Research and Implementation of Automatic Following Algorithm Based on Ultra-Wideband Positioning

Zining Lv[a], Zhitao Dai[b], Chang Liu[c],

Beijing Key Laboratory of Intelligent Telecommunication Software and Multimedia. Beijing University of Posts and Telecommunication. Beijing, China

[a]18345197177@163.com, [b]daizt@bupt.edu.cn, [c]lchang1994@outlook.com

Keywords: Ultra-wideband positioning, Self-walking follow-up process, software control logic

Abstract: This paper describes the research and implementation process of automatic tracking system based on ultra-wideband positioning, including hardware architecture and software control logic. The paper analyzes the influence of various internal factors such as positioning data jitter, suitcase's own inertia, data arrival delay and hardware drive system limitations on the smoothness and stability of the suitcase following the user process, and considering external factors such as the user's walking speed, etc. Improved the control process of changing the speed and steering, and propose an optimized follow-up algorithm. The experimental results show that the optimized following algorithm can greatly improve the stability of the self-walking follow-up process and reduce the rolloves and slipping.

1. Introduction

With the development of technology, automatic follow-up technology, which is widely used in the field of robots and artificial intelligence, is gradually entering people's daily lives. For example, a suitcase equipped with a power system that can accurately and automatically follow the users walking can greatly facilitate traveling process. In the current domestic self-propelled technology field, there has been a company which has launched a suitcase based on Bluetooth positioning that can actively follow the user's movement. However, due to the low precision and mutual interference of the Bluetooth positioning technology, the suitcase has not been widely used. Thus, a more stable and accurate positioning and following system has become the focus and hotspot of current research.

Ultra-wideband technology is a relatively advanced positioning technology, featuring high positioning accuracy and strong anti-interference ability. Now there is a non-line-of-sight base station screening algorithm that can reduce the influence of electromagnetic wave non-line-of-sight propagation on ranging, which can achieve more accurate ranging and positioning functions. Because ultra-wideband ranging has centimeter-level accuracy, it is often used in indoor location system. In the actual ranging scenario, the data returned by the ultra-wideband base station has a large jitter, which cannot be directly used in the algorithm. Also, considering the inertia of the hardware, a sudden change of speed and angle may easily lead to rollover or slippage. These are some issues that a smooth automatic following system needs to solve.

An automatic following algorithm is designed in this paper, based on the ranging function of UWB signals. The algorithm includes linear regression and sliding weighted averaging of ranging information, Kalman filtering on jitter data, a controling system based on calculation of angle and distance. Finally, combined with the hardware design, a stable and efficient self-propelled following terminal is realized.

Ultra-wideband (UWB) positioning technology is a hotspot among new communication technologies. It has been widely researched by people sence first proposed in 1965. In the 863 Program Communication Technology Researching Project, Chinese scientist officially listed UWB technology and its compatible technologies as the research content of wireless communication common technology. However, at present, China's UWB communication system has not yet formed, and mainstream mobile terminals such as computers and mobile phones cannot support the transmission and reception of ultra-wideband signals. Ultra-wideband technology has high positioning accuracy [1], large bandwidth and low-rate spectral density [2, 3], and has a wide range of applications in the field of indoor positioning and ranging.

The concept of automatic following system was first proposed in the field of robots and artificial intelligence. The self-propelled terminal can follow the users by identifying the relative position of the base station in the user's hand. There are many kinds of signals can be used as a positioning signal transmission medium, such as Bluetooth, zigbee [4], RFID [5], etc., these traditional media have different short boards, for example, Bluetooth is lack of anti-interference ability, zigbee's transmission distance is short. Applying ultra-wideband technology to the automatic following system is currently a hot research topic.

