Abstract—Satellite navigation signals are blocked by the buildings and can’t provide the positioning service for the indoor users. In 2016, Chinese government supports the research and development of the BeiDou/GPS pseudolites for indoor and outdoor seamless positioning in the national key research and development program, in order to reduce application costs, the combination technology of pseudolites and PDR is used for indoor positioning. Firstly, the seamless positioning system architecture, the signal format and navigation message, indoor positioning principle of Beidou/GPS pseudolites are introduced in this paper, the positioning results of array pseudolites begin to converge and the horizontal positioning error is about 1 meter. After the positioning results become very stable, the positioning error of 0.5 meters. Secondly, the pseudolites and PDR combination localization algorithm is studied, the average positioning error of PDR is 5.5 m and 10 m, while the average positioning error of PL_PDR is 2 meters and 2.3 meters. It can be seen that the combined technology of pseudolites and PDR can achieve high-precision indoor positioning under a long time and long-distance conditions.

Keywords—indoor positioning; Pseudolites; PDR; Combination positioning

I. INTRODUCTION

Satellite navigation signals are blocked by the buildings and can’t provide the positioning service for the indoor users. Therefore, the pseudolites technology has become the research hotspot of researchers. The European Communications Regulatory Commission (ECC) has issued the Galileo pseudolites management framework, and allows pseudolites to use the navigation signal band of E1. Japan has been in the country to promote a kind of indoor positioning system, which is called IMES and support for GPS signal. Locata pseudolites in Australia are also trying to be used indoors. In 2016, Chinese government supports the research and development of the BeiDou/GPS pseudolites for indoor and outdoor seamless positioning in the national key research and development program, and in order to reduce application costs, the combination technology of pseudolites and PDR is used for indoor positioning.

Firstly, the seamless positioning system architecture, the signal format and navigation message, indoor positioning principle of Beidou/GPS pseudolites are introduced in this paper, at the same time, the indoor positioning test results are given. Secondly, the method of PDR is introduced. Finally, the method of combining pseudolites and PDR is introduced, and the validity of the method is proved by the experimental data.

II. THE INDOOR POSITIONING SYSTEM ARCHITECTURE OF PSEUDOLITES

Fig.1. is the Indoor Positioning System Architecture of pseudolites, including outdoor forwarding pseudolites, outdoor straight pseudolites and indoor array pseudolites. System indicators of pseudolites: outdoor positioning accuracy is better than 0.2 meters, indoor positioning accuracy is better than 1 meter. Outdoor pseudolites can be combination positioning with space navigation satellites, indoor pseudolites can be combination positioning with PDR on smart phone.

A. Signal Format and Navigation Message

In order to make the GNSS receiver or chips, can receive signal of pseudolites signal parameters as shown in table 1. Pseudolite modulation method adopts "TDMA+BPSK" method, so as to solve the problem of near-far effect.

| TABLE I. SIGNAL PARAMETERS BETWEEN PSEUDOLITES AND BEIDOU/GPS |
|------------------|-----------|-----------|-----------|-----------|
| FrequencyMHz | 1575.42 | 1561.098 | 1575.42 | 1561.098 |
| Spread spectrum code | 1-32 | 1-32 | 173-184 | 173-184 |
| Code rate | 1.023MHz | 1.023MHz | 1.023MHz | 1.023MHz |
| Code length | 1ms | 1ms | 1ms | 1ms |
| Data rate | 50bps | 50bps | 50bps | 50bps |
| Modulation method | BPSK | BPSK | pulse | pulse |
| Polarization mode | RHCP | RHCP | RHCP | RHCP |

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B. Indoor Positioning Principle of Array Pseudolites

Fig.2 is indoor high precision positioning of array pseudolites, it consists of a 4-channel transmitter and an array antenna. The distance between the antennas is less than half the wavelength of the GPS L1 (95.15 mm). Because the navigation signal transmission path is same, this approach does not need to consider time synchronization and ambiguity resolution problems, and can suppress multipath effects.

![Array Pseudolite](image)

**Fig. 2. Indoor High Precision Positioning of Array Pseudolite**

The receiver tracks the signals of array pseudolites and outputs the carrier phase observations:

\[
\begin{align*}
\phi_{11}^1 &= \lambda_{11} r_{11}^1 + \lambda_{11} c (\delta t - \delta T) + N_{11}^1 + \varepsilon_{11}^1, \\
\phi_{11}^2 &= \lambda_{11} r_{11}^2 + \lambda_{11} c (\delta t - \delta T) + N_{11}^2 + \varepsilon_{11}^2, \\
\phi_{11}^3 &= \lambda_{11} r_{11}^3 + \lambda_{11} c (\delta t - \delta T) + N_{11}^3 + \varepsilon_{11}^3, \\
\phi_{11}^4 &= \lambda_{11} r_{11}^4 + \lambda_{11} c (\delta t - \delta T) + N_{11}^4 + \varepsilon_{11}^4.
\end{align*}
\]

Where, \( \lambda_{11} \) is the wavelength of B1, \( \phi_{11}^1, \phi_{11}^2, \phi_{11}^3 \) and \( \phi_{11}^4 \) are carrier phase observations, \( N_{11}^1, N_{11}^2, N_{11}^3 \) and \( N_{11}^4 \) are number of ambiguity, \( c \) is speed of light.

