ISSN: 2688-9323

Research on Pseudo Satellite Positioning System based on Closed Environment

Quan Jiang, Tianhu Wang*, Yang Zhong and Yunhao Qu

School of Electrical and Information Engineering, Jiangsu University of Technology, Changzhou, Jiangsu 213001, China

*Corresponding Author

Abstract

Global navigation satellite system (GNSS) is an important technology to enhance the availability and geometric characteristics of GPS navigation and positioning, pseudo satellite technology is currently attracting the focus of all countries around the world. The pseudo satellite positioning system was designed in this paper, using pseudo satellite to broadcast the location of the host station GPS signal, host station after receiving the GPS signal, resolve out the longitude and latitude, upload the upper computer, upper computer combined with UWB positioning technology to the receiver location and longitude and latitude information, calculate the receiver latitude and longitude data, finally the upper computer will display the location information.

Keywords

GMSS; Positioning; UWB.

1. Introduction

Global navigation satellite system (GNSS) is a system that uses satellite positioning technology to provide global navigation, positioning, timing and other services to ground users, vehicles and ships. The main components of the global satellite navigation system include a set of in-orbit satellites, ground control systems, and user receiving equipment. Major global navigation satellite systems currently include the US GPS system, Russia's GLONASS system, China's Beidou system and Europe's Galileo system. These systems can provide high precision and high reliability of navigation, positioning, timing and other services, and have important application value for military, civil and other fields. However, in indoor confined Spaces, GNSS satellite signals are blocked, and it is difficult to provide accurate positioning services. However, the accuracy of GNSS mainly depends on the number of visible satellites and their geometric distribution, which cannot provide high-precision positioning services in a closed environment. Therefore, the virtual GPS positioning technology in a closed environment is currently being widely studied.

A pseudo satellite is a global positioning system based on ground base stations, similar to a satellite navigation system, but its signal comes not from a satellite but from a transmitter installed on the ground. Pseudo satellite enable the receiver to perform precise positioning by transmitting signals similar to satellite signals. Pseudo satellites can be installed in buildings, Bridges, tunnels and other places, these places often can not receive satellite signals due to buildings, mountains and other reasons, the use of pseudo satellites can make up for the lack of satellite navigation system. Compared with satellite navigation systems, pseudo satellite have smaller coverage, but they have higher positioning accuracy and lower cost to use, so they have an important role in some special application scenarios. As an important technology to enhance the availability and geometric characteristics of GPS navigation and positioning, pseudo satellite technology is currently attracting the focus of all countries around the world.

ISSN: 2688-9323

According to the survey, there is no relevant application case and corresponding solution report and reference in the underground space positioning of domestic rail transit.

If the conventional positioning technology in special scenarios of underground enclosed space, such as urban rail transit, is difficult to meet the requirements, The system takes the pseudo satellite as the main body, Using pseudo satellites to simulate the motion state of GPS satellites to ensure that the working parameters of virtual satellites and GPS satellites are consistent, According to the actual needs of calculus, group satellite navigation message broadcast transfer mobile phones, vehicle navigation and other general navigation terminals can be analyzed and used for real-time positioning of navigation satellite signals; The system uses the self-developed high-precision positioning base station and receiver to receive the GPS signals broadcast by virtual satellites, Realize the GPS signal coverage and high-precision positioning in a closed environment, According to the relevant data uploaded by the base station, Functions such as positioning data display, positioning map fitting, real-time trajectory display and receiver longitude solution calculation are realized.

2. Principle Analysis and Hardware Circuit Diagram

2.1. The Working Principle of the Pseudo Satellites

Each satellite has an atomic clock (a clock) that always broadcasts its position, time, and a pseudo-random noise code (PRN code). All GPS satellites will broadcast civilian signals at the same RF operating frequency, and these PRN codes can be used to identify the signal transmitting source. The GPS network consists of 24 satellites, which broadcast both civilian and military PRN codes, among which the civilian PRN code is not encrypted and its calculation method is disclosed. The military PRN code is encrypted, and only when the GPS receiver has the corresponding decryption key can it receive the decoding data.