2. hardware design

The self-propelled terminal is mainly divided into three parts: a positioning module, a central control module and a lower-position driving module. At present, the positioning module adopts an ultra-wideband positioning unit. Ultra-wideband positioning has the characteristics of high precision and strong real-time performance, and has certain anti-interference ability, which can better meet the requirements of precise positioning. The hardware architecture diagram of the self-traveling terminal is shown in Figure 1. The central control module is connected to the positioning module and the driving module through the GPIO, receives the positioning data of the target and generates the command to control the moving process.At present, the central control unit uses the stm32 as a mainboard. Compared with other boards, the stm32 is relatively Cost-effective, and has a stable GPIO signal, which is more suitable for hardware controlling.The lower-position driving module includes tires, DC brushless motors, large capacity batteries, voltage regulator modules, etc. The battery provides 24 volts for the tires. The voltage regulator module provides 5 volts of stable voltage for the central control board and the UWB station. The speed control signal and brake signal of the left and right tires are respectively connected to the GPIO of the central control board for receiving commands from the control board. Two base stations are mounted on both sides of the terminal, and the relative distance from the user's wristband returned by the two base stations is used to determine the positions of the user relative to the self-traveling terminal. When the distances measured by the base stations on both sides are the same, it is determined that the current self-traveling terminal and the user are in the same direction. When the average value of the two base stations exceeds 5 meters, an alarm signal is issued to remind the distance that the distance is too long. The infrared device on the self-travel terminal detects the front environment in real time, and immediately controls the brakes when encountering obstacles to prevent a safety hazard in the moving process.The Bluetooth module is mainly used for debugging work, and sends the relative distance calculated by the base stations on both sides of the terminal to the serial port of the computer, which is convenient for observing and analyzing the accuracy of the ranging data.

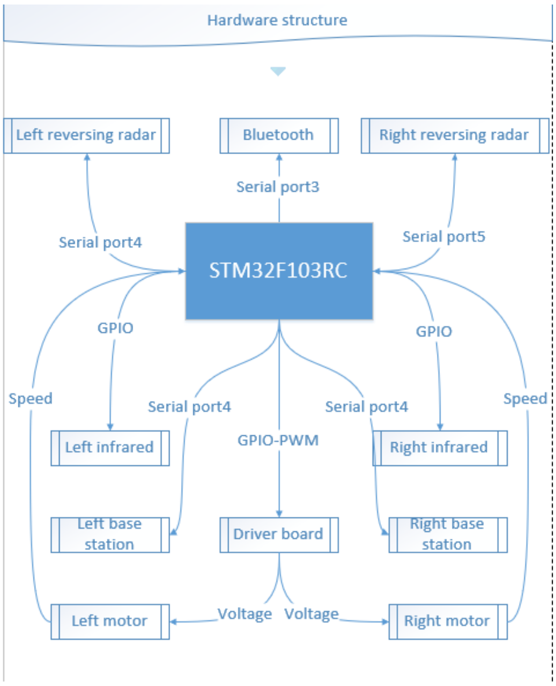

Fig 1. hardware architecture diagram

The electric drive design of the self-propelled terminal is shown in Figure 2. The 24V lithium battery is used to supply power to the entire cabinet. Equipment that needs to be powered includes a motor drive board, a central control board STM32, two lreversing radars, a Bluetooth communication device, and a left and right UWB base station. The motor drive board is directly connected to the 24V power supply; the central control board is connected to the power supply through a 24V to 5V voltage regulator module; the left and right UWB base stations are connected to the power supply through a 24V to 4V voltage regulator module; the reversing radars are directly output by the central control board.

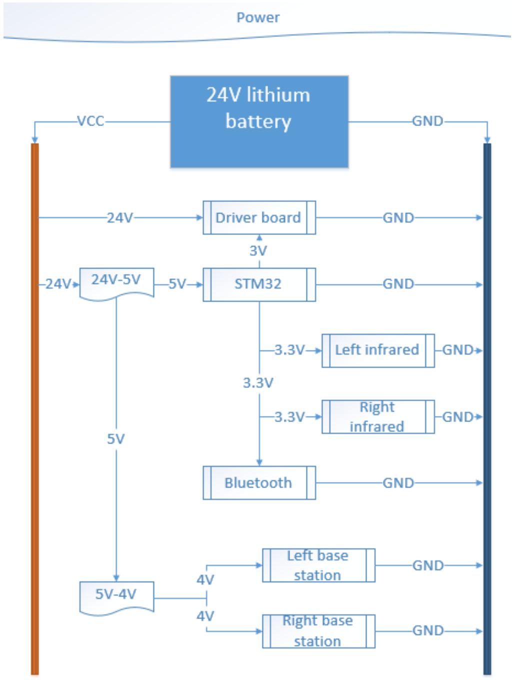

Fig 2. Schematic diagram of power system

3. Processing and calculation of data

Ultra-wideband technology is a new technology that uses a signal with a bandwidth of GHz to communicate directly by pulsing impulse pulses with very steep rise and fall times. Due to its high accuracy [6] and strong anti-interference ability, Ultra-wideband technology is widely used in indoor positioning scenes [7]. Using the two-way arrival time ranging method to analyze the UWB signal, the point-to-point distance between the signal base stations can be obtained. The positioning accuracy of the distance can reach the centimeter level, far exceeding the accuracy of other ranging technologies such as Bluetooth and infrared.

