Research on Dual-MIMU Trajectory Tracking Based on Support Vector Machine Constraint

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Abstract: Using foot-mounted inertial sensor to track the trajectory is one of the main methods for indoor autonomous pedestrian navigation. However, due to its algorithm, inertial error accumulates over time. To solve this problem, the zero velocity update (ZUPT) takes the velocity error as the observation to amend other information of the carrier. Because zero velocity update can only observe the information of velocity and two horizontal angles, we cannot obtain the position information. In this paper, a dual-MIMU trajectory tracking based on support vector machine(SVM) constraint method is proposed. According to the motion of the human body, in the process of walking, the horizontal angular velocity is the greatest when the toes are off the ground. The theory of s SVM is used to collect the angular velocity of foot movement to classify the movements during the traveling process, Increase the number of observations, after observability analysis to improve positioning accuracy. According to the constraint of the largest step in walking, the inequality equation is constructed and a Kalman filter algorithm is designed. The average position error is 1.3% after 5min's walking. It verifies that this system has higher positioning accuracy.

Keywords: MIMU; inequality constraint; SVM

I. INTRODUCTION

In recent years, the demand for positioning and navigation is rapidly increasing. In particular, complex indoor environments such as warehouses, supermarkets, mining environments, underground parking lots, etc. often require obtaining pedestrian's indoor location information. Pedestrian navigation system (PNS) can provide pedestrian's velocity, position and other information, widely used in military, rescue, electronics and other fields. Global positioning system (GPS) technology is relatively mature, can provide three-dimensional absolute position and velocity information, widely used in outdoor environments, However, due to satellite signals can easily receive the attenuation and interference in the buildings. Information GPS provided is unreliable and difficult to provide accurate information in the environment pedestrians walking. According to statistics, 80%-90% time of people is in the indoor environment. To provide seamless positioning, technologies such as ultra-wideband (UWB), radio frequency identification (RFID) and wireless local area network (WLAN) are used. However, all these require install the infrastructures in advance. There is no guarantee that all environments are equipped. Using wearable sensors, an autonomous navigation system is a solution. Miniature inertial measurement unit (MIMU) uses MEMS technology, MEMS sensors have low power consumption, small size, high autonomy and other characteristics, is an ideal device for autonomous pedestrian navigation.

At present, there are many advanced MEMS-based theories both at home and abroad. In order to improve the indoor positioning accuracy of pedestrians, some people improve the fusion algorithm, aiming at the problem that traditional Kalman filter is only applicable to linear systems, the quaternion based on extended Kalman filter is proposed in [4]. And the use of multi-sensor Algorithms for data-aided correction, such as one proposed by Chen Yuan et al., using frame the IMUs on the shoulders and the feet [5]. The threshold for zero velocity update (ZUPT) is difficult to determine. R Zhang propose the method using chest-mounted accelerometer to eliminate error[6]; [7] mentioned a dual-MIMU/magnetometer combination method, using magnetometer value to provide an additional navigation information for the MIMU, correct the MEMS gyroscope error parameter; literature[8] mention a method that using the relative geographical coordinate system as the navigation coordinate system then use visual aiding inertial positioning, while reducing the amount of computation system; Literature[9] proposes a method for threshold selection, In this paper, we propose a method to set the threshold of multi-conditional constraints through modulo, variance, amplitude, and peak of the data. In [10], for the unobservable heading propose a particle filter algorithm.