The pseudo satellite determines the orbital satellite near the target in a given time area, and then obtains the PRN code information of different satellites by using the PRN code calculation method. Near the GPS signal receiver, it broadcasts the PRN code value information the same as the satellite signal, so that the GPS receiver receives the GPS signal sent by the approval.

The principle of GPS signal broadcasting is as follows: first, GPS signal data generation on the PC, And communicate with the NXP LP43xx microcontroller via the USB interface, The microcontroller is connected to the CPLD through the parallel bus and the JTAG interface simulated by GPIO, Then we perform a digital-to-analog transformation of the sent data using MAX5864, Model-to-digital transformation of the received data, MAX2837 Complete the up / down frequency conversion, And through the broadband mixer RFFC5072 to improve the GPS frequency range, The RF front end is amplified using a primary LNA / PA, And eventually to be connected to the antenna via the TR Switch, Transmitting the GPS signals.

2.2. The Principle of Ranging

Time of Flight Ranging (TWR) ranging algorithm is a common wireless ranging method. It calculates the distance between devices by measuring the time from the signal sent to the signal received. TWR ranging algorithm has high accuracy, strong reliability and is suitable for indoor and outdoor environments.

From the picture:

$$\mathrm{T}_1 = 2 \times TOF + T_2 \tag{1}$$

$$\mathrm{T}_5 = 2 \times TOF + T_4 \tag{2}$$

$$T_1 + T_4 = T_2 + T_5 \tag{3}$$

Multiply the left and right sides of Eq.(1) and Eq.(2) to get:

ISSN: 2688-9323

$$T_1 \times T_5 - T_2 \times T_4 = 2 \times TOF(\mathrm{T}_5 + T_2) \tag{4}$$

Connecting Eq. (3) and Eq. (4) to get signal flight time:

$$TOF = \frac{T_1 \times T_5 - \mathrm{T}_2 \times T_4}{T_1 + T_2 + \mathrm{T}_3 + T_4} \tag{5}$$

The distance between nodes A and B is multiplied by TOF and electromagnetic wave transmission rate.

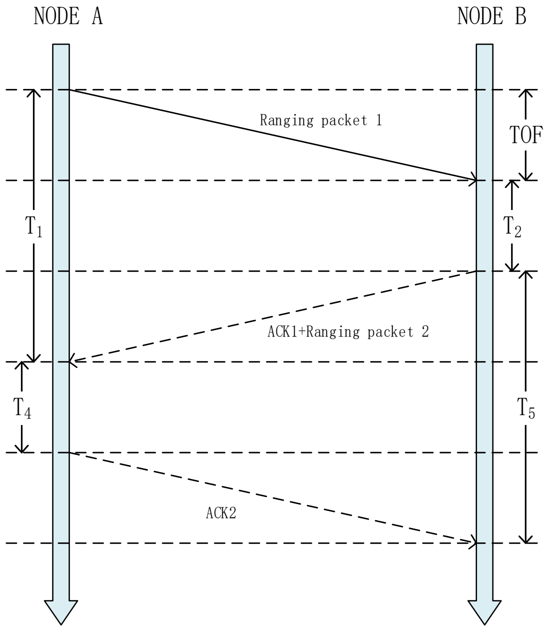

Figure 1. The system uses TWR ranging algorithm, ranging through the tag and the base station

2.3. Conversion between Geodetic Coordinates and Spatial Rectangular Coordinates

Since the location information of the positioning base station is based on the spatial rectangular coordinate system and the satellite signal based on the pseudo satellite technology, the GPS receiving module of the system and the solution of the real location coordinates of each base station arranged in the system, it is based on the conversion of the spatial rectangular coordinate system of the base station and the geodetic coordinate system of the pseudo satellite signal should be completed. For geodetic coordinates (B, L, H), B represents the latitude, L the longitude, and H the altitude. For spatial rectangular coordinates (X, Y, Z), because the receiver and the positioning base station are highly unified during positioning, each base station and the receiver are regarded as the unified plane, and as a two-dimensional positioning when positioning.