The self-propelled follower terminal implemented in this paper uses the point-to-point ultra-wideband ranging method which is relatively mature at present, and calculates the relative position of the user and the terminal through the ultra-wideband networking mode, and completes the follow-up actions. At present, two ultra-wideband signal receiving base stations are installed on the terminal equipment, and the signals sent by the user are calculated in real time, and the distance between the two receiving base stations and the transmitting base station is calculated. Since the distance between the two receiving base stations is constant, the relative position coordinates of the user can be obtained by using the three-point positioning method.

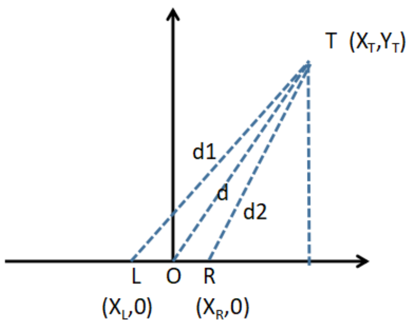

Fig 3. schematic diag ram of the algorithm

The schematic diagram of the measurement data is shown in Figure 3, where L and R are the two receiving base stations on the terminal respectively, T is the user's handheld transmitting base station. LR is a constant, LT, RT can be obtained in real time through the ultra-wideband signal two-way arrival time ranging method. The terminal-user relative position OT we need can be calculated by Equation 1. The simplification of the available distance OT is shown in Equation 2. The cosine of the relative deflection angle ∠TOR can be calculated by Equation 3. The distance OT and ∠TOR have important reference functions in the subsequent speed control and differential steering. According to the two, the relative coordinates of the point T can be obtained.

$$OT^2 = OR^2 + RT^2 - 2 \bullet OR \bullet RT \bullet \frac{LR^2 + RT^2 - LT^2}{2 \bullet LR \bullet RT} \quad (1)$$

$$OT = \sqrt{\frac{LT^2}{2} + \frac{RT^2}{2} - \frac{LR^2}{4}} \quad (2)$$

$$\cos\angle TOR = \frac{OT^2 + \frac{LR^2}{4} - RT^2}{OT \bullet LR} \quad (3)$$

The previous section introduced the data processing process under ideal conditions. However, in the actual data acquisition process, it was found that there were a lot of jitter and hopping in the ultra-wideband ranging data, as shown in Figure 4.Since the size of the self-traveling follower itself is limited, the distance LR of the base stations on both sides is small, and the sharp jitter of the ranging information of the left and right base stations will have a great influence on the final calculation result. We find that the amplitude of the data jitter can reach more than 0.5 meters in the limit case, and even exceed the spacing LR of the two receiving base stations. If not processed, the terminal will only rotate in place and cannot realize the function. To solve the problem of data jitter, we perform sliding weighted averaging and linear regression on the measured values of distance.

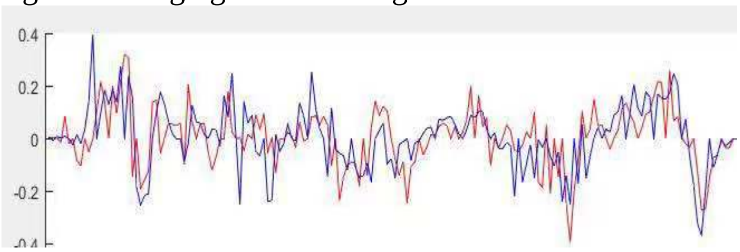

Fig 4. Ranging information returned by the base stations on both sides

Taking the ranging information received by the left base station as an example, it is assumed that the distance measurement data calculated by the base station at the current time is d. The calculated distance fitting values for three, two, and one-time unit are RT3, RT2, and RT1, and the distance fitting value of the current time is calculated using Equation 4. The weighting method is to consider the ranging data of the current time and the distance fitting value of the previous three-time nodes, and the later the data is, the larger the weight of the data is. Such linear regression considers the results of the pre-sorted data, making the distance data more gradual over time, effectively reducing the large jumps and jitters of the data. FIG. 5 is an effect diagram of the linear regression processing of the ranging data in the static state of the user, the blue and yellow represent the change of the ranging information of the base stations on both sides, and the red represents the relative distance after the calculation.