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According to the algorithm of indoor pedestrian positioning, the accuracy of the gyroscope determines the accuracy of the positioning. However, gyroscopes based on the MEMS technology have lower accuracy, and the drift level is typically larger than tens of degrees over an hour. In the pedestrian positioning system, if the error is not corrected, In the process of integration, error increases with the third power of time, after the experiment proved that pedestrian with the accuracy of 10°/h's gyroscope walks 5min , the error up to 10000m, The longer the time, the poorer the error, eventually losing navigation ability . Therefore, the most important thing about MEMS-based indoor pedestrian positioning is to carry out an effective error correction solution. MEMS inertial devices are mostly installed on the human foot, using the state of movement to correct, When the carrier is still, the velocity as an observation to correct the navigation system, that is, when the carrier is stationary to ground ,velocity is zero, That is to say, for some time when the foot is in contact with the ground, the velocity calculated by the MIMU should also be zero, input the velocity error into the Kalman filter to correct parameters, It is a currently widely used optimization algorithm. However, although zero velocity update can correct the error of pedestrian positioning, not all the errors can be observed in the calibration process. Because zero velocity update can only observe the velocity and the information of two horizontal angles, the position information cannot be obtained. In view of the limitation of the algorithm itself, the accurate pedestrian positioning results cannot be obtained by the zero velocity update only. To solve this problem, this paper proposes a foot-mounted dual-MIMU tracking method based on Support Vector Machine (SVM) constraint. Using MEMS inertial device for pedestrian tracking, adopts the action-based intelligent decision-making technique of support vector machine, determines the action category according to the signal characteristics. This paper makes a simple introduction and the mathematical derivation of relevant conclusions, and proposes the algorithm to correct the error. According to the law of pedestrian movement, people in the process of travel, the horizontal angular velocity is maximum when the toe off. Firstly, the data acquisition is carried out on the movement of personnel. Secondly, the feature extraction of the data is carried out. Then the feature vector is discriminated by SVM to analyze the footsteps' movement characteristics at that moment. The theory of support vector machine is used to find the maximum horizontal angular velocity, Combined with zero velocity update, increase the number of observations, after observability analysis to improve the accuracy of pedestrian positioning. In the meantime, from the point of increasing the number of sensors, this paper adopts a dual-MIMU pedestrian localization scheme that using information fusion to calibrate each other. That is, setting two MIMUs (including MEMS gyroscope and MEMS accelerometer) on the pedestrian's foot. This paper constructs inequality equations according to the relative position of the system in the physical space. Error secondary correction to reduce the cumulative accuracy of low-precision MEMS positioning system with the inequality constraint filtering algorithm, and ultimately improve the positioning accuracy. The MTI-G710 sensor manufactured by XSENS Company of Netherlands was used to test the effectiveness of the algorithm. This paper verifies the effectiveness of the algorithm.

The structure of this paper is as follows. In the second part, we introduce the structure of MEMS algorithm and the specific technique used. The third part introduces the use of SVM algorithm and inequality constraints to correct errors and improve the accuracy of zero velocity update. In the fourth part, experimental process and result evaluation are demonstrated; the fifth part gives the conclusion.

II. Structure and Analysis of MEMS Pedestrian Indoor Positioning System Algorithm

A. Algorithm structure

MEMS inertial unit for indoor pedestrian can use two ways: the method of pedestrian dead reckoning and continuous integration. Continuous integration of the method is used in this article .through 6 degrees of freedom navigation solution to provide complete navigation information, because MEMS Low accuracy of the device, if cannot be effectively amended during navigation, the position error diverges with the third power of time eventually losing navigation ability. Therefore, the biggest difficulty of this algorithm lies in the effective correction algorithm. In this paper, two inertial measurement units are fixedly attached to the shoe, and the law of movement of the foot during walking is combined with zero velocity update to make a real-time correction of the navigation to improve the navigation accuracy. The algorithm structure is shown in Fig.1:

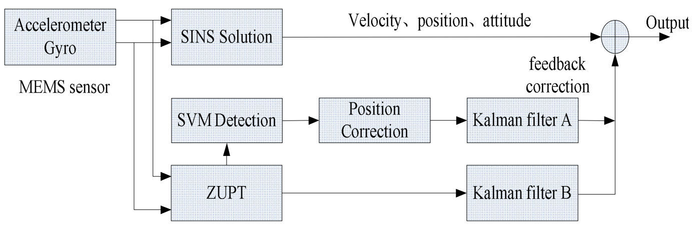

Fig.1 pedestrian indoor positioning system algorithm structure

B. Initial alignment

MEMS pedestrian navigation system using SINS solution algorithm, including the initial alignment and navigation solution two parts. Initial alignment provides initial attitude information for navigation. For the MEMS inertial navigation system, the gyroscope's accuracy cannot be sensitive to the rotation angular velocity of the earth. Therefore, the initial alignment cannot achieve the azimuth alignment. The horizontal alignment can only be achieved according to the accelerometer output, as shown in Equation 1. The estimate of the pitch and roll angles of the shoe is summed, while the azimuth is given by external information, such as a magnetometer.

