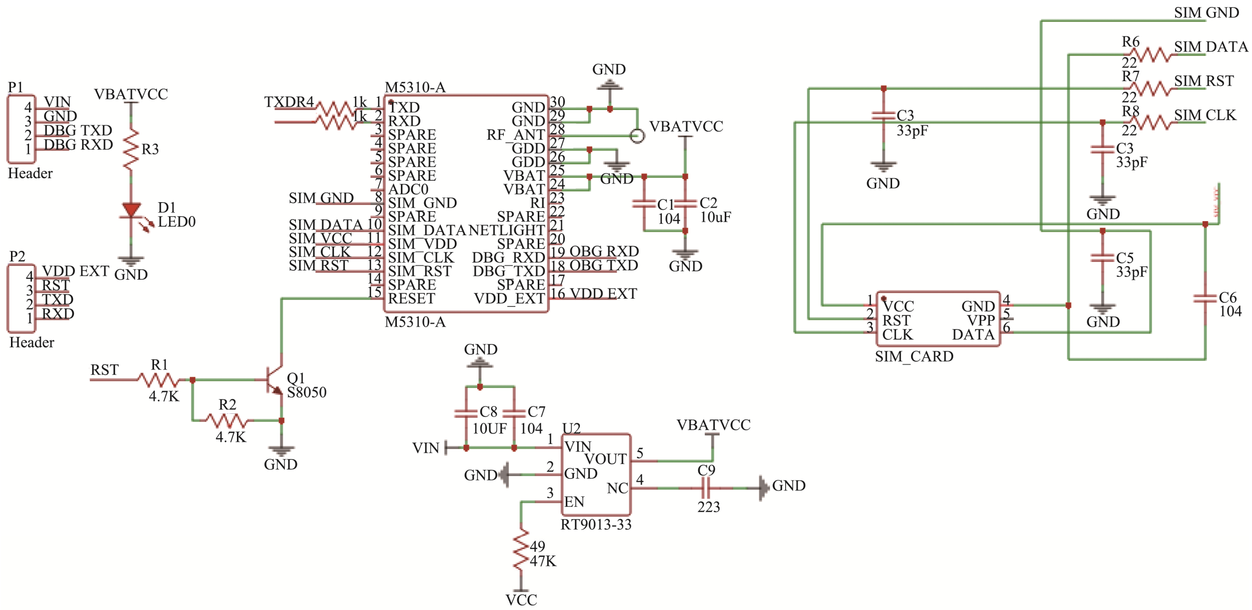


Fig.4 M5310-A Circuit Schematic

2.2 System Software Design

The system software design mainly includes the following three parts: main control program design, positioning label program design and data upload program design.

1) Main Control Program Design

The main control program mainly realizes the interaction of information between STM32 and PC. STM32 automatically collects and sends location data to PC, and PC calls each module of the system to upload location data to the cloud. The main control program flow chart is shown in Fig.5:

2) Positioning Tag Program Design

After receiving the Inform packet sent by the main base station, the receiver will return the Poll packet and start the ranging. After the receiver sends the Poll packet, it waits for the base station to return the Resp packet. After receiving the Resp packet, it sends the Final packet to the main base station. The receiver program flow chart is shown in Fig.6.