$RT = 0.1 * RT3 + 0.2 * RT2 + 0.3 * RT1 + 0.4 * d$ Equation 4

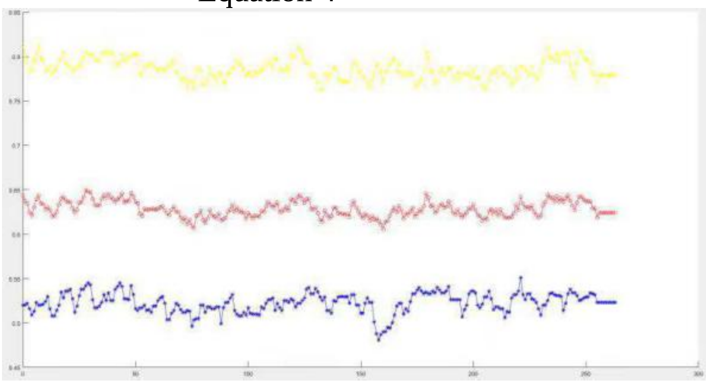

Fig 5. Ranging and fitting data

Since the self-propelled follower terminal is not equipped with an odometer, it is impossible to obtain clear angular velocity and position change information during the movement process, and the entire following process needs to be adjusted in real time according to the relative displacement of the terminal and the user and the relative declination. In the actual following scene, if the data is not further processed, due to the lag of the data arrival and calculation, the following terminal will continue to appear in the real-time adjustment process when the actual steering angle is greater than the theoretical steering angle. The excessive deflection will continue to be corrected during the movement, as a result, the self-propelled terminal being able to follow the user in the following process, but the following trajectory is often a S-shaped curve that swings left and right. To solve the problem that the following process is not smooth, Kalman filter processing [8] is performed on the relative coordinates calculated in the previous text. The processing method used in this paper is to filter the horizontal and vertical coordinates respectively. The processed data is shown in Figure 6. By filtering the relative position between the user and the terminal in a certain period, the position of the user at the next moment is predicted, the number of occurrences of the excessive deflection is reduced, and the S-shaped walking problem can be effectively solved.

Figure 6 shows the distance calculation data after Kalman filtering. The filtered black trajectory has a certain error when it starts to move, because the starting point of Kalman filtering is different from the real position. The filtered trajectory gradually shows better stability with respect to the blue sampling point of the unfiltered wave after a period of adjustment.

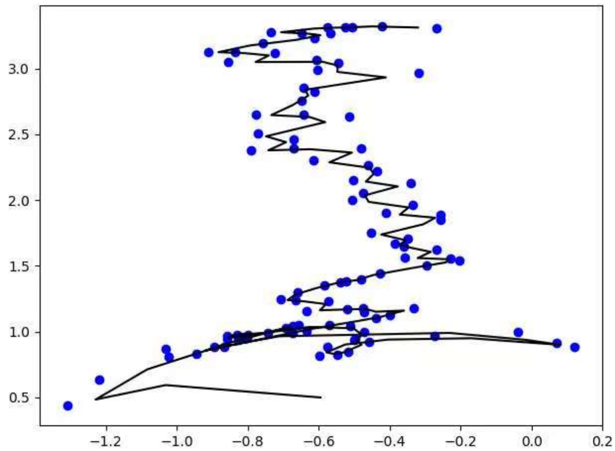

Figure 6. Kalman filter

4. Drive control system

An important part of the hardware control of the self-propelled terminal is the control of the chassis wheel speed. Whether or not the turn adjustment can be made in time depends on whether the wheel speed can be accurately controlled. The wheels of the suitcase use PI control, which is essentially the feedback control through the proportional link and the integral link. Proportional control is to multiply the difference between the actual speed and the expected speed by a proportional parameter to obtain the output of the proportional link. The integral control is to integrate the speed difference of each control cycle, and the obtained integral value is multiplied by an integral parameter to obtain the output of the integral link. Finally, we add the outputs of the two parts is the total output of the PI controller. In the controller, the proportional part acts to make the system react quickly, and can quickly respond to the vicinity of the target value when the error is large; The function of the integral link is to stabilize the output of the system at the expected value, which can eliminate the error generated by the proportional link and make the accurate output.