$$\begin{cases} f_x^b = -|g|\sin\gamma \\ f_y^b = |g|\cos\gamma\sin\theta \end{cases} \Rightarrow \begin{cases} \hat{\gamma} = \arcsin(-\bar{f}_x^b / |g|) \\ \hat{\theta} = \arcsin(\bar{f}_y^b / (|g|\cos\hat{\gamma})) \end{cases} \quad (1)$$

In the formula, the superscript b denotes the coordinate system of the carrier, x, y and z denote the right, front and top three directions of the carrier respectively, g denotes the gravitational acceleration and the f_x^b and f_y^b are the output of the accelerometer , $\bar{f}_x^b$ and $\bar{f}_y^b$ are the output average.

C. Attitude update

MEMS pedestrian positioning's attitude updating process is a real-time calculation process. The quaternion $\mathbf{Q}$ can be used to indicate the rotation of the b system relative to the n system:

$$\mathbf{Q} = q_0 + q_1\mathbf{i}_b + q_2\mathbf{j}_b + q_3\mathbf{k}_b \quad (2)$$

In the formula 2, $\mathbf{i}_b$ 、 $\mathbf{j}_b$ 、 $\mathbf{k}_b$ are the basis of quaternion. q_0 、 q_1 、 q_2 、 q_3 are four real numbers.

The differential equation of $\mathbf{Q}$ can be expressed as:

$$\dot{\mathbf{Q}} = \frac{1}{2}\mathbf{Q}\boldsymbol{\omega} \quad (3)$$

Among them:

$$\boldsymbol{\omega} = 0 + \omega_x\mathbf{i}_b + \omega_y\mathbf{j}_b + \omega_z\mathbf{k}_b \quad (4)$$

Writing formula 3 in matrix form:

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 0 & -\omega_x & -\omega_y & -\omega_z \\ \omega_x & 0 & -\omega_y & -\omega_y \\ \omega_y & -\omega_z & 0 & \omega_x \\ \omega_z & \omega_y & -\omega_x & 0 \end{bmatrix}\begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} \quad (5)$$

Solving the four differential equations, and then get the system of the strapdown matrix is:

$$\mathbf{C}_b^n = \begin{bmatrix} q_0^2+q_1^2-q_2^2-q_3^2 & 2(q_1q_2-q_0q_3) & 2(q_1q_3+q_0q_2) \\ 2(q_1q_2+q_0q_3) & q_0^2-q_1^2+q_2^2-q_3^2 & 2(q_2q_3-q_0q_1) \\ 2(q_1q_3-q_0q_2) & 2(q_2q_3+q_0q_1) & q_0^2-q_1^2-q_2^2+q_3^2 \end{bmatrix} \quad (6)$$

D. Coordinate conversion

The data of motion parameters output by MEMS is actually the data of the carrier coordinate system. However the inertial navigation solves in the east-north-day navigation coordinate system (geographic coordinate system). Therefore, the acceleration, angular velocity data in the carrier coordinate system should be transformed into the geographic coordinate system.