The geodetic coordinate system selected is WGS-84 coordinate system. The WGS-84 coordinate system, fully known as the World Geodetic System, is a geodetic system standard for cartography, geodesy, and navigation (including global positioning systems). WGS 84 contains a set of Earth's standard latitude and longitude coordinates, a reference ellipsoid for calculating the original elevation data, and a set of gravitational equipotential surface data to define sea level height. WGS 84 coordinate is a geocentric coordinate system, where the coordinate origin is the earth center of mass. It uses a reference ellipsoid very similar to the natural shape of the earth as a datum to describe and calculate the position and relationship of the ground points. A geodetic system must clearly define the orientation of its three axes and the position of its center. Generally, the short axis of the starting axis of the rotating spheroid is used to determine the average rotation axis of the earth. If the reference ellipsoid center coincides with the average earth centroid, the geodetic coordinate system is defined and established. It is the basis for various positioning, measurement and orbit measurement in space and long-range weapons and space science.

1. Convert geodetic coordinates(B, L, H) to spatial rectangular coordinates(X, Y, Z), If the geodetic coordinates of an ellipsoid are known, then:

$$\begin{cases} X = (\mathrm{N}+\mathrm{H})\times\cos B\times\cos L \\ Y = (\mathrm{N}+\mathrm{H})\times\cos B\times\sin L \\ Z = [\mathrm{N}\times(1-e^2)+\mathrm{H}](\mathrm{N}+\mathrm{H})\times\mathrm{sinB} \end{cases} \tag{6}$$

In the above Eq. 6, let a and b be the length and length radii of the ellipsoid, and f be the offset rate of the ellipsoid, $e=\frac{\sqrt{a^2-b^2}}{a}$ or $e=\frac{\sqrt{2\times f-1}}{f}$ be the first eccentricity of the ellipsoid, $W=\sqrt{1-e^2\times\sin^2 B}$ be the first basic latitude function, $\frac{a}{W}$ be the Meridian Radius of Curvature.

2. Convert spatial Cartesian coordinates(X, Y, Z) to geodetic coordinates(B, L, H), If the spatial Cartesian coordinates are known, then:

$$\begin{cases} L = \arctan\frac{Y}{X} \\ B = \arctan\left[\frac{Z}{\sqrt{X^2+Y^2}}(1-\frac{e^2N}{N+H})^{-1}\right] \\ H = \frac{\sqrt{X^2+Y^2}}{\cos B}-N \end{cases} \tag{7}$$

Iterate over the initial value:

$$N_0 = a \tag{8}$$

$$H_0 = \sqrt{X^2+Y^2+Z^2}-\sqrt{a\times b} \tag{9}$$

$$B_0 = \arctan[\frac{Z}{\sqrt{X^2+Y^2}}(1-\frac{e^2N}{N+H})^{-1}] \tag{10}$$

Each iteration is carried out according to the formula below:

$$N_1 = \frac{a}{\sqrt{1-e^2\sin^2 B_{i-1}}} \tag{11}$$

$$H_i = \frac{\sqrt{X^2+Y^2}}{\cos B_{i-1}}-N_i \tag{12}$$

$$B_i = \arctan[\frac{Z}{\sqrt{X^2+Y^2}}(1-\frac{e^2N_i}{N_i+H_i})^{-1}] \tag{13}$$

The iteration is carried out according to the Eq. (11-12) until the difference between two adjacent B and H calculated is lower than the required limit, and the iteration is stopped. However, when the calculation accuracy of H is required to be 0.001m, and the calculation accuracy of B is required to be 0.00001m, it generally only needs about 4-5 iterations.

ISSN: 2688-9323

3. Hardware Design

The structural characteristics and hardware structure of the main base station, the secondary base station and the tag of this system are similar and the design is relatively simple. The main base station, the secondary base station and the tag all send and receive data packets according to a certain period.

The MCU of the controller module is the STM32F103C8T6 chip, which is connected with the DW1000 chip through the SPI bus protocol to send relevant operation commands to the DW1000 chip. Due to the mismatch of interface and level, USB interface and TTL serial port can not communicate directly. CP2102 chip is selected for hardware interface module to realize the conversion of interface and level between STM32F103C8T6 and PC. Through the MICRO_USB interface and USB data cable, the STM32F103C8T6 chip can upload the collected data to the PC. The MCU of the data upload module is the STM32F103ZET6 chip, which mainly uses the serial communication protocol to upload the processed data from the PC to the cloud. The PC side provides a 5V power supply to the hardware through a USB data cable.

