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Design of Embedded System based on UWB PDOA Technology

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Abstract

Ultra Wide Band (UWB) is a wireless carrier communication technology that combines positioning and communication with a frequency bandwidth of more than 1GHz, and Phase Difference of Arrival (PDOA) is a kind of distance measurement algorithm that finds the distance between a reference point and an unknown point by measuring the phase difference of the same signal arriving at different antennas. Azimuth ranging algorithm. In this paper, the azimuthal ranging system based on UWB PDOA technology can realize accurate positioning within 15 cm under the premise of short-range low-power consumption, and this paper mainly investigates the algorithm derivation, the base station design and the embedded program development in three parts, and the work done mainly includes: (1) Referring to the existing positioning system scheme based on time algorithm, we make optimization to verify the feasibility of this system design scheme for the insufficient part of the original phase difference positioning system. (2) Study the parameters and deployment of the array antenna and the performance indexes and influencing factors of the PDOA azimuthal ranging algorithm, and integrate the antenna layout design suitable for the system. (3) In promoting the process of the subject, the feasibility of the program plan is verified by comparing the test data of dual-antenna base station and four-antenna base station, the test data of four-antenna base station before and after filtering, and the effect of different orientation of the tag on the base station.

Keywords

Precise Positioning; UWB; PDOA Algorithm; Locating Base Station.

1. Introduction to UWB PDOA based Orientation Ranging System

The orientation ranging system in this paper adopts the ultra-wideband UWB communication technology with the phase difference of arrival PDOA ranging algorithm, the former utilizes nanosecond non-sinusoidal narrow pulses for the transmission of data signals; the latter uses the phase difference of different moments of the same sinusoidal wave as the basis to obtain the distance difference, which is measured by the parameters such as the distance between two antennas, and the distance of the tag from one of the antennas, and finally obtains the localization base station and the localization tag's The orientation information of the positioning base station and the positioning tag is finally obtained.

The hardware part of the system includes at least one set of base stations and one setof tags, said tags and base stations can be movedrelative to each other, and the base stations include four antennas, a UWB positioning chip and an STM32 microcontroller development board. Said antennas may receive signals sent by the tags, and further comprising a first control switch and a second control switch, said first control switch being cooperatively connected with at least two non-adjacent antennas, and said second control switch being cooperatively connected with the remaining antennas, and the first

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and second control switches may respectively realize a single antenna and the chip's signal transmission connection.

When the azimuth ranging system works, the positioning base station requires 5V external power supply, and the positioning tag has a built-in rechargeable lithium battery with a capacity of 370mA. The collected orientation information is transmitted to the cell phone applet through the Bluetooth module, and the relative movement of the base station and the tag is displayed in real time in the form of a two-dimensional moving picture [6].

Based on UWB PDOA orientation ranging system products Figure 1 as Figure 2 and shown.

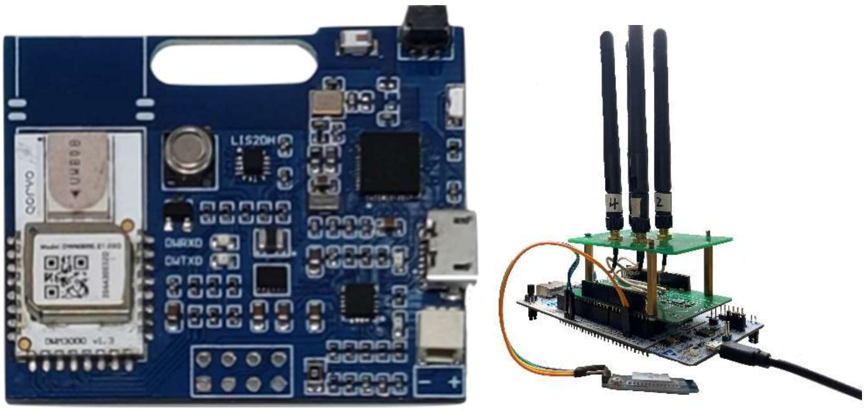

Figure 1. UWB positioning base station and positioning tags physical figure

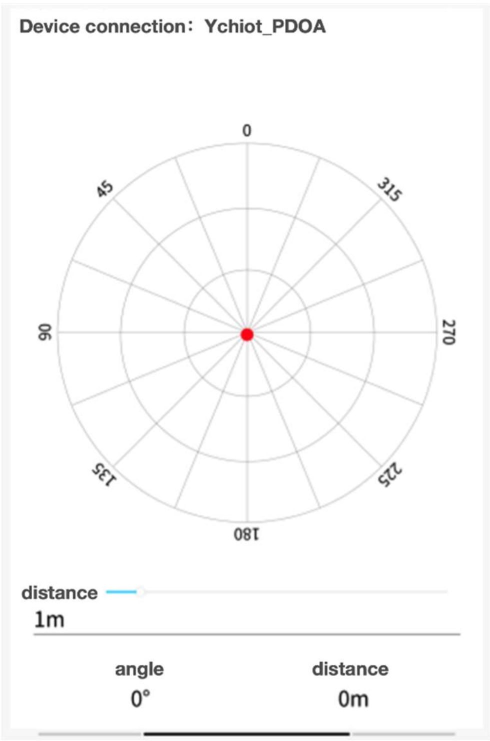

Figure 2. real-time positioning applet physical diagram

2. Overview of UWB Wireless Communication Technology

2.1 UWB Wireless Communication Technology Overview

2.1.1 UWB Definition

Ultra-wideband UWB is a carrierless communication technology that utilizes narrow non-sinusoidal pulses of nanoseconds to micro-microseconds to transmit data. As the name implies, it occupies a

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very wide spectrum range, and according to the FCC regulations, the frequency range from 3.1GHz to 10.6GHz belongs to the frequency band range of UWB.

UWB technology has the advantages of easy system realization, fast data transmission speed, low transmit signal power, high security, strong multipath resolution, high positioning accuracy, etc. It is suitable for high-speed wireless access in dense multipath places.

2.1.2 UWB Positioning Technology

The wireless network positioning system based on UWB technology is usually composed of positioning tags, positioning communication base stations and algorithm software. In the special area deployment of a moderate number of positioning communication base station, continuous collection of staff, cars, property, special tools, positioning mark back to the factors of the time coordinates of the data information, to give instant accurate positioning, real-time supervision, correct guidance, alarms and other roles.

Ultra-wideband positioning has centimeter-level high-precision positioning capability, which can reach 7 cm accuracy. UWB signal frequency domain total width is very narrow, the receiver in the detection can get especially high time resolution, and at the same time has especially strong anti-multipath ability, from different directions to arrive at the signal is difficult to cause overlap influence, improve the positioning accuracy. Ultra-wideband positioning systems use periodic pulses to send data. The pulse duration is very short. In general, the duty cycle in the middle of 0.20ns to 1.5ns is very low, thus reducing power consumption a lot when pushing continuous carrier communication. As a result, the endurance of the positioning system will be relatively longer. The network bandwidth is large, the transmit power spectral density is less than the noise, and the chance of the transmitted data being engulfed, blocked and affected by the noise is extremely low. In other words, the possibility of jeopardizing other wireless communications (e.g., Wi-Fi signals, Bluetooth signals) is also low.

UWB positioning systems incur higher costs because they require additional deployment of specialized signal measurement equipment and encounter wall obstructions that require network redeployment, among other reasons.

2.2 Theoretical Basis of PDOA Positioning Algorithm

2.2.1 Derivation of PDOA positioning algorithm

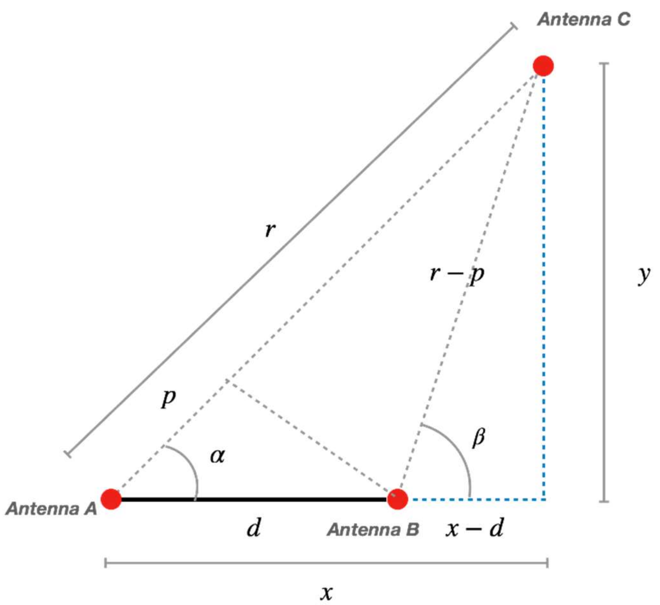

Figure 3. PDOA Positioning Principle Diagram

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Phase Difference of Arrival (PDOA) [3], by measuring the phase difference to find out the propagation time of the signal round trip to calculate the round trip distance. At least two antennas of the same type and spaced apart are placed on $d < \lambda/2$ the positioning base station, and the phase difference between the signals on the positioning tag arriving at the two $-180°$ antennas $180°$ is within the to range. The measured phase difference is converted into a distance(P) difference using the time of flight to$r$get A the C distance (point-to-point distance), and finally the coordinate (x, y) values Figure 3 are obtained as shown.