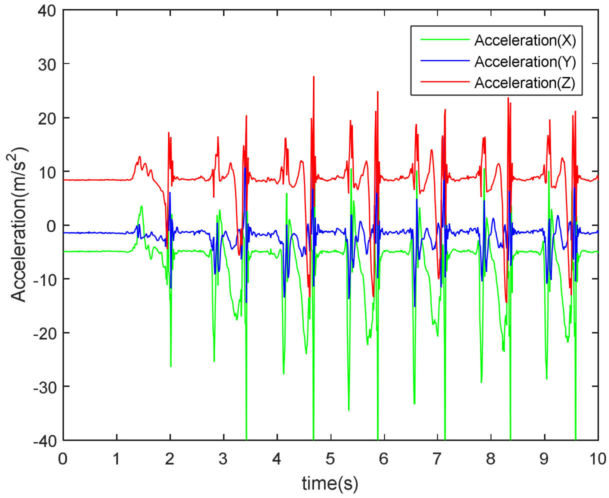

Fig.2 Three-axis acceleration of the carrier system

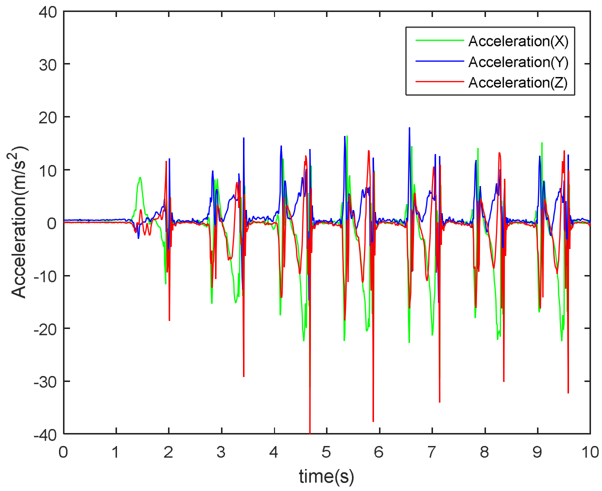

Fig.3 three-axis navigation system under the acceleration

Fig.2 and Fig.3 show the acceleration curves of the three axes under the carrier system and the navigation system respectively. It can be seen that in the carrier coordinate system, due to the human body orientation and the acceleration of gravity in the three axes, the triaxial acceleration is not zero, which makes it difficult for detecting the zero-velocity interval. After the coordinate transformation, the triaxial acceleration at the foot of the pedestrian is linear and zero, and the converted curve is more convenient for correctly counting the number of pedestrians.

E. Zero velocity update algorithm

The zero velocity update algorithm is based on the measured output from the MEMS inertial device. Fig.4 and Fig.5 show the measured values of the acceleration and the angular velocity when walking. It can be seen that the modulus are significant change. Therefore, it is known that the state of motion can be detected by analyzing the acceleration mode value and the angular velocity mode value. The specific method is to design a time window with a fixed length, and the window slides forward along with the change of time, and the modal value of the acceleration and the modal value of the angular velocity in the time window are used as the basis for determining the stillness. The testing process is as follows:

1) At each discrete moment of MEMS inertial output t_1 , t_2 , … t_N , t_{N+1} , … , calculate the amplitude of the accelerometer output at the current moment $|f_N| = \sqrt{f_x^2(t_N) + f_y^2(t_N) + f_z^2(t_N)}$. The angular velocity modal output by the gyroscope:. $|\omega_N| = \sqrt{\omega_x^2(t_N) + \omega_y^2(t_N) + \omega_z^2(t_N)}$

2) Calculate two judgment indicators: acceleration variance Var_f and angular velocity variance Var_w .

3) Design the acceleration threshold value $Gate_f$ and the angular velocity judgment threshold value $Gate_w$. Static detection method is: first assume that the current moment of motion is at rest, that is, the default state of rest; and then compare judgments, and if, $Var_f \le Gate_f$ and $Var_w \le Gate_w$ .then determine the state of motion is movement, otherwise maintain the original hypothesis.

The threshold value is related to the variance characteristic of acceleration and angular velocity, and the interval length parameter is related to the output frequency of MEMS. The test result is shown in Fig.4.