DW1000 is a fully 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 IEEE802.15.4-2011 ultra wideband standard. The highest data rate of the chip can reach 6.8Mbps, and it can be processed in multipath environment. The chip has the advantages of low power consumption, bidirectional ranging and positioning, and is suitable for indoor positioning.

The NB-loT M5310-A module of China Mobile is selected for the computer-cloud interaction part of the data upload module. M5310-A is an industrial grade NB-loT module working in Band3/Band5/Band8 band. Its package size and hardware and software interface are sealed with LCC. Its size is only 19mm×18.4mm×2.2mm, which can maximally meet the demand of terminal equipment for small-size module products. On the basis of supporting M2M chip and host computer platform protocol, M5310-A supports the latest Release14 standard, supports higher communication rate, and supports base station positioning. With its compact size, ultra-low power consumption, and ultra-wide temperature range, the M5310-A provides perfect data transfer services.

GPS signal receiving master control board uses ATK-S1216F8-BD GPS/ Beidou module. The module is a high-performance GPS/ Beidou module produced by ALIENTEK. The core of the module is the S1216F8-BD module of SkyTraq Company. It has 167 channels, tracking sensitivity up to -165dBm, and measurement output frequency up to 20Hz. By default, the module uses NMEA-0183 protocol to output GPS/ Beidou positioning data, and can be configured through SkyTraq protocol.

4. Experimental Results and Analysis

The system takes the pseudo satellite as the main body, and uses the pseudo satellite to simulate the motion state of the GPS satellite to ensure that the working parameters of the virtual satellite and the GPS satellite are consistent. According to the actual needs, the navigation satellite messages are calculated and grouped to broadcast, so that the navigation satellite signals can be analyzed and used for real-time positioning by the mobile phone, vehicle navigation and other general navigation terminals. The system uses self-developed high-precision positioning base station and receiver to receive GPS signals broadcast by virtual satellite, and realizes GPS signal coverage and high-precision positioning in closed environment. According to the relevant data uploaded by the base station, the background management center of the system realizes functions such as positioning data display, positioning map fitting, real-time trajectory display, and receiver longitude and latitude calculation.

ISSN: 2688-9323

The positioning core of the system is that the system obtains the ranging value of each base station and the receiver and then uses the trilateral positioning algorithm to solve the positioning, so the positioning accuracy of the system is closely related to the ranging accuracy between the base station and the receiver.

Table 1. Experimental data

Numble	Positioning frequency		500cm	1000cm	3000cm	5000cm
1	15:21:38 013	15:21:38 363	502	1013	2983	5037
2	15:21:38 027	15:21:38 377	508	1010	2980	5040
3	15:21:38 041	15:21:38 391	501	1010	2981	5038
4	15:21:38 055	15:21:38 405	501	1009	2983	5037
5	15:21:38 069	15:21:38 419	504	1010	2982	5036
6	15:21:38 083	15:21:38 433	504	1010	2984	5038
7	15:21:38 097	15:21:38 447	502	1012	2983	5039
8	15:21:38 111	15:21:38 516	503	1010	2981	5041
9	15:21:38 125	15:21:38 530	501	1010	2980	5040
10	15:21:38 139	15:21:38 544	505	1009	2985	5040
11	15:21:38 153	15:21:38 558	500	1011	2972	5041
12	15:21:38 167	15:21:38 572	506	1011	2972	5041
13	15:21:38 182	15:21:38 586	505	1011	2969	5040
14	15:21:38 195	15:21:38 600	504	1011	2969	5037
15	15:21:38 209	15:21:38 614	501	1010	2968	5039
16	15:21:38 223	15:21:38 628	502	1010	2982	5041
17	15:21:38 237	15:21:38 642	502	1009	2986	5040
18	15:21:38 251	15:21:38 656	503	1009	2985	5042
19	15:21:38 265	15:21:38 670	505	1006	2982	5031
20	15:21:38 279	15:21:38 684	506	1011	2987	5030
21	15:21:38 293	15:21:38 698	502	1011	2984	5036
22	15:21:38 307	15:21:38 712	504	1011	2982	5031
23	15:21:38 321	15:21:38 726	503	1007	2980	5037
24	15:21:38 335	15:21:38 740	505	1013	2988	5031
25	15:21:38 349	5:21:38 754	503	1011	2984	5037
	Average error		3.28cm	10.2cm	19.52cm	37.6cm