The specific description of (x, y) obtaining the coordinate values is as follows.

The distance of the signal A transmission to r the antenna and the A distance to $r - p$ the arrival antenna to B the arrival antenna. The distance between two antennas d is. The distance between the antenna and the A antenna is C obtained using the r time of flight, and the path difference p will d always be between and as long as the C distance between the two antennas is less than or $\lambda/2$ equal to half the wave length of $-\lambda/2$ the $+\lambda/2$ radio signal transmitted from the antenna. Therefore, if the arrival phase of each antenna can be measured, $-180°$ a $180°$ path difference from to $-\lambda/2$ is $+\lambda/2$ obtained from to range. In order to get the position of x, y the localization tag, we can get equation (1) by the following calculation.

$$\cos(A) = \frac{b^2 + c^2 - a^2}{2bc}$$

(1) According to the cosine theorem

$$\begin{aligned} \cos(\alpha) &= \frac{r^2 + d^2 - (r-p)^2}{2rd} \\ \frac{x}{r} &= \frac{r^2 + d^2 - r^2 + 2rp - p^2}{2rd} \\ x &= \frac{d^2 + 2rp - p^2}{2d} \\ x &= \left(r - \frac{p}{2}\right)\frac{p}{d} + \frac{d}{2} \\ r^2 &= x^2 + y^2 \\ y &= \pm\sqrt{r^2 - x^2} \end{aligned} \tag{1}$$

(2) According to the collinear theorem, we get equation (2)

$$x^2 + y^2 = \left(\frac{d^2 + 2rp - p^2}{2d}\right)^2 + y^2 = r^2$$

$$y^2 = r^2 - (\frac{d^2 + 2rp - p^2}{2d})^2$$

$$y = \pm\frac{\sqrt{(d^2 - p^2)(2r - p)^2 - d^2}}{2d}$$

$$y = \pm\frac{\sqrt{(d^2 - p^2)(4r^2 - 4rp + p^2 - d^2)}}{2d}$$

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$$y=\pm\frac{\sqrt{(d^2-p^2)(4r^2-4rp+p^2-d^2)}}{2d}$$

$$y=\pm\frac{\sqrt{\left(1-\left(\frac{p}{d}\right)^2\right)(4r^2-4rp+p^2-d^2)}}{2} \tag{2}$$

At this point it is not y possible to determine whether the values of the coordinates are positive or negative.

Further simplification can be done to get equation (3), d which r is negligibly small d^2 for r^2 because it is much smaller than.

$$y\approx\pm\frac{\sqrt{\left(1-(\frac{p}{d})^2\right)(4r^2-4rp+p^2)}}{2}$$

$$y\approx\pm\left(r-\frac{p}{2}\right)\sqrt{1-\frac{p^2}{d}} \tag{3}$$

So the coordinate position of the tag can be obtained by knowing only the value of x, y:

r: The distance from the tag to one of the base stations.

d: The distance between two neighboring antennas.

p: The path difference of the tag signal to reach the two antennas.

The defect of the above two-antenna structure of the base station is that its positioning accuracy is still not high enough, and it can only $180°$ carry out the angular calculation of the range, and when the moving range of the positioning tag $180°$ is out of the range, there will be a case of miscalculation.

Therefore, this positioning system adopts four antennas in a square deployment, to achieve a $360°$ full range of angle calculation, can further improve the positioning accuracy, and at the same time can reduce the number of chips, make its structure compact and reduce the cost of production, effectively reduce the volume, make the production and assembly more convenient high-precision PDOA positioning system [7].

2.2.2 Application of PDOA Technology

The use of PDOA technology usually requires at least one positioning base station and one positioning tag to be realized, in other words, unlike the time difference of arrival TDOA algorithm which requires at least four tags and one base station to complete a positioning, PDOA only requires one base station and one tag to complete a positioning, which not only further improves the positioning accuracy, but also reduces the number of chips, and further reduces the size of the positioning base station to make the product more convenient to produce and assemble. It can not only further improve the positioning accuracy, but also reduce the number of chips, further reduce the size of the positioning base station so that the product integration is higher, and achieve the purpose of cost reduction.

PDOA positioning algorithm is mainly through the tag and the antenna on the base station for signal reception and transmission of the angle obtained to carry out azimuthal ranging, based on the above prerequisites for the application of the algorithm puts forward the limitations of the scenarios, the distance between the base station and the tag can not be too far away from each other, the farther away the two are, the greater the deviation of the measured azimuthal data, which is equivalent to the following equipment equipped with the base station can not be too far away from the tag carrier who

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is being followed. The following device equipped with a base station cannot be too far away from the tagged person. Then, TDOA algorithm in this regard compared to the PDOA algorithm has a better effect, as long as in the area covered by the base station, the positioning accuracy of the system will have a certain degree of assurance, the tag is farther away from the base station, the deviation of the orientation ranging than the use of the PDOA algorithm to be smaller, but the use of the TDOA algorithm is the premise of a number of base stations to be deployed in advance in the specific area. Therefore, the PDOA algorithm is suitable for luggage and military material following and other scenarios, in the absence of advance arrangement of the base station, you can move arbitrarily over a wide range, greatly reducing the cost of time and capital costs, and the above application scenarios all need to be followed by the object at any time at a short distance, to some extent, to avoid the disadvantages of the use of the PDOA algorithm far away resulting in inaccurate azimuthal ranging [8].

3. UWB Positioning Base Station

The UWB positioning base station consists of two layers of Printed Circuit Board (PCB) and one layer of STM32 stand-alone development Figure 4 board, as shown.

Figure 4. UWB Positioning Base Station Physical Diagram

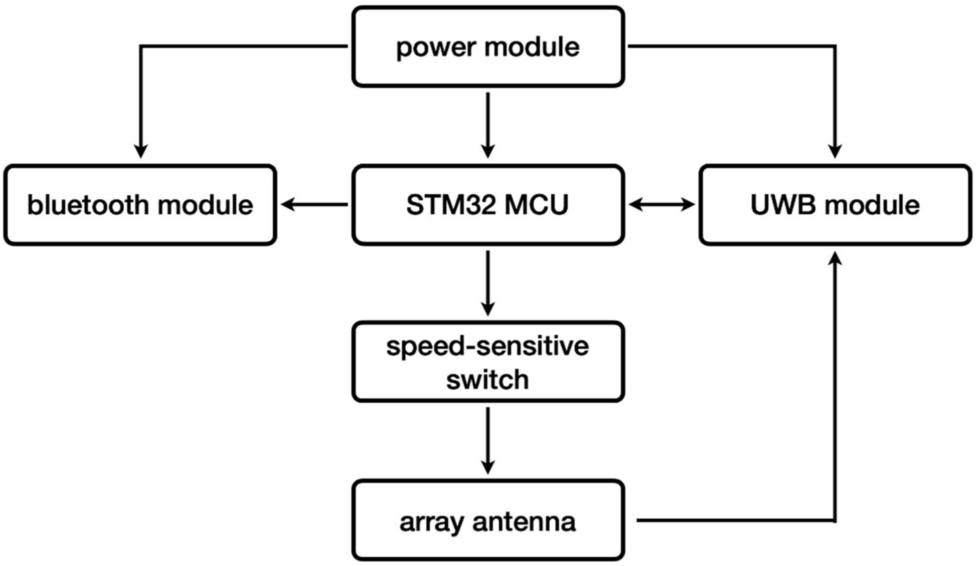

Figure 5. Block diagram of UWB positioning base station

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Above the upper printed circuit board, four RP-SMA interfaces are deployed at the four corners of the central square for connecting the UWB glue stick antenna, and four copper spools of signal wires are connected to the lower IPEX pedestal at the lower RP-SMA of the upper printed circuit board; the lower printed circuit board has a copper post at the corners of the lower printed circuit board for fixing the two layers of printed circuit boards, which contain the UWB positioning chip, two high-speed switches, power supply circuits and peripheral circuits, which are connected to the I/O ports of the lowest layer of the microcontroller development board through rows of pins for communication and fixation. The third layer of STM32 microcontroller is used for the development of positioning algorithm, optimization and data optimization, as shown Figure 5 in the figure.