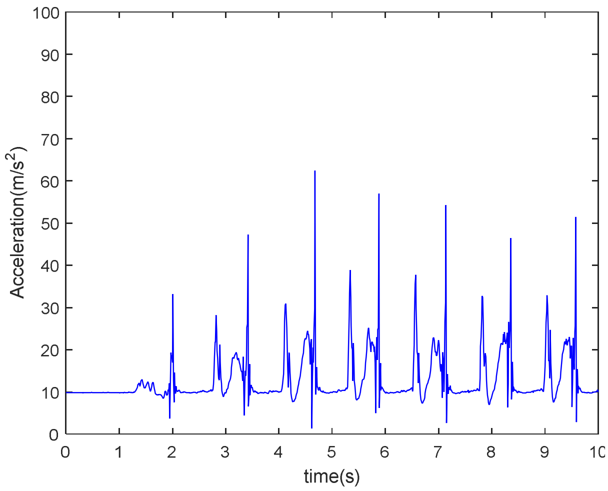

Fig.4 acceleration mode value

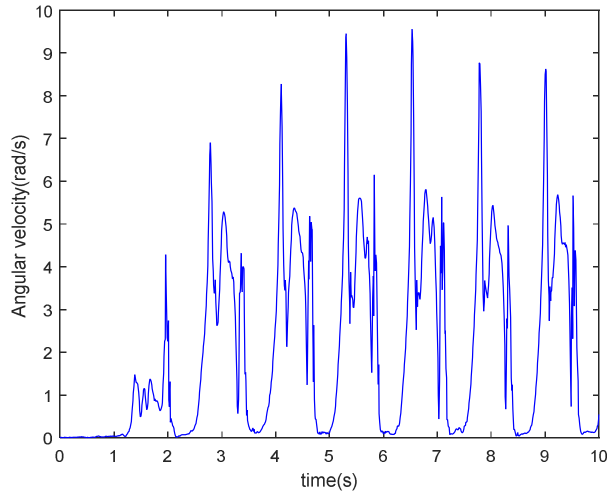

Fig.5 angular velocity mode value

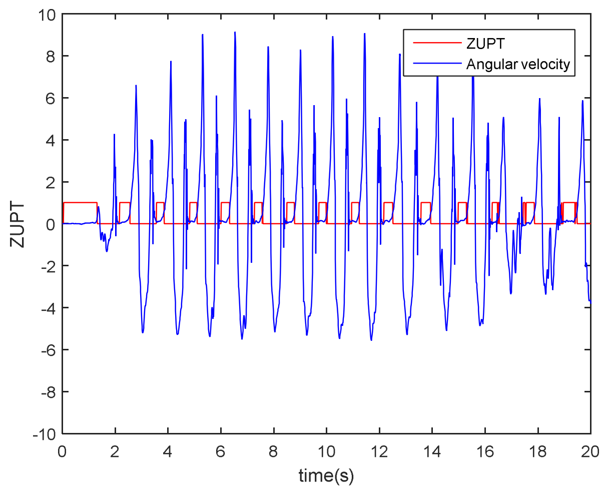

Fig.6 zero velocity interval test results

Still detection triggers a zero velocity update, setting the speed to 0 during a stationary time of detection. In this paper, we use stationary detection to estimate more error parameters. According to the navigation model, we design a zero velocity update Kalman filter. The state variables are as follows $\delta\mathbf{X} = \left[\delta\mathbf{p}^T \ \delta\mathbf{v}^T \ \delta\mathbf{a}^T\right]^T$, including the most basic information of navigation, followed by position, velocity and attitude. Detect the solution speed error $\mathbf{Z} = \delta\mathbf{v} = \mathbf{v}_{INS} - \mathbf{0} = \left[\mathbf{v}_x \ \mathbf{v}_y \ \mathbf{v}_z\right]$, the zero-speed calibration measurement matrix is: $\mathbf{H} = \left[\mathbf{0}_{3\times3} \ \mathbf{I}_{3\times3} \ \mathbf{0}_{3\times3}\right]$. Kalman filter can be expressed as:

$$\mathbf{X}_k = \mathbf{A}\mathbf{X}_{k-1} + \mathbf{B}\mathbf{W}_{k-1} \tag{7}$$

$$\mathbf{Z}_k = \mathbf{H}\mathbf{X}_{k-1} + \mathbf{V}_k \tag{8}$$

Where $\mathbf{X}$ is the state vector, $\mathbf{W}$ is the system excitation noise sequence, $\mathbf{V}$ is the measurement noise matrix, $\mathbf{A}$ is the one-step transfer matrix, and $\mathbf{H}$ is the measurement matrix.