The navigation signals are transmitted from the same pseudolites, all channels are synchronized, then

\[
\begin{align*}
\phi_{11}^{12} &= \lambda_{12} r_{12}^{12} + N_{11}^{12} + \varepsilon_{11}^{12}, \\
\phi_{11}^{13} &= \lambda_{13} r_{13}^{13} + N_{11}^{13} + \varepsilon_{11}^{13}, \\
\phi_{11}^{14} &= \lambda_{14} r_{14}^{14} + N_{11}^{14} + \varepsilon_{11}^{14}.
\end{align*}
\]

Where, \( \phi_{11}^{12}, \phi_{11}^{13}, \phi_{11}^{14} \) are carrier-phase difference, \( r_{12}^{12}, r_{13}^{13}, r_{14}^{14} \) are distance deviation from receiver to the channels of pseudolites, \( N_{11}^{12}, N_{11}^{13}, N_{11}^{14} \) are the difference between the number of carrier waves.

Because the center of the phase between the transmitting antennas is less than half the wavelength, \( N_{11}^1, N_{11}^2, N_{11}^3 \) and \( N_{11}^4 \) are same, \( N_{11}^{12}, N_{11}^{13}, N_{11}^{14} \) are zero.

\[
\begin{align*}
\phi_{i1}^1 &= \lambda_{i1} r_{i1}^1 + \lambda_{i1} c (\delta t - \delta T) + N_{i1}^1 + \varepsilon_{i1}^1, \\
\phi_{i1}^2 &= \lambda_{i1} r_{i1}^2 + \lambda_{i1} c (\delta t - \delta T) + N_{i1}^2 + \varepsilon_{i1}^2, \\
\phi_{i1}^3 &= \lambda_{i1} r_{i1}^3 + \lambda_{i1} c (\delta t - \delta T) + N_{i1}^3 + \varepsilon_{i1}^3, \\
\phi_{i1}^4 &= \lambda_{i1} r_{i1}^4 + \lambda_{i1} c (\delta t - \delta T) + N_{i1}^4 + \varepsilon_{i1}^4.
\end{align*}
\]

Where, \( r_{i1}^{11} = \| r_i^1 - r_c \| = \| r_i^j - r_c \|.

The position of receiver can be solved by the Taylor series expansion algorithm and the CHAN algorithm.

C. Indoor Positioning Accuracy Test of Pseudolites

Fig.3 is the indoor positioning test environment of pseudolites. Pseudolites are mounted on a roof with a height of 2.1 meters, emitting array antenna direction downwards. The user receiver has a height of 1.2 meters.

![Indoor positioning test environment of pseudolites](image)

**Fig. 3. Indoor positioning test environment of pseudolites**

Fig.4 is the positioning error of test point 2. After 700 seconds, the positioning results begin to converge and the horizontal positioning error is about 1 meter. After the positioning results become very stable, the positioning error of 0.5 meters.

![Positioning error of test point 2](image)

**Fig. 4. The positioning error of test point 2**

III. PEDESTRIAN DEAD RECKONING (PDR)

A. Indoor Positioning Principle of PDR

Pedestrian Dead Reckoning (referred to as PDR) is the pedestrian’s indoor activities as a plane on the two-dimensional movement, if the pedestrian’s initial position and the initial azimuth are obtained, By measuring the walking step and the direction angle, the pedestrian’s next position is estimated.

Fig.5 is Pedestrian Dead Reckoning algorithm. E and N represent east and north respectively. The initial position...
$P_0(N_0, E_0)$ of pedestrians at time $t_0$. The position of the next moment $t_1$ is $P_1(N_1, E_1)$, the heading angle from $t_0$ to $t_1$ is $\theta_1$, then,

$$\begin{align*}
N_1 &= N_0 + d_o \cos \theta_1 \\
E_1 &= E_0 + d_o \sin \theta_1
\end{align*}$$

The position $P_2(N_2, E_2)$ of Pedestrians at $t_2$ moments is:

$$\begin{align*}
N_2 &= N_1 + d_i \cos \theta_i = N_0 + d_o \cos \theta_0 + d_i \cos \theta_i \\
E_2 &= E_1 + d_i \sin \theta_i = E_0 + d_o \sin \theta_0 + d_i \sin \theta_i
\end{align*}$$

The position $P_k(N_k, E_k)$ of Pedestrians at $t_k$ moments is:

$$\begin{align*}
N_k &= N_0 + \sum_{i=0}^{k-1} d_i \cos \theta_i \\
E_k &= E_0 + \sum_{i=0}^{k-1} d_i \sin \theta_i
\end{align*}$$

Where, $d_i$ is the displacement vector from $t_{i-1}$ to $t_i$, $\theta_i$ is direction angle of displacement vector.