In a shielded room, any signal from the outside world cannot be transmitted, and the GPS terminal (here used is a smart phone) cannot receive the GPS signal, so it cannot realize positioning. Turn on the pseudo satellite and broadcast the set GPS signal (in this experiment, the positioning position is set in Lhasa). Through the above tests, the hardware and software test results of the system all meet the requirements.

5. Conclusion

In view of the fact that the staff can not receive GPS signals in the closed environment such as tunnels or underground tunnels, this paper proposes a pseudo satellite positioning system based on closed environment to realize the positioning in the closed environment such as tunnels. The principle is as follows: the GPS signal of the host station is broadcast by the pseudo satellite, and the host station uploads the GPS signal to the host computer after receiving the GPS signal. The host computer combines the real-time position and latitude and longitude

ISSN: 2688-9323

information of the receiver obtained by the UWB positioning technology, and calculates the real-time longitude and latitude position of the receiver, and finally the host computer displays it. According to the above content, this design mainly completes the work of the following aspects:

1. Pseudo design based on analog GNSS satellite signals. The system chooses HackRF ONE as the carrier of GPS signal transmission, and writes relevant programs, so that it can send GPS signals at any place according to actual needs, so as to realize the coverage of GPS signals in closed space and the positioning of GPS positioning terminal.

2. Indoor positioning hardware design based on UWB technology. The combination of D-DWM-PG positioning module, M5310-A Internet of things module and ATK-S1216F8-BD GPS/ BEIDOU module realizes the function of extracting longitude and latitude information from GPS signal reception, collecting receiver ranging data and uploading data. At the same time, the robust Kalman filter algorithm with higher accuracy is transplanted into the D-DWM-PG positioning module. The experimental results show that the accuracy of fixed-point positioning is significantly improved after optimization.

3. Research on pseudo satellite positioning system based on closed environment. The system is mainly based on Modbus protocol and SPI protocol, receives the ranging data and latitude and longitude data uploaded by each module, calculates the real-time position of the receiver through the trilateral positioning algorithm, and then obtains the real-time latitude and longitude information of the receiver by using the geodetic coordinates to spatial rectangular coordinates conversion formula, and finally uploads it to the host computer for display.

Acknowledgments

Jiangsu University Student Innovation Training Program (No. 202211463060Y).

References

[1] Hu Rong-ming, LI Zhi, ZHOU Zi-xiang, et al. Simulation research on positioning accuracy of pseudolites based on Kalman Filtering[J]. Standardization of Surveying and Mapping, 2019,35 (04): 5-8.

[2] Wang J. Pseudolite Applications in Positioning and Navigation Progress and Problems[J]. Journal of Global Positioning Systems, 2002(1): 48-56.

[3] Dai L, Wang J, Rizos C. Pseudo satellite Applications in Deformation Monitoring[J]. GPS Solutions, 2002 (5): 80–87.

[4] H.Stwart Cobb. GPS Pseudolites: Theory, Design and Applications[D]. USA: Standford University. 1997.

[5] Chen Ming-jin, ZHANG Jian-wei, WANG Meng-hua, et al. Application analysis of Ultra-wideband technology (UWB)[J]. Resources Guide,2017(24): 34-36.

[6] Wang Xun, ZuO Qi-yao, HONG Shi-ping, Cet al. A New Method for Performance Evaluation of Positioning Solution Based on Kalman Filter[J]. Navigation Positioning and Time Service, 2018, 5 (05): 73-82.

[7] Lu Yan-yi, XU Tianhe, LI Yu-jie, et al. A Robust Kalman Filter Indoor Positioning Method Considering TOA Data Optimization[J]. Geo-information World, 2020, 27(04): 95-101.

[8] Liu Tao, Xu Ai-gong, Sui Xin. UWB indoor positioning based on Adaptive robust Kalman Filter[J]. Journal of Sensor Technology, 2018, 31(04): 567-572.