The basic equation is:

$$\hat{\mathbf{X}}_{k/k-1} = \mathbf{\Phi}_{k,k-1}\hat{\mathbf{X}}_{k-1} \tag{9}$$

$$\mathbf{P}_{k/k-1} = \mathbf{\Phi}_{k,k-1}\mathbf{P}_{k-1}\mathbf{\Phi}_{k,k-1}^{T} + \mathbf{\Gamma}_{k-1}\mathbf{Q}_{k-1}\mathbf{\Gamma}_{k-1}^{T} \tag{10}$$

$$\hat{\mathbf{X}}_{k} = \hat{\mathbf{X}}_{k/k-1} + \mathbf{K}_{k}(\mathbf{Z}_{k} - \mathbf{H}_{K}\hat{\mathbf{X}}_{k/k-1}) \tag{11}$$

$$\mathbf{P}_{k} = \left(\mathbf{I} - \mathbf{K}_{k}\mathbf{H}_{k}\right)\mathbf{P}_{k/k-1} \tag{12}$$

$$\mathbf{K}_{k} = \mathbf{P}_{k/k-1}\mathbf{H}_{k}^{T}(\mathbf{H}_{k}\mathbf{P}_{k/k-1}\mathbf{H}_{k}^{T} + \mathbf{R}_{k})^{-1} \tag{13}$$

By estimating the square error matrix to obtain the optimal solution:

$$f(x) = P_{k} = E[\tilde{x}_{k}\tilde{x}_{k}^{T}] \tag{14}$$

The extreme point is the estimated value, the filter starts from the given initial value P_0 、 $\hat{x}_0$, and is updated sequentially.

In the current algorithm, zero velocity update based on the Kalman filter can only provide a velocity error as the observation, and the position error is not considered. At the same time in the detection of zero velocity interval, it is assumed that the pedestrian foot speed in the interval is zero, due to walking characteristics and data perturbations, resulting in foot velocity in the interval is not absolute zero, this pseudo-observation also has a random and the cumulative error over time.

III. THE PROPOSED ALGORITHM

In this paper, a dual-MIMU trajectory tracking method based on SVM constraint is proposed. In addition to using the current zero velocity update, the theory of SVM is also used. Starting from the observed data to find the law between the data, increase the number of observations. Due to the fact that there is a no zero-position interval after a zero-velocity interval. The algorithm proposed in this paper uses SVM theory to find the interval and correct the position error, while using dual-MIMU constraint method , two MEMS sensors are used to measure the maximum step distance during walking to further correct the error.

A. Feature Extraction of Gait Data and Design of Classifier

SVM is a classical theory in machine learning field. In this paper, gait recognition classifier is designed by using SVM theory. SVM is a pattern recognition method derived from statistical learning theory. The kernel function divides the linearly inseparable sample in low-dimensional space into high-dimensional feature space so that it can be linearly separable. Using the theory of structural risk minimization to construct the optimal hyperplane and classify the samples through decision-making. The decision function is:

$$f(x) = \operatorname{sgn}\left(\sum_{i=1}^{ns} a_i y_i K(x_i, x) + b\right) \tag{15}$$

In formula 14: ns is the vector number, b is selected according to the training sample threshold, is a constant. For a test vector, if $\sum_{i=1}^{ns} a_i y_i K\left(x_i, x\right) + b \geq 0$, then x will be classified as "1" category, otherwise be classified as "0" category. In the above formula, the $K(x_i, x)$ is kernel function , usually a linear kernel, polynomial, Radial Basis Function (RBF), sigmoid kernel function, etc. Different types of machine learning can be achieved by using different kernel functions, and the classification results are also different. The results of the classification can be related to the number of training samples.

Gait division will divide a continuous process into a number of single gait. The corresponding inertia parameters for each gait are: $\left\{a_{xi}, a_{yi}, a_{zi}, \omega_{xi}, \omega_{yi}, \omega_{zi}\right\}$, $i = 1,2,3,...,k$. The different modes of motion lead to inertia parameters different. Different gait types with the same type of motion have similar inertia parameter statistics. Assuming an inertia parameter is, $\left\{x_1, x_2, x_3, ...x_k\right\}$ extract several parameters as gait features shown in Table.1:

Table.1 gait characteristics

Feature amount	definition
Mean	$\bar{x} = \frac{1}{k}\sum_{i=1}^{k} x_i$
variance	$\sigma = \sqrt{\frac{\left(x_1 - \bar{x}\right)^2 + ... + \left(x_k - \bar{x}\right)^2}{k}}$
Root mean square	$x_{rms} = \sqrt{\frac{x_1^2 + x_2^2 + ... + x_k^2}{k}}$
Maximum	$x_{\max} = \max\left\{x_1, x_2, ..., x_k\right\}$
Minimum	$x_{\max} = \max\left\{x_1, x_2, ..., x_k\right\}$