3.1 UWB Positioning Module

3.1.1 UWB Positioning Chip

The UWB positioning chip used in this azimuthal ranging system is the DW3110IC provided by Qorvo (hereinafter referred to as DW3000).

DW3110IC (hereinafter referred to as DW3000) provided by Qorvo is used Figure 6 in this azimuthal ranging system as shown.

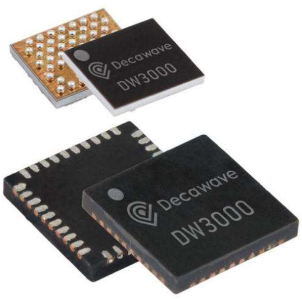

Figure 6. DW3000 chip physical diagram

Referring to the IC block diagram in the DW3000 manual, the RF part of the positioning module can be laid out Figure 7 as shown.

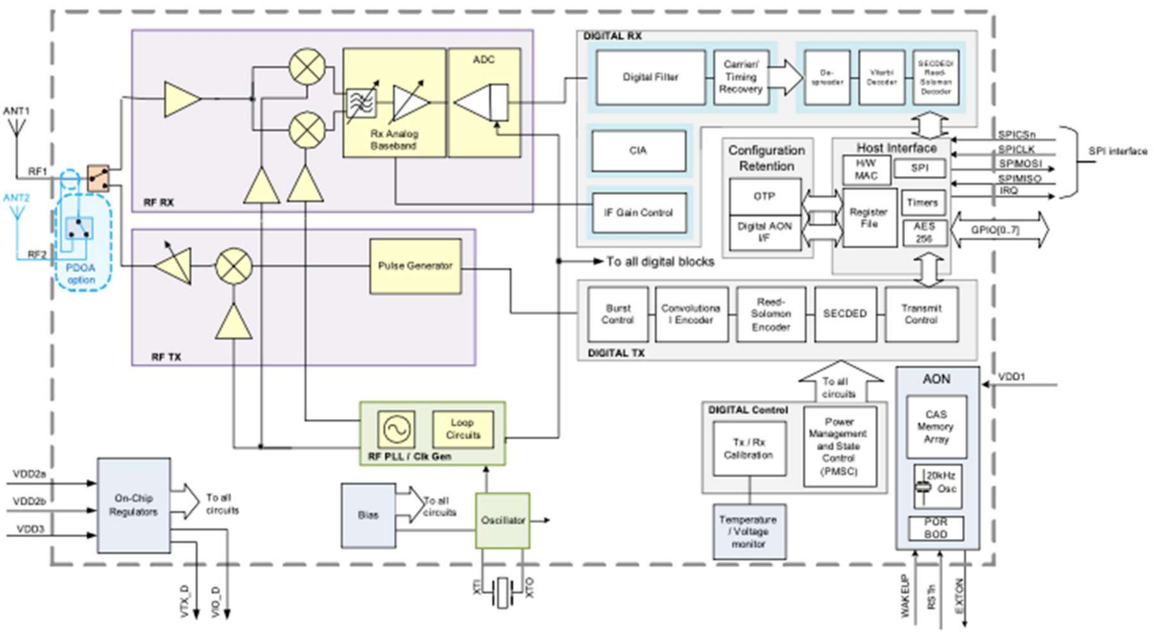

Figure 7. DW3000 integrated circuit block diagram

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The DW3000 consists of an analog front-end, in which TX/RX switches connect the receiver and transmitter to the ports of the antenna, and a digital back-end, which is connected to the host processor outside the chip.

The analog front-end amplifies the received signal in a low-noise amplifier and then converts the signal directly to baseband, where the baseband signal is demodulated by the analog receiver to generate the received data that is provided to the host controller via SPI. The transmitted pulse is generated by digitally encoding the transmitted data before applying it to the analog pulse generator. The IC variant has two RF antenna ports and the receiver switches between the antenna ports for application in PDOA orientation measurements [4].

3.1.2 Design of the Positioning Module

The positioning module consists of an RF circuit, a power supply section and a 38.4 MHz active Figure 8 crystal as shown.

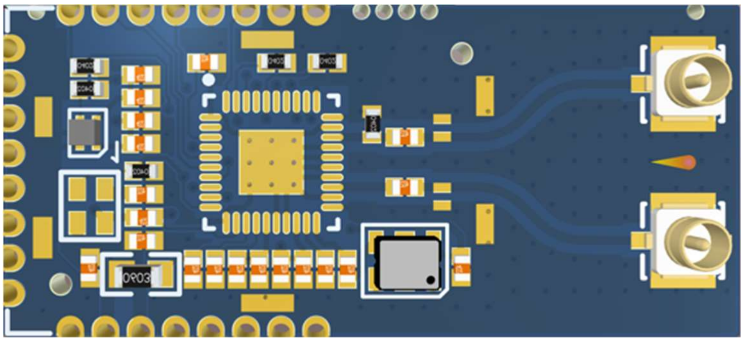

Figure 8. Dview of the UWB positioning module

The middle of the 3D view of the UWB positioning module is the RF part, the DW3000 chip is placed in the middle of the module, the right side is a number of filter capacitors, the pin Figure 9 configuration is shown.

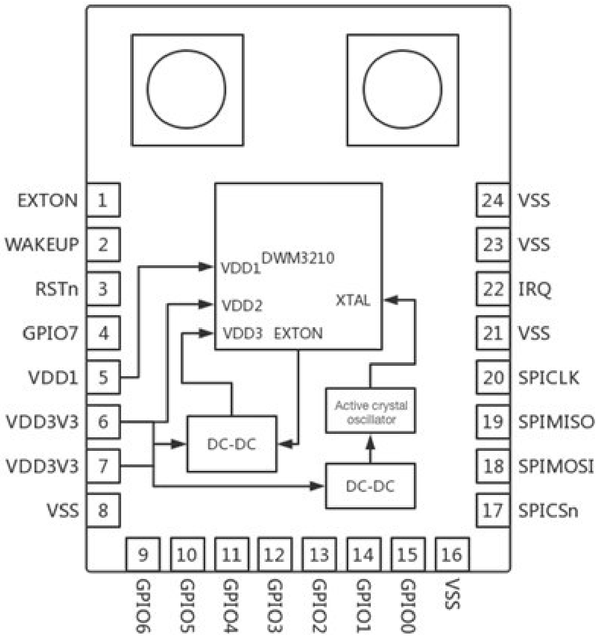

Figure 9. DWM3210 functional block diagram

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UWB positioning module 3D view of the lower right placed in the 38.4MHz active crystal oscillator, as a quartz crystal oscillator to provide a more stable clock signal, the schematic diagram Figure 10 is shown.

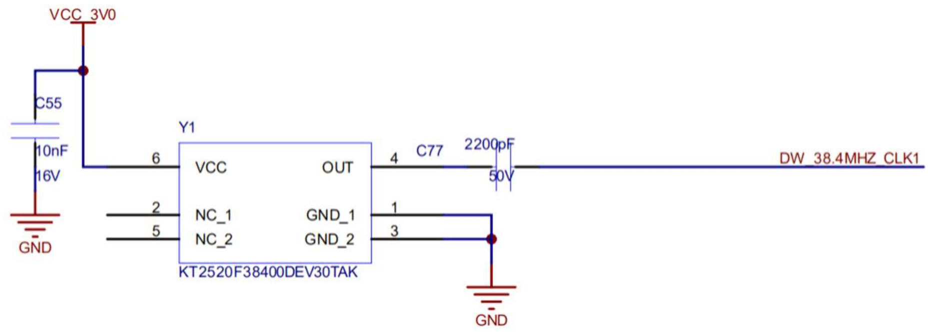

Figure 10. Schematic diagram of the active crystal

The upper left of the 3D view of the UWB positioning module is the power supply part of the active crystal, which realizes to convert the 3.3V input voltage to 3V for power supply, the schematic Figure 11 diagram is shown.