The self-propelled follower terminal itself is not equipped with a steering servo, and the steering function is realized by differential rotation of the left and right wheels. Assume that the absolute difference between the speeds of the two wheels is ΔV. The larger the ΔV is, the more severe the steering amplitude of the terminal is; the smaller the ΔV is, the smoother the steering amplitude of the terminal is. In the actual following movement process, the user's walking speed and steering amplitude are unknown. To avoid accidents such as rollover and slip, the terminal needs to adjust the speed and steering range in real time. To achieve the above adjustment function, this article uses the idea of expert system. The distance d between the user and the self-traveling follower terminal and the relative deflection angle θ are used as input variables of the expert decision system, and the ideal speed V of the terminal and the two-wheel speed difference ΔV are taken as output variables.

The ideal speed is the speed at which the two wheels rotate faster. The greater the distance between the user and the terminal, the faster the ideal speed. The relationship between ideal speed and distance should not be linear. To make the following process relatively stable, the trend of speed increasing with distance should tend to rise gently. The ideal speed is obtained by Equation 5, where m is the safety distance between the following terminal and the user. When the distance between the two is less than or equal to m, the speed is 0; When the distance exceeds m, the ideal speed increases slowly in a logarithmic relationship with the increase of the distance d. λ is the control parameter of the speed variation amplitude, and the magnitude of the speed variation with distance can be linearly adjusted. We also compare calculated result with the maximum speed VMAX that the hardware can support. If the maximum speed is exceeded, the maximum speed is applied to the ideal speed.

$$V = \ln(\frac{d}{m}) \bullet \lambda \quad (4)$$

The speed difference can control the differential steering of the two wheels, and its value can control the severity of the steering process. When the deflection angle is constant, the speed difference is inversely proportional to the distance; when the distance is constant, the speed difference is proportional to the deflection angle. The speed difference can be found by Equation 6, where β is a parameter that controls the degree of steering sensitivity. When the terminal determines that there is a steering demand in a certain direction, the tire speed in this direction is adjusted to V-ΔV, while the other side maintains the ideal speed V, and the steering process is realized by the speed difference.

$$\Delta V = |\theta| \bullet \frac{\beta}{d \bullet \frac{\pi}{2}} \bullet V \quad (5)$$

5. conclusion

In this paper, the sliding weighted average of the ranging data obtained by the two ultra-wideband base stations of the self-traveling follower is used to keep the correlation between the measured value and the pre-order data at each moment, which reduces the large jitter and jump of the data. Then, the relative coordinates between the user and the terminal are obtained according to the three-point positioning method, and the obtained relative coordinates are Kalman filtered to form a smooth motion curve. Finally, combined with the PI control of the tire speed and the differential control based on the expert system idea, an optimized automatic tracking algorithm based on UWB positioning is designed and implemented. By using the algorithm proposed in this paper, the self-walking follower terminal can accurately and stably follow the user's movement.

References

[1] SAHINOGLU Z, GEZICI S, GUVENC I. Ultra -wideband PositioningSystems:Theoretical Limits, Ranging Algorithms, and Protocols [M].UK:Cambridge University Press, 2008

[2] Wymeersch H,Maranos,Gifford W M, et al. A machine learning approach to ranging error mitigation for UWB localization [J]. IEEE Transactions on Communications, 2012.

[3] Stephan A,Gueguen E,Crussiere M,et al.Optimization of linear preceded OFDM for high-data-rate UWB systems [J].EURASIP Journal on Wireless Communications and Networking, 2008.

[4] CHAI Jihong. Patient Positioning System in Hospital Based on Zigbee [C]// Proceedings of the 2011 International Conference on Intelligent Computation and Bio-Medical Instrumentation (ICBMI): December 14-17, 2011. Wuhan, Hubei, China. IEEE Computer Society, 2011: 159-162.

[5] LIN C J, LEE T L, SYU S L, et al. Application of Intelligent Agent and RFID Technology for Indoor Position: Safety of Kindergarten as Example [C]// Proceedings of the 2010 International Conference on Machine Learning and Cybernetics (ICMLC): July 11-14, 2010. Qingdao, China. IEEE, 2010: 2571-2576.

[6] SAHINOGLU Z, GEZICI S, GUVENC I. Ultra -wideband Positioning Systems:Theoretical Limits, Ranging Algorithms, and Protocols [M].UK:Cambridge University Press, 2008.

[7] DARDARI D, LUISE M, FALLETTI E. Satellite and Terrestrial Radio Positioning Techniques:A Signal Processing Perspective [M]. Oxford:Elsevier, 2012.

[8] Random-pointbased filters:analysis and comparison in target tracking. Dunik J,Straka O,Simandl M,Blasch E. IEEE Transactions on Aerospace and Electronic Systems . 2015