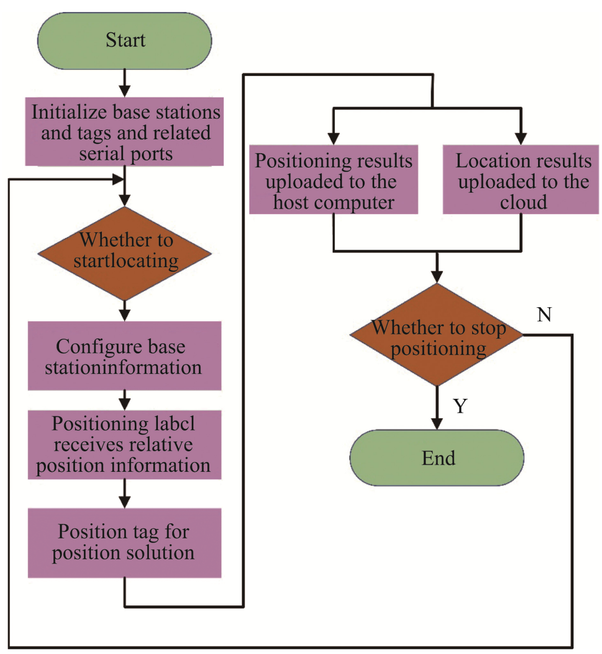


Fig.5 Main Program Control Flowchart

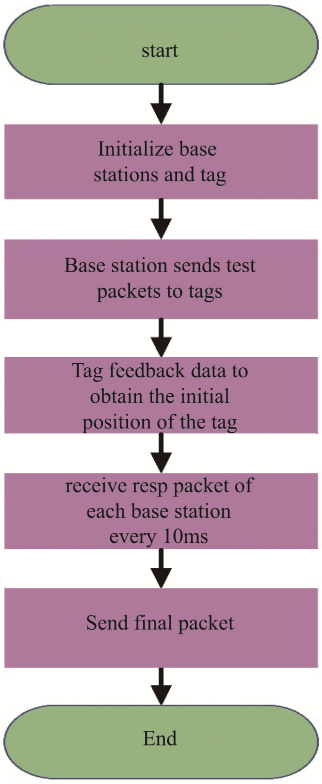


Fig.6 Positioning Label Program Flowchart

3) Data Upload Program Design

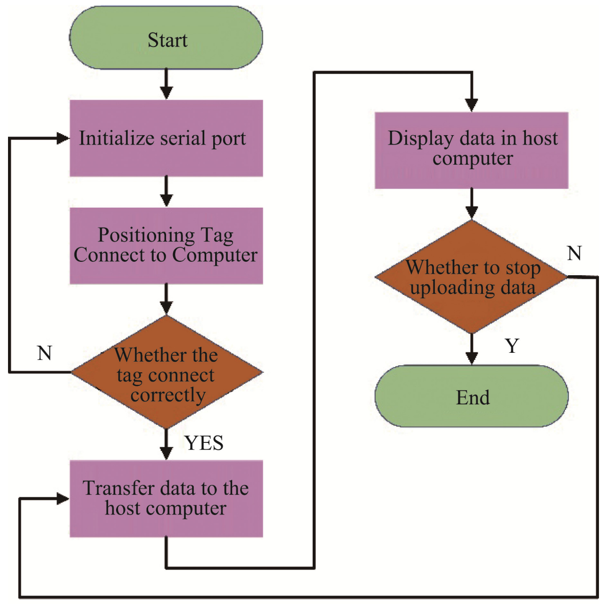
The data upload part program is divided into two parts: the host computer part and the STM32 part. The host computer searches the serial port used for communication with STM32, and sets the serial port baud rate, check bit, stop bit and other parameters, and then sends the real-time data of the receiver to the STM32 microcontroller through the serial port. After initializing the relevant pins, the STM32 single chip packages the latitude and longitude to the M5310-A module. M5310-A packages and sends data to the cloud. The program flow chart is shown in Fig.7:

3 Experimental Verification

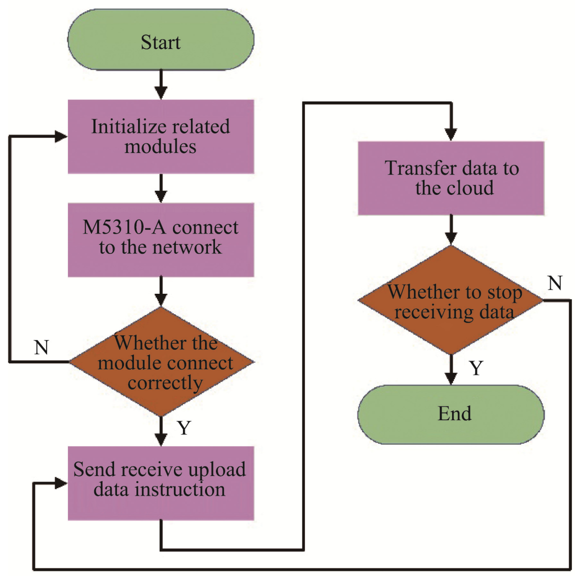
In order to verify the feasibility of this system, this paper uses the proposed system model to carry out fixed-point and dynamic experiments in a confined space.

3.1 Fixed-point Experiment

The fixed-point experiment is completed in the navigation and positioning laboratory. During the experiment, a region was selected to build an experimental platform, and obstacles were randomly arranged in the positioning space and the experimental environment where the experimental personnel caused the UWB signal non-line-of-sight. At this time, one of the experimenters walked freely in the positioning area with a positioning tag, and the positioning results were shown in tables 1 and 2. Compared with the traditional TDOA positioning method, the variance of the positioning result decreases, and the average error of the positioning result decreases, indicating that the accuracy and accuracy of the positioning are improved.



(a) PC Flowchart



(b) M5310-A Module Flowchart

Fig.7 Data Upload Program Flowchart

Table 1 Comparison of Variance Data before and after Application of Algorithm

Coordinate Axis	Traditional Module	System Module	Percentage
X-axis	0.057793607	0.054440322	5.80%
Y-axis	0.000294435	0.000241247	18.06%
X-Y plane	0.057993143	0.054681569	5.71%

Table 2 Comparison of Average Error Data before and after Application of Algorithm

Coordinate Axis	Traditional Module	System Module	Percentage
X-axis	0.240036753	0.233146596	2.87%
Y-axis	0.015250321	0.013417041	12.02%
X-Y plane	0.255287074	0.246514376	3.44%

3.2 Dynamic Experiment

The dynamic experiment is carried out in the underground pedestrian channel. According to the experimental environment shown in Fig.8, the experimental personnel randomly walk in the positioning area for positioning. The positioning results are shown in Table 3 and Table 4. It can be seen from the table that the positioning accuracy and stability of the system have been improved.

(a) Experimental Scene Construction

(b) Experimental Equipment Debugging

Fig.8 Dynamic Experimental Scene

Table 3 Comparison of Variance Data before and after Application of Algorithm

Coordinate Axis	Traditional Module	System Module	Percentage
X-axis	0.031677597	0.029103541	8.12%
Y-axis	0.006565621	0.004416145	32.74%
X-Y plane	0.038191202	0.033519686	12.23%

Table 4 Comparison of Average Error Data before and after Application of Algorithm

Coordinate Axis	Traditional Module	System Module	Percentage
X-axis	0.136256431	0.119801334	12.08%
Y-axis	0.088191084	0.066946247	24.10%
X-Y plane	0.224447515	0.186747581	16.80%

4 Conclusion

In order to solve the problem that UWB indoor positioning system is susceptible to non-line-of-sight effect and multipath effect in indoor and confined space. This paper designs a positioning system based on UWB and IMU. The system can realize high-precision positioning in a closed environment and real-time cloud upload of positioning data. The positioning system has high positioning accuracy and wide positioning range. When the positioning system is in a closed environment and is affected by the non-line-of-sight effect, it can still provide better positioning function. And it can be seen from the experiment that the accuracy of the positioning result and the stability of the positioning result are greatly improved. Moreover, the UWB and IMU used in the system designed in this paper are both consumer-grade and have high practicability, which is very suitable for industrial production and daily life and teaching.

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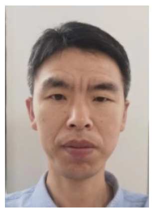

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