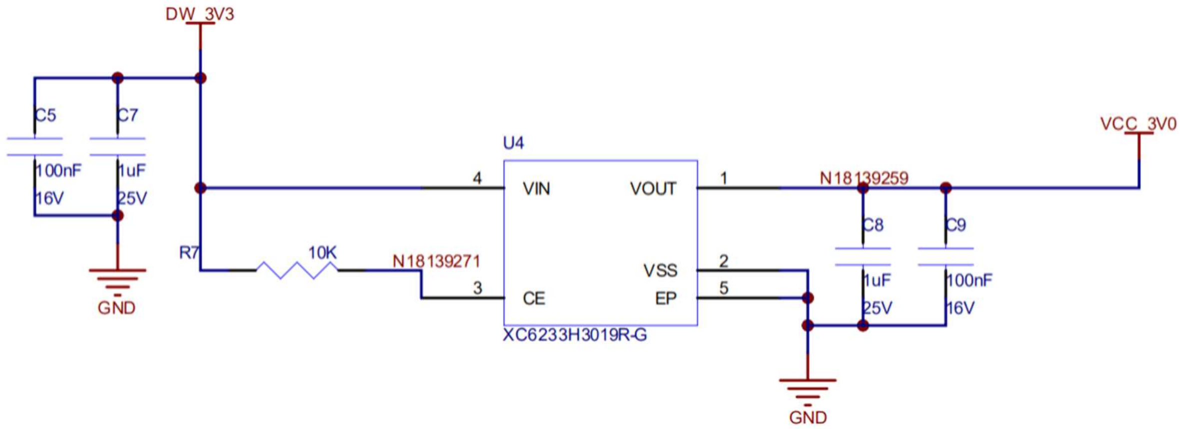

Figure 11. 3.3V to 3V schematic diagram

The lower left of the 3D view of the UWB positioning module is the power supply part of the DW3000, which realizes to convert the input voltage of 3.3V to 1.8V, and the schematic diagram Figure 12 is as shown.

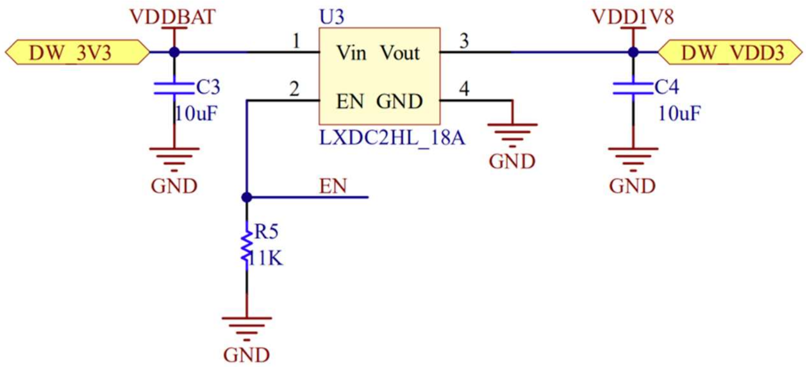

Figure 12. 3.3V to 1.8V schematic diagram

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3.2 Power Supply Circuit

This azimuthal ranging system uses a step-down chip model LD39050PU33R, which can provide a maximum current of 500mA, the power supply ripple rejection ratio (PSRR) is: 65dB@(1kHz), 62dB@(10kHz), the total current consumption is less1μAthan.

Through the bottom of the microcontroller development board power supply port can provide 5V main power supply to the entire positioning base station, the lower printed circuit board circuit can be real 5V power step-down to 3.3V, to provide the active crystal power supply circuit part of the DW3000 positioning Figure 13 module, as shown.

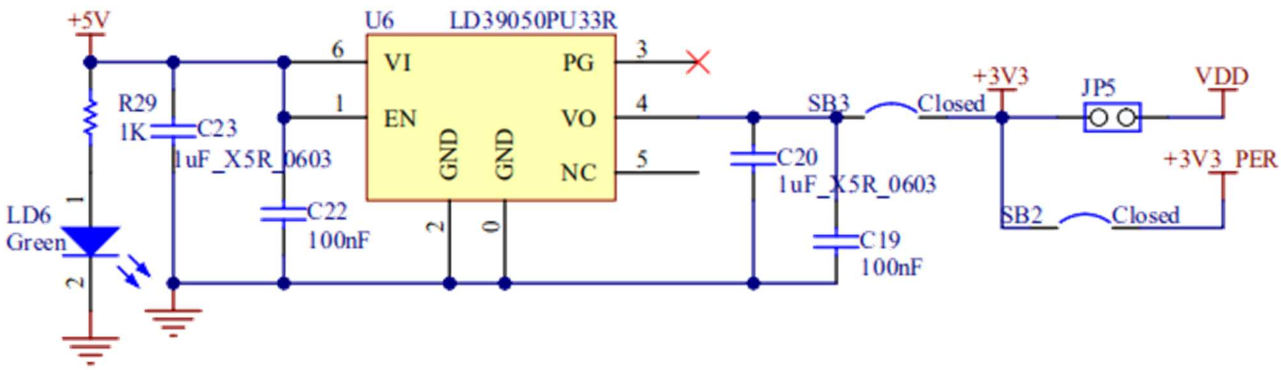

Figure 13. 5V to 3.3V schematic diagram

3.3 High-speed Switch and UWB Antenna

3.3.1 High-speed Switch and UWB Antenna Selection

This azimuthal ranging system adopts the high-speed switch model MASW-007107 and the UWB antenna of SMA head [1] Figure 14 as shown.

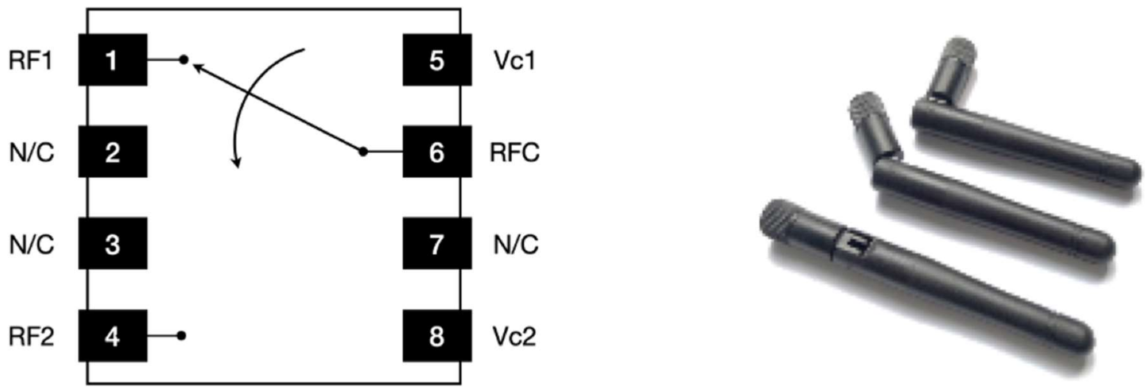

Figure 14. High-speed switch function illustration (left 1) and UWB antenna (right 1)

3.3.2 High-speed Switch and UWB Antenna Application

This azimuthal ranging system through four UWB glue stick antennas for signal reception, so that more data can be obtained, and then feedback to the microcontroller for calculation, can effectively improve the accuracy of the PDOA azimuthal ranging, and at the same time cover360°the full range of reception of signals issued by the tag, effectively improving the practicality. In addition, by setting two control switches to realize the signal input of the two antennas, only one microcontroller can realize the reception and calculation of the signal, which effectively reduces the number of chips, makes its structure compact and reduces the cost, effectively reduces its volume, and makes the production and assembly more convenient, Figure 15 as shown.

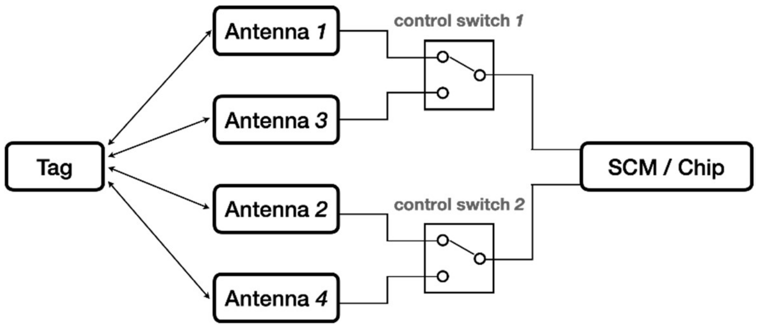

Figure 15. High-speed switch and UWB antenna application principle block diagram

According Figure 1 to the shown, this azimuthal ranging system includes a set of base stations and a set of tags, the tags and base stations can be moved relative to each other, there are four UBW glue stick antennas uniformly surrounded by the base station on the upper circuit printing board, with an adjacent interval of 2 cm; two high-speed switches on the base station on the lower circuit printing board on both sides of the two high-speed switches, through the coaxial line is connected to one antenna each.