In order to establish the classification model, the SVM training data was first collected, and the following experiment was set up for this experiment: 4 sets of experiments were performed, from south to north, from north to south, from east to west, and from west to east. Each of them is 50m long. The above data are saved as attribute vector and label vector, respectively. Because SVM can use the characteristics of small sample training. It can speed up the training speed. Put the attribute matrix and label matrix into MATLAB SVM data training module to complete the data training. After training, the SVM classifier has associative memory and predictive ability. When we send the attributes and labels of the test to the classifier, the classifier will automatically output the action class, which is a crucial step in positioning. Process shown in Fig.7.

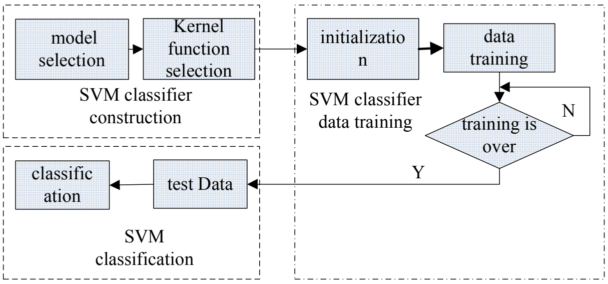

Fig.7 training flow chart

According to the laws of human movement, people can be divided into two stages within the range of one-step walking: the stationary stage and the swinging stage. The swinging stage can be divided into three parts: toe off, air swing and heel to ground, as shown in Fig.8. The angular velocity reaches a peak just when the toe is off the ground. The gait situation is shown in Fig.9, in which the horizontal angular velocity is the most obvious, and the foot is not displaced during this period. Based on the SVM principle, gait statistical characteristics are extracted and classified, According to the stop time at zero velocity interval, it is concluded that the foot is in contact with the ground during the time period, and there is no displacement, that is, the zero shift interval. The test result is shown in Fig.10.

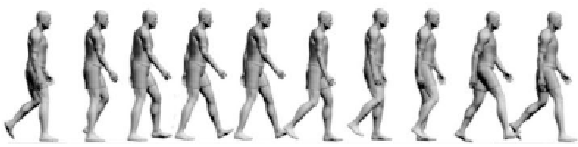

Fig.8 walking gait division

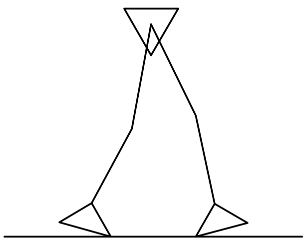

Fig.9 toe off the ground state

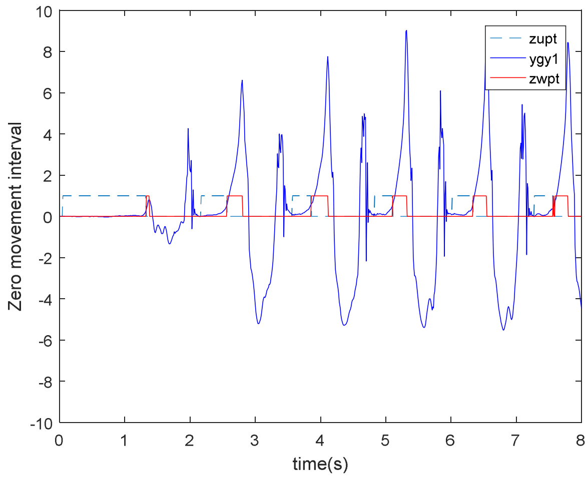

Fig.10 zero displacement interval

B. Maximum step inequality constraints

According to the law of human motion, pedestrians in a walking range, when a foot just to leave the ground, there will be a maximum distance between feet, that is, the maximum step, we can use it to constrain the navigation states. In the A of section Ⅲ, as constraint equations, and then combined with Kalman filtering to make the optimal solution strictly meet the inequality constraints existing between state vectors. The state is estimated by solving the inequality constrained Kalman filter to obtain the optimal solution.