![Pedestrian Dead Reckoning algorithm](image)

**B. PDR based on smart phone**

Fig.6 is the realization of PDR on smart phone, the measurement data of accelerometer, gyroscope and geomorphic sensor on the smartphone is output, and the horizontal position of pedestrians is calculated by step size estimation and heading estimation algorithm. The steps of PDR in the smartphone positioning are as follows:

1) pedestrian step detection by collecting and processing the smart phone in the acceleration of the three-axis sensor to the data.

2) the step size of each pedestrian walk by the change of the data value of each step acceleration sensor and the relationship between user height and step size.

3) combined with the smart phone acceleration sensor data and magnetic sensor data calculation, can be pedestrians walking in the world coordinate system under the heading angle.

4) in the coordinate system to get the pedestrian user's walking direction angle, real-time calculation of the user walking the length of the steps to detect the user to walk the final number of steps and calculate the user's location.

**IV. COMBINED POSITIONING ALGORITHM OF PSEUDOLITES AND PDR**

Fig.9. is the combined positioning algorithm of pseudolites and PDR (Referred to PL_PDR). The capability of pseudolites indoor high-precision positioning and PDR continuous positioning are combined. The positioning results of pseudolites can correct the positioning bias of PDR. At the same time, the continuous position obtained by the PDR can assist pseudolites to quickly capture the tracking signal. The positioning algorithm steps of pseudolites and PDR are as follows:

1) Smart phone through the pseudolites to obtain accurate indoor position, as the initial value to the PDR module.

2) PDR using the accelerometer, MEMS gyroscope, geomagnetic sensor on the smartphone for pedestrian track projections, to obtain a continuous position coordinates.

3) The position of the next pseudolites is estimated based on the PDR position, In order to assist the satellite navigation chip to quickly capture pseudolites signals.

4) Comparing the positioning results of PDR and PL_PDR, if the tolerance, then use the position from pseudolites to correct the location of the PDR.

It can achieve continuous, stable and high precision indoor positioning by iterations to from step 1 to step 4.

![Combined positioning algorithm of pseudolites and PDR](image)

**V. EXPERIMENT VALIDATION**

**A. Experiment Methodology**

The indoor positioning precision testbed for pseudolite and PDR was build, such as Fig.7. Pseudolites are deployed in the door, the corner of the room, the elevator entrance area, which are used to correct PDR. The indoor positioning software was developed to the combined positioning accuracy test. Test scenes of indoor square trajectory and indoor linear trajectory was chosen.

![Testbed of Pseudolites and PDR Combination Positioning](image)
B. Test of Indoor Square Trajectory

Fig. 8. is shown the indoor positioning accuracy of the PDR_only and PL_PDR under the square trajectory conditions, the black trajectory in the figure is the real walking path, the blue trajectory is the indoor positioning result for PDR_only, and the red trajectory is the indoor positioning result for PL_PDR. In two tests, the average positioning error of PDR_only is 5.5 m and 10 m, while the average positioning error of PL_PDR is 2 meters and 2.3 meters. we can see that the combined technology of PL_PDR can achieve high-precision indoor positioning under a long time and long-distance conditions.

![Fig. 8. Indoor positioning results of the square trajectory with PDR_only and PL_PDR](image)

C. Test of Indoor Linear Trajectory

Fig. 9. is shown the Comparison of indoor positioning accuracy with PDR_only and PL_PDR (70 m distance with two inflection points). Fig. 12 is selected in the course of nine test points for the assessment of the two methods Stability, PDR_only algorithm increases the error with time and distance, and the combined positioning algorithm with pseudolites and PDR can realize high precision, continuous and stable.

![Fig. 9. Comparison of indoor positioning accuracy with PDR_only and PL_PDR](image)

VI. CONCLUSION

In this paper, the principle of pseudo-satellite indoor positioning, PDR and the combination positioning technology of pseudolites and PDR are introduced in detail, Simultaneously, the square and linear two indoor positioning accuracy test scenarios are designed, it can be seen that PDR_only algorithm increases the error with time and distance, and the combined positioning algorithm with pseudolites and PDR can realize high precision, continuous and stable. In the follow-up work, WiFi, Bluetooth sensor signal and pseudo-satellite combination will be the focus of research. Indoor map matching technology will also be used in the pseudolites indoor positioning system.

REFERENCES