According Figure 15 to the shown, antennas 1, 2, 3 and 4 will receive the tag to send ultra-wideband pulse signals respectively, after which control switch 1 selects antenna 1 or antenna 3 to be connected to the microcontroller, and control switch 2 selects antenna 2 or antenna 4 to be connected to the microcontroller, which receives the data signals from two of the antennas, and then performs the calculation. It can be set by the software to carry out the calculation 50 times per second to ensure the reliability of the calculation results. By selecting the antennas to be accessed through the control switch 1 and the control switch 2, the antenna 1 and antenna 2, antenna 2 and antenna 3, antenna 3 and antenna 4, and antenna 4 and antenna 1 can be realized as the antenna accessed by the antennas in the four different ways, and the microcontroller will carry out the calculation, and then screen out the most reliable angular data.

In addition, refer to 0 thechapter can be seen that a certain antenna of the antenna group will send a signal to the tag, when the positioning tag receives the signal, the tag will then provide the antenna with a feedback signal, through the signal time-of-flight to get the distance between the antenna to the tag (remembered r as), and finally a combination of the angular$r$position and the distance, to get the tag's coordinates value.

4. Microcontroller Program Writing

4.1 High-speed Switch Control Logic

Referring to 0 the chapter, we can know that this orientation ranging system adopts the deployment of four Figure 8 antennas, and as in the right side, there are only two RF antenna interfaces on the DW3000 positioning module, so each orientation ranging can only use two antennas to obtain the parameters, so we add two high-speed switches to control four antennas Table 1 separately, as shown.

Table 1. High-speed switch control logic

Sequence	PF1(main)	PF2 (secondary)
1	0(RF1)	1(RF2)
2	1(RF3)	1(RF2)
3	1(RF3)	0(RF4)
4	0(RF1)	0(RF4)

As Figure 4 shown, the upper printed circuit board has four antennas deployed in a quadrilateral shape with Figure 16 reference to the antenna placement. When the high-speed switch controls antenna 1 and antenna 2 to work, the tag in the upper right corner will send pulse signals to the two antennas respectively to obtain two orientation information; when the high-speed switch controls antenna 1 and antenna 4 to work, it will also obtain two orientation information after the tag in the upper right corner sends pulse signals to the two antennas, and so on, then it will generate two groups of antenna 4 and antenna 3, and antenna 3 and antenna 2, and a total of 8 orientations information.

4.2 Angle Calibration

Referring to 0 the chapter can get the angle algorithm in PDOA, the 0 chapter can get the deployment design and working mode of the high-speed control switch and the UWB glue stick antenna, combined with the above two chapters, the angle calibration will be carried out for different antenna groups to obtain different angle values under different coordinate axes, as Figure 16 shown in the figure.

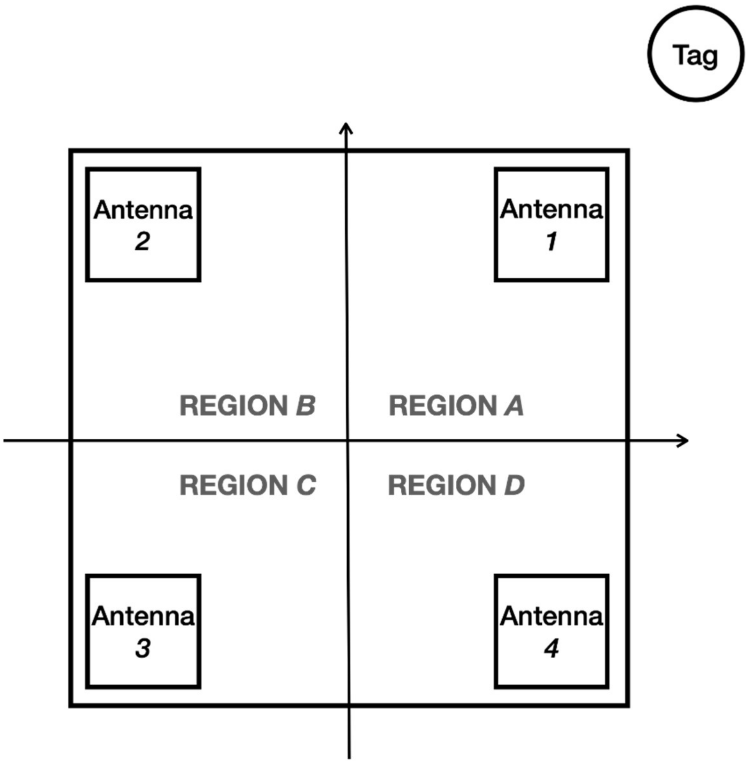

Figure 16. Angle calibration top view schematic

The coordinate axes formed by different antenna groups are rotated to the same coordinates, and the 8 angles after rotation are algorithmized to further improve the accuracy of azimuthal ranging.

Group I: When antenna 1 and antenna 2 are a group, the region A, B, C, D as the first, second, third and fourth quadrant, assuming that the angle of the tag for antenna 1 and antenna 2 at this time are approximately $45°$ and $18.4°$ respectively;

Group II: when antenna 4 and antenna 1 are a group, regions D, A, B, and C are used as the first, second, third, and fourth quadrants, respectively, assuming that the angles of the tag for antenna 4 and antenna 1 at this time are approximately $18.4°$ and, $45°$ respectively;

Group III: when antenna 3 and antenna 4 are a group, regions C, D, A, and B serve as the first, second, third, and fourth quadrants, respectively, assuming that the angles of the tag for antenna 3 and antenna 4 at this time are approximately $45°$ and $71.5°$ respectively;

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Group IV: when antenna 2 and antenna 3 are a group, regions B, C, D, and A are used as the first, second, third, and fourth quadrants, respectively, assuming that the angles of the tag for antenna 2 and antenna 3 at this time are approximately $71.5°$ and $45°$ respectively.

Now the coordinate axes of group II, III and IV are rotated counterclockwise around the origin, and the coordinate $90°$, $180°$ and $270°$ group I coincide with each other, at this time, the microcontroller obtains the angle from antenna 4 and antenna 1 of group II, the angle from antenna 3 and antenna 4 of group III, the angle from antenna $315°$ and $245°$ and antenna 3 of group IV, the angle from antenna 2 and antenna 3, the angle from antenna 2 and antenna $225°$ and $315°$ of group IV, the angle from group II, the angle from group IV and antenna 4, the angle from group IV $135°$ and antenna 3, respectively $225°$.

In reality ranging, the angle obtained after rotation of the same antenna of different antenna groups is not necessarily exactly the same, for example, in the above mentioned group II antenna 4 and group III antenna 4 will not both be in $315°$ reality, and the occurrence of a slight angular deviation and a great angular deviation are normal, and when the rotated 8 angles are excluded or recalculated by the filtering algorithm, they are then used for the coordinate calculation of the tag to realize the further improve the accuracy of azimuthal ranging.

4.3 Kalman Filter Algorithm

The Kalman filter algorithm is used in this azimuthal ranging system [2]. As 4.1 can be seen from the chapter, in the actual signal reception, the angle value obtained is biased and not completely practical, in order to get closer to the ideal angle to get more accurate azimuthal ranging accuracy, so in the PDOA azimuthal ranging algorithm Kalman filtering algorithm is added to the actual angle of exclusion or estimation, and then used in the calculation of the coordinates of the tag [5].

The Kalman filter program is written by rewriting the core formula in the basic theoretical derivation of the Kalman filter algorithm, and the rewritten formula is shown below.