The optimal solution of inequality-constrained Kalman filter is expressed as:

$$\begin{cases}\min(\hat{\mathbf{x}}_k - \mathbf{x}_k)^T \mathbf{P}(\hat{\mathbf{x}}_k - \mathbf{x}_k) \\ \mathbf{L}\mathbf{x}_k \le \mathbf{d}\end{cases} \tag{16}$$

The first formula of formula 16 will be expanded:

$$(\hat{\mathbf{x}}_k - \mathbf{x}_k)^T \mathbf{P}(\hat{\mathbf{x}}_k - \mathbf{x}_k) = \hat{\mathbf{x}}_k^T \mathbf{P}\hat{\mathbf{x}}_k - 2\mathbf{x}_k^T \mathbf{P}\hat{\mathbf{x}}_k + \mathbf{x}_k^T \mathbf{P}\mathbf{x}_k \tag{17}$$

Therefore, the problem of inequality constraints can be further simplified as:

$$\begin{cases}\min(\hat{\mathbf{x}}_k^T \mathbf{P}\hat{\mathbf{x}}_k - 2\mathbf{x}_k^T \mathbf{P}\hat{\mathbf{x}}_k) \\ \mathbf{L}\mathbf{x}_k \le \mathbf{d}\end{cases} \tag{18}$$

IV. EXPERIMENTAL VERIFICATION AND RESULTS

The MEMS inertial device used in this paper is the MTI-G710 sensor manufactured by XSENS in the Netherlands. As shown in Fig.11, Three-axis gyroscope, three-axis accelerometer, barometer, thermometer, magnetometer and GNSS receiver are integrated inertial measurement unit, It has small size and good stability. Accuracy to bias stability as an indicator of the measurement range and bias stability shown in Table 2:

Fig.11 MEMS device

Table 2 measurement range and accuracy of inertial device

MTI-G710	Three-axis accelerometer	Three-axis gyroscope
measurement range	$\pm 50 m/s^2$	$\pm 450^\circ/s$
accuracy	$\pm 0.03 m/s^2$	$\pm 12^\circ/h$

Firmly attach the two IMUs to the tips of both feet, as shown in Fig.12. Experiments walking in the teaching building, divided into straight-line stage and turn, in strict accordance with the turn at right angles. The distance is 200m, the route is 55m north, 45m east and 1 lap.

The three lines in the figure are the true path, the simulation path when only ZUPT is used, and the simulation path of the new algorithm. The experimental results are shown in Fig.13, with a positioning accuracy of 1.3%.

Fig.12 IMU firmware

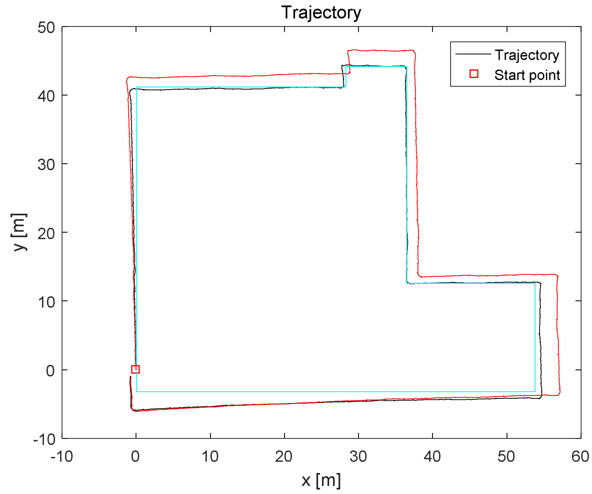

Fig.13 Trajectory

V. Conclusion

Based on the zero velocity update, SVM theory is used to extract the walking characteristics of the walking process and to classify the walking characteristics of the foot to find the time to go off the ground. The observational quantity is used to correct the position error. At the same time, the navigation state is constrained according to the maximum step size. The position error is corrected according to the observability analysis, which improves the accuracy of pedestrian positioning. The experimental results show that the proposed method has high positioning accuracy, and the accuracy of walking 200m is 1.3%. It can be applied to pedestrian indoor positioning system.

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