$x\_mid = x\_last; // x\_last = x(k-1|k-1), x\_mid = x(k|k-1)$

$p\_mid = p\_last + Q; // p\_mid = p(k|k-1), p\_last = p(k-1|k-1), Q = \text{ noise}$

$kg = p\_mid/(p\_mid + R); // kg\text{Filter for the Kamal}, R \text{ For noise}$

$z\_measure = z\_real + frand() * 0.03; // \text{ measured value}$

$x\_now = x\_mid + kg * (z\_measure - x\_mid); // \text{The estimated optimal value}$

$p\_now = (1 - kg) * p\_mid; // \text{Covariance corresponding to the optimal value}$

$p\_last = p\_now; // \text{The latest covariance values}$

$x\_last = x\_now; // \text{Latest system status value}$

5. System Test and Data Analysis

5.1 Dual-antenna Base Station Test

Through the dual-antenna positioning base station and positioning tags on the azimuthal ranging system for accuracy testing, the collected tag history trajectory is drawn, Figure 17 as shown.

The test method is as follows, with the base station as the origin of the coordinate axis, the base station main antenna leaning to the positive half-axis side of the transverse coordinate, the base station secondary antenna leaning to the negative half-axis side of the transverse coordinate, the base station and the tag distance between the tag is always taged to maintain the 160 centimeters, the tag's front face towards the center of the circle base station, start from the positive half-axis of the transverse coordinate of the 0-degree angle of the beginning of the counterclockwise movement to the negative half-axis of the transverse coordinate of the angle of the base station each time around the center $180°$ of the circle to rotate and collect the data for 200 Each $22.5°$ rotation around the center base station and collect 200 times coordinate data.

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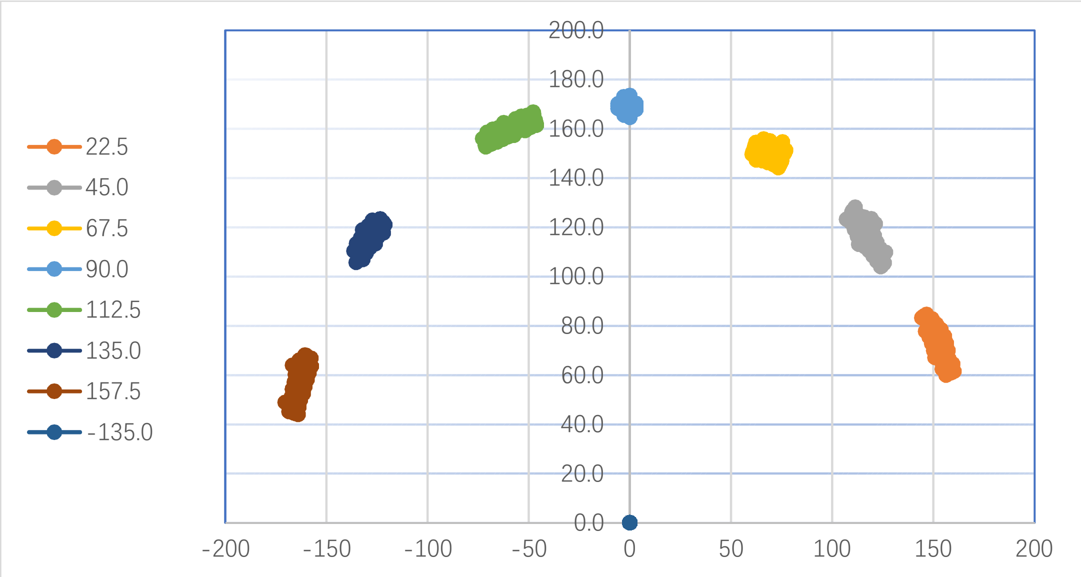

Figure 17. tag history trajectory (after filtering of dual-antenna base station)

According Figure 17 to the analysis of the test results, from the overall distribution of the tag history trajectory, it can be obtained that the positioning accuracy 45°of 135° the tag in the to is 0° more 45° accurate 135° compared 180° to the to and to, while the positioning 0° accuracy 45° of the to is slightly better 135° than 180° the positioning accuracy of the to. When the tag is 45° between 135° to, the measured deviation of the actual angle is, for example, ±5°when the tag is at the idea l45° angle, the test gets the actual data for to; 40° when 50° the tag is between 0° to 45° (close to the side of the main antenna of the base station), the measured deviation of the actual ±8° angle is; when the 135° tag 180° is between to (close to the side of the secondary antenna of the base station), the ±12° deviation of the angle is.

Using dual antennas to implement the PDOA algorithm to obtain the positioning data error can reach a minimum of 10 cm or so, but 45° for 135° to the range of the tag will appear more than 20 cm deviation or miscalculation of the situation.

5.2 Comparison of Four-antenna Base Station before and after Filtering

Four-antenna base station filtering before and after the test method with the tag orientation is as follows: take the base station as the origin of the coordinate axis, the main antenna of the base station leans to the side of the first and the third quadrant, the secondary antenna of the base station leans to the side of the second and the fourth quadrant, and the distance between the base station and the tag is always taged to keep 160 cm, and the front of the tag is facing to the center of the base station, and it begins to start moving counterclockwise from the angle of the positive half-axis of the 0° transverse coordinate for one week, and it rotates and collects 200 times of coordinate data every time around the center of 22.5° the circle base station. Rotate and collect coordinate data 200 times.

5.2.1 Four-antenna Base Station Pre-filtering Test

The accuracy of the azimuthal ranging system is tested by the four-antenna positioning base station and positioning tags without Kalman filtering data processing, and the collected tag history trajectory is plotted Figure 18 as shown.

According Figure 18 to the analysis of the test results, from the overall distribution of the tag history trajectory, it can be obtained that the positioning 90° accuracy −90° of the tag in and at two places is more accurate compared to the positioning accuracy of other angles. When the tag 90° is −90° at and, the measured deviation of the actual ±10° angle is; when the tag is at other angles, the measured deviation of the actual ±20° angle is.

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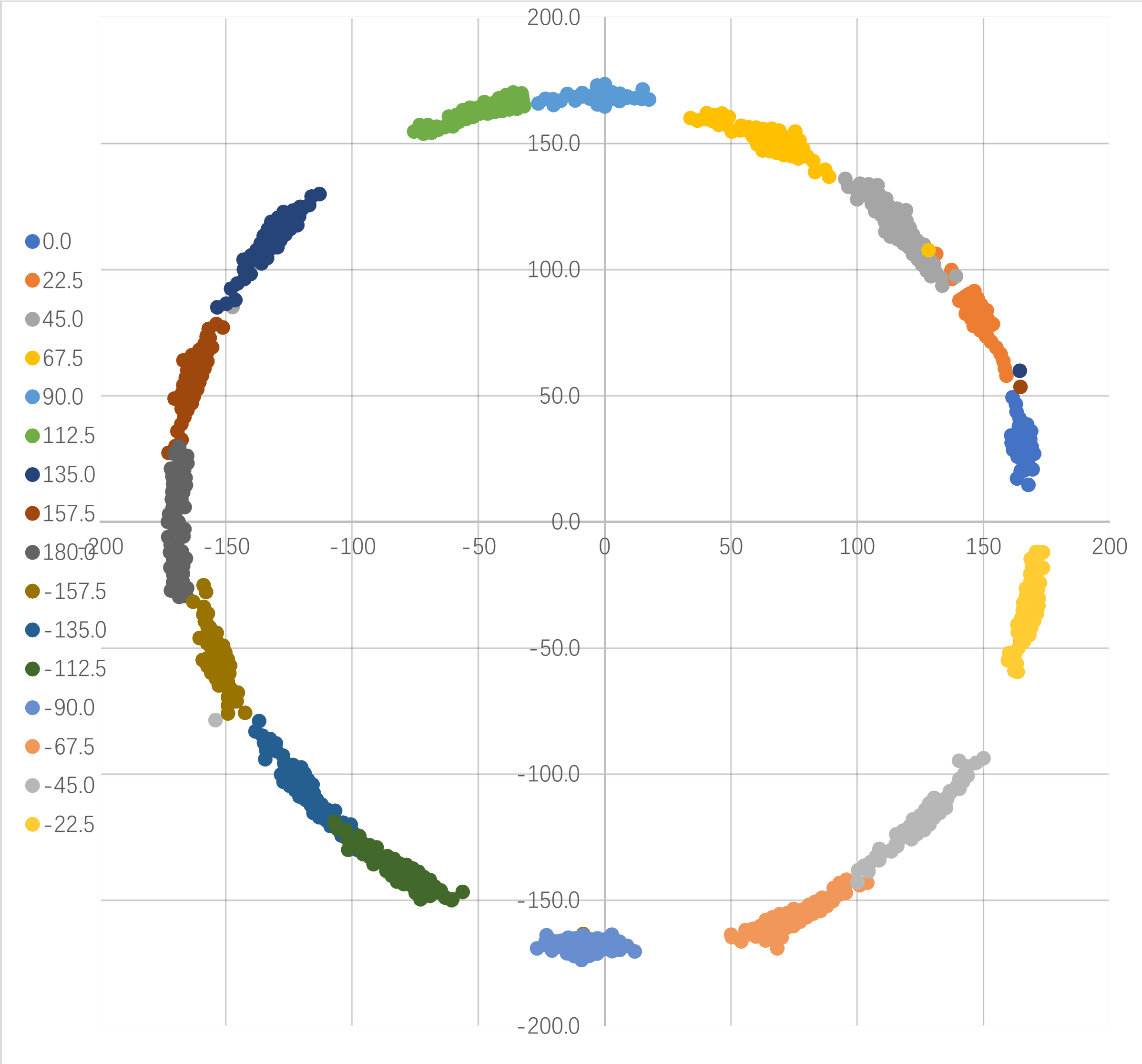

Figure 18. tag history trajectory (four-antenna base station before filtering)

5.2.2 Four-antenna Base Station Filtering Test

Through the Kalman filtered data processing of the four antenna positioning base station and positioning tags on the azimuthal ranging system to test the accuracy of the collected tag history trajectory is drawn, Figure 19 as shown.

According Figure 19 to the analysis of the test results, from the overall distribution of the tag history trajectory, it can be obtained that the positioning 90° accuracy −90° of the tag in and at the two places is more accurate compared to the positioning accuracy of other 0° angles, 90° while 0° the −90° positioning accuracy to and to 90° is 180° better −90° than 0° the positioning accuracy to and to. When the tag 90° is −90° in and , the deviation of the actual angle ±5° is measured; when the 0° tag 90° is 0° in −90° between to and to (near the main antenna side of the base station), the deviation of the actual angle ±10° is measured; when the 135° tag 180° is in between to (near the secondary antenna side of the base station), the deviation ±15° of the angle is.

According Figure 17 to Figure 19 the comparison with and can beobtained, in the case of both using the PDOA algorithm and after the Kalman filter algorithm processing,the four-antenna base station to make up for the defects of the dual-antenna base station for the side ranging deviation is large and miscalculation, 360° and can realize the azimuthal ranging within the range. In terms of the ranging accuracy of dual-antenna base station and four-antenna base station, the accuracy of both of them is achieved 90° when the tags are in the same position; when ±5° the tags are in the side close to the main antenna of the base station, the ranging accuracy of the former is better than that of the latter;

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similarly, when the tags are in the side close to the secondary antenna of the base station, the accuracy of the former is better than that of the latter. After analyzing, the two high-speed switches in the dual-antenna base station only need to control the work of one main antenna and the secondary antenna, and the two high-speed switches in the four-antenna base station need to control the work of two main antennas and the secondary antenna respectively. Although the high-speed switch of the latter can theoretically control only one main antenna at the same time, but in practice the other main antenna may work intermittently, so that the ranging accuracy of the deviation.

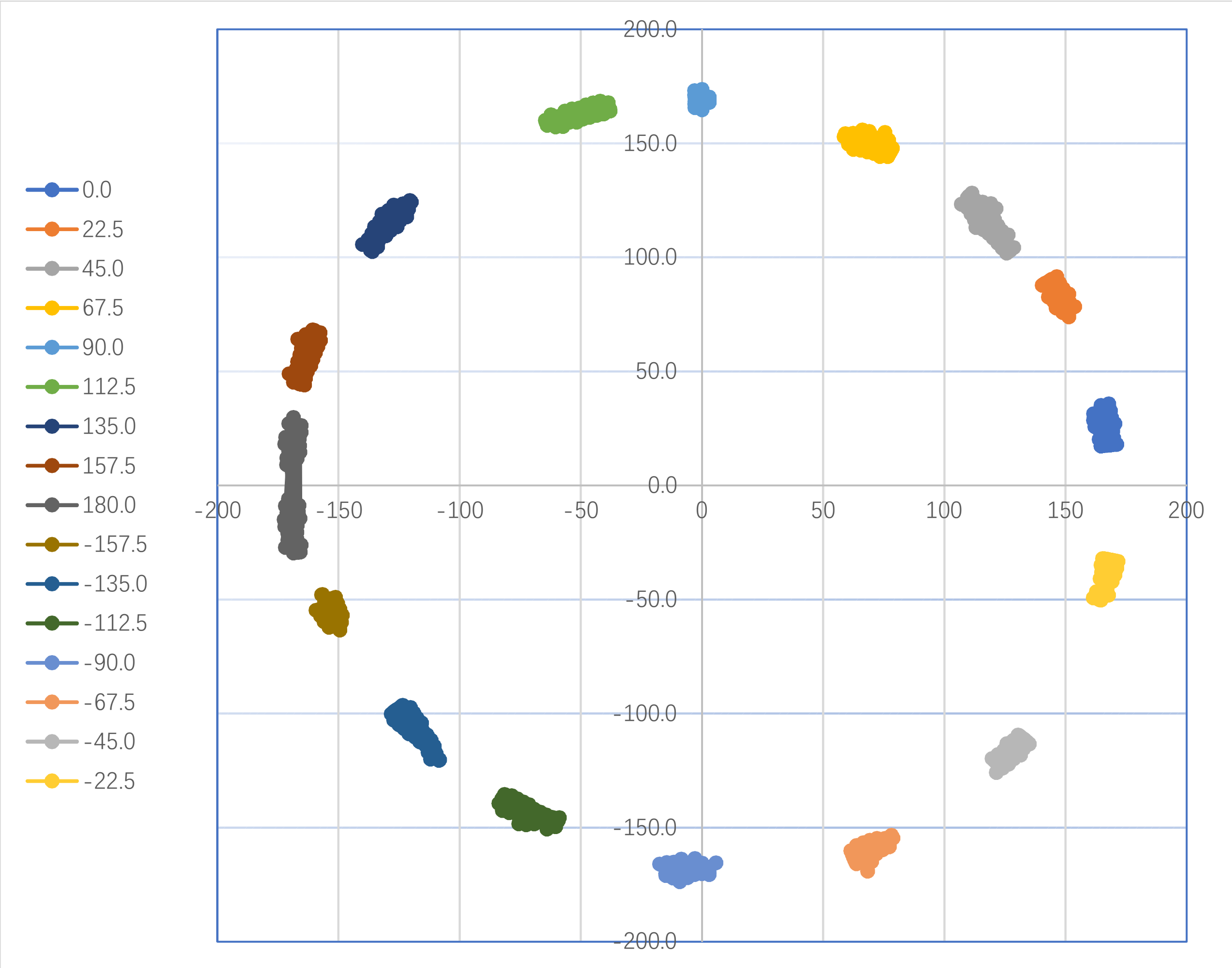

Figure 19. tag history trajectory (four-antenna base station after filtering)

According Figure 18 to Figure 19 and for comparison, Kalman filtering effectively filters the miscalculated orientation data, and calibrates and recalculates the four groups of orientation data obtained at each moment, reducing the deviation of ranging accuracy, but for the tag at 180° the location, there is still a large positional deviation after filtering.

5.3 Four-antenna Base Station Tag Orientation Test

Through the four-antenna positioning base station and positioning tags in different orientations to the azimuthal ranging system for accuracy testing, the collected tag history trajectory is plotted, Figure 20 as shown.

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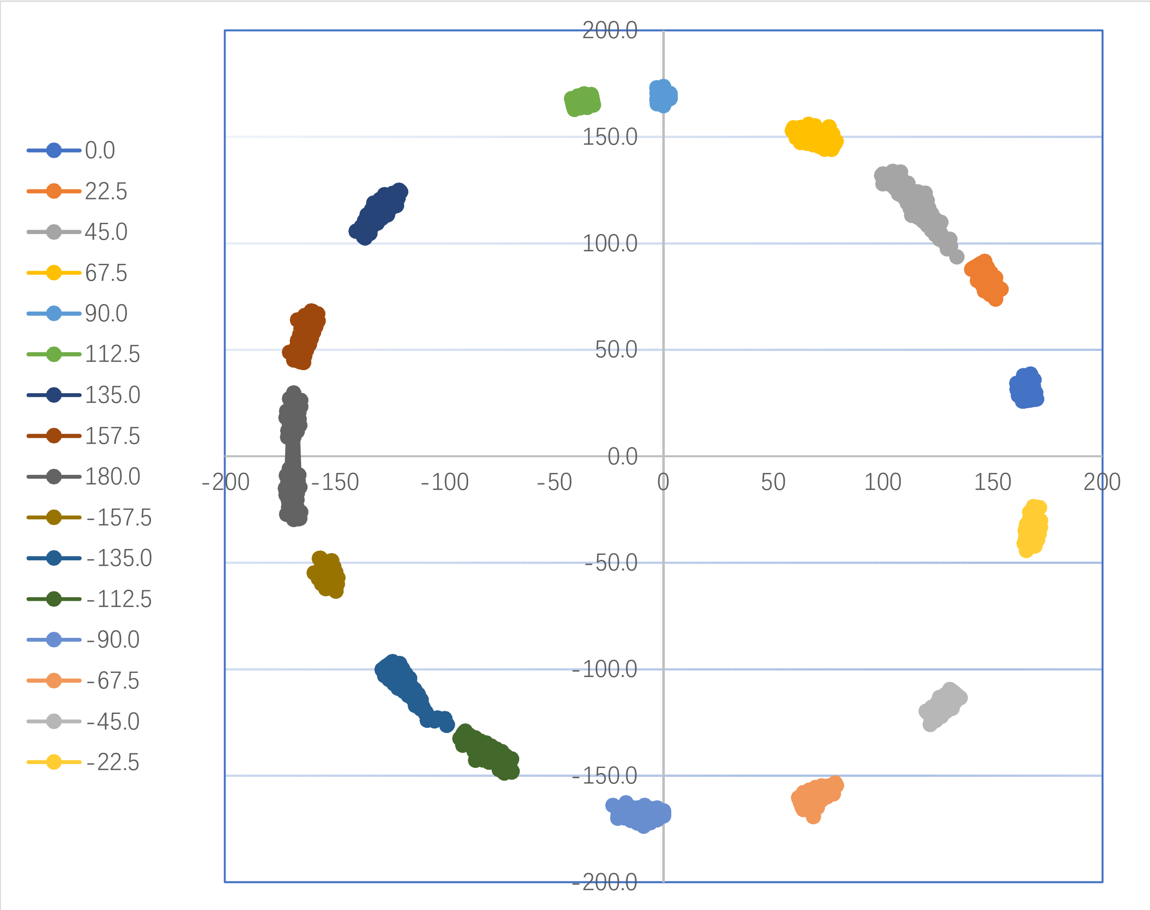

Figure 20. tag different orientation history trajectory (four antenna base station after filtering)

According Figure 20 to the analysis of the test results, from the overall distribution of the tag history trajectory, it can be obtained that the 90° positioning −90° accuracy of the tag in and at the two places is more accurate compared to the positioning accuracy of 0° other 90° angles, 0° while −90° the positioning accuracy to and 90° to 180° is −90° better 0° than that to and to. When the tag is 90° at −90° and , the deviation of the measured actual angle ±5° is; when the tag 0° is 90° between 0° to −90° and to (near the side of the main antenna of the base station), the deviation of the measured actual ±10° angle is; when the 135° tag 180° is between to (near the side of the secondary antenna of the base station), the deviation ±15° of the angle is.

According Figure 19 to Figure 20 and comparative analysis, it can be obtained that in the case of both using the PDOA algorithm and processed by the Kalman filter algorithm, with the base station as the reference point, the different orientations of the tag have less influence on the ranging accuracy. After analysis, when the DWM3000 module of the tag is facing the base station, the ceramic antenna on the tag is not affected by the printed circuit board for the reception and transmission of signals, so the ranging accuracy will be slightly better compared with the back facing the base station, but it is not an absolute influence factor from time to time.

5.4 Four-antenna Base Station Filtering Phase Difference Analysis

According Figure 19 to the obtained test data, it is made into a point line graph of the angle change with Figure 21 time, as shown.

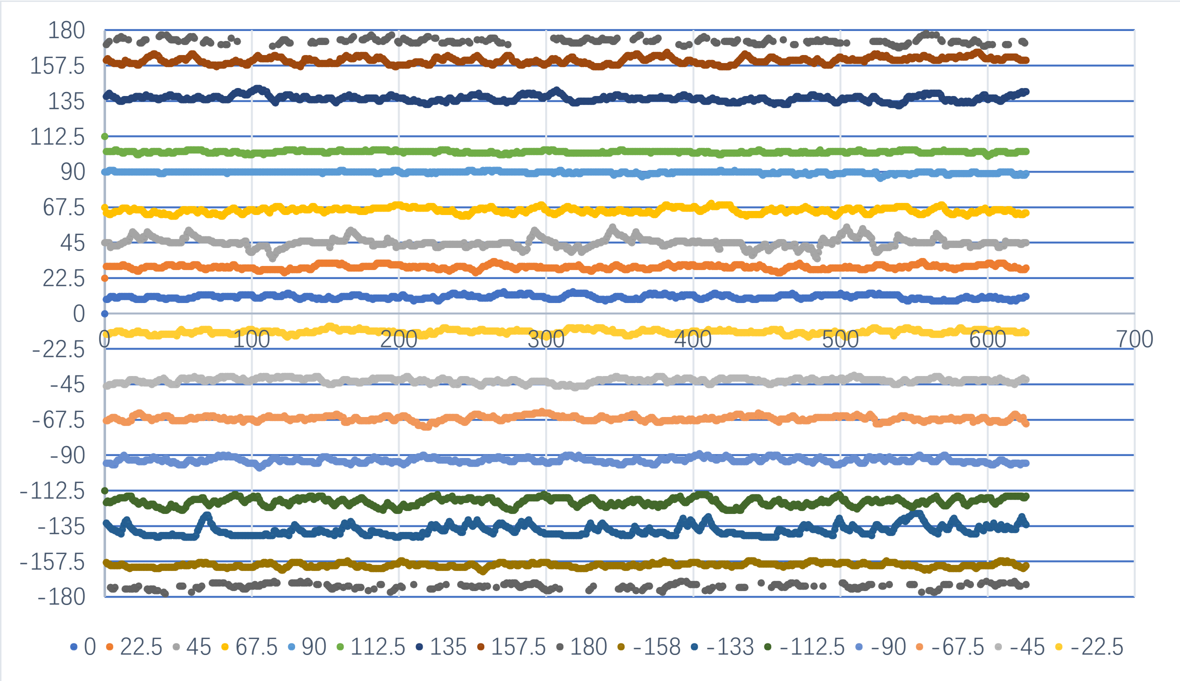

Figure 21. ephase difference over time (after four antenna base station filtering)

According Figure 21 to the analysis carried out, it can be observed that $-22.5°$ the $0°$ actual $22.5°$ measured orientation information is greater than the ideal angle when the tag is in, and the ideal angle; the $-112.5°$ actual $112.5°$ measured orientation information is less than the ideal angle when the tag is in and the ideal angle; the $180°$ tag is in the ideal angle when the positioning error is larger, so it is planned to optimize and improve the orientation data when the tag is in the angle between each set of two antennas.

6. Summary

In the scheme design of this paper, the deployment method of quadrilateral array antenna is proposed. By collecting the Angle data from the same base station to different antennas in multiple directions, the positioning accuracy is improved after analysis and calculation. Then in practical applications, with the relative movement of the positioning base station and the positioning label, the base station is not always in the horizontal direction, in other words, the four antennas at the top of the base station will not always be perpendicular to the ground, but will present an acute or obtuse Angle with the ground, and the positioning accuracy will be affected by the pitch Angle, which is the first shortcoming of the system at present. The second shortcoming is that the cause of clutter has not been found. Although it has no impact on the PDOA ranging accuracy, it does not mean that other parameters will not be affected.

In view of the first shortcoming, we plan to test the deviation of PDOA azimuth ranging when the horizontal Angle is $\pm 30°$ and $\pm 60°$, and the pitch Angle is $0° \sim 20°$ and $20° \sim 25°$. After integrating the data variation, we will optimize it in the software part.

In the follow-up development, after solving the above two shortcomings proposed in this study, the following two aspects can be further studied:

(1) How to achieve PDOA azimuth ranging in a non-line-of-sight environment to accurately locate the tag target.

(2) How to extend point-to-point collaborative tracking to point-to-multipoint collaboration to achieve multi-goal collaborative positioning tracking.

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