Research and Practice on Testing Methods for Mobile Robot Positioning Accuracy

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Abstract: To solve the problem of low positioning precision of mobile robot in conventional manual test with low test efficiency,and pose measurement based on high-precision pose measurement tools show deficiency in a low degree of automation, which fails to be directly used to evaluate test results. This paper proposes a position precision based on high precision position measuring tool automation testing methods, which can not only solve the low conventional manual test precision, and when the positioning accuracy is required to reach a higher standard, the error caused by manual measurement makes the measurement result fails to be used as the evaluation benchmark.In addition, it can automatically collect pose points in the process of repeated autonomous movement of mobile robots, and then automatically analyze the pose error when reaching a specific position point every time. It is suitable for repeated testing in industrial scenes for a long time, and achieves the purpose of improving test efficiency and productivity.
***Keywords*:** precision testing, positioning accuracy, automatic testing, robot

With the development of artificial intelligence technology, autonomous mobile robots enjoy an increasing popularity in warehousing, logistics, commercial services and other scenarios. However, in all these applications, there is a common core technology target, namely. That is, when the user wants the robot to reach a certain point, the robot can reach the point accurately, so as to meet the precise docking of logistics delivery and other applications. For this, researchers continue to conduct research and exploration in the field of positioning technology. However, the matching positioning accuracy test, especially the automated test, lags behind. Therefore, the research on mobile robot positioning accuracy testing is of great significance to support the development of positioning technology and the popularization and application of autonomous mobile robots based on different sensors in various industries.

General Technical Specification CR1-0303TS: 2018 clearly defines the positioning accuracy as the deviation between the actual and theoretical position of the robot positioning[1], and explains the test method: On the specified movement track, the positioning error mark of pre-stop is made in advance. When the logistics robot changes from rated speed to normal stop state, the maximum value of the deviation from the stopping position of the logistics robot is measured with a measuring tool after the stop.

Therefore, the important basis of positioning accuracy test is to measure the pose of the mobile robot in the space. At present, there are two methods that can be applied to the pose measurement of the mobile robot: The first type is based on manual dotting, that is, to use the laser pointer or any other way to manually mark the posture of the mobile robot. The second type is based on pose measurement tools. For example, reference[2] uses laser tracker to obtain the position and pose of moving objects, infrared optical capture system is adopted in the reference[3] to obtain the position and pose of moving objects, and video parsing technology is utilized in reference [4] to obtain the position and pose of moving objects.

However, the manual method has low accuracy and low efficiency,which fails to cope with the scene with high accuracy requirements and a large number of tests in a short time. The method based on pose measurement tools can output the real-time pose of moving objects, but the "test" is not for the purpose of obtaining the pose. It is the ability to efficiently and easily implement the test process and evaluate the measurement results in hundreds or more tests, and further, to identify failures or test results in the middle process. Therefore, the only effective way to solve the problem is to integrate the implementation of measurement process, analysis of measurement data, evaluation of measurement results and judgment.

1. Application scenarios

In the field of industrial logistics, autonomous mobile robot can be summarized as most of the practical application of scene at a certain time, fixed line movement between the established several points, such as transporting materials between different workshop, assembly line in a factory, this scenario requires the robot to move back and forth on the path planned in a long duration and precisely stop in pr-planned location of the point, so as to conduct interconnection with other devices or people.

This paper presents a positioning accuracy test method for autonomous mobile robot in multiple position points.Combined with infrared optical motion capture system,the positioning accuracy of mobile robot can be tested and evaluated with a little manual pre-operation.

2. System structure

The integrated positioning accuracy system proposed in this paper consists of four parts: test configuration module, data acquisition module, data processing module and test result display module. See Figure 1.

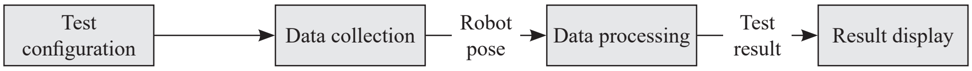

Figure 1. System structure diagram

Through the test configuration module to configure the name of a single test, the number of test location points and other information. The data acquisition module collects and saves the time stamp in the pre-processing stage and the pose of the mobile robot in the testing process. The data processing module analyzes and processes the collected pose data of the mobile robot to obtain the positioning accuracy test results. Test results display module can be capable of testing results data and graphical display. Because the data processing module is the core of the integrated positioning accuracy testing system, this paper focuses on the data processing part.

3. Data processing

Taking the positioning accuracy test of autonomous mobile robot in the scenario of cyclic operation between two position points as an example, the manual test method is described as follows:

I. Set two position points P1 and P2;

II. Mark the reference pose of the mobile robot at position point P1 as reference point R1;

III. Reference pose of the marking mobile robot at position point P2 is reference point R2;

IV. Visual observation of autonomous operation of mobile robot to position point P1;

V. Measure the deviation between the pose T1 of the mobile robot reaching position P1 for several times and the reference pose R1 of the marked position point P1;

VI. Measure the deviation between the pose T2 of the mobile robot reaching position P2 for several times and the reference pose R2 of the marked position P2.

Therefore, after obtaining all pose data of the mobile robot in the process of cyclic operation between position points P1 and P2 through the pose measurement tool infrared motion capture system, it is hoped that the system can automatically identify whether the mobile robot has reached the set position points P1 and P2. To replace the manual visual inspection of the process of mobile robot reaching position point P1 and P2; Secondly, it is our thought that the system can automatically extract the position and pose of the mobile robot in the space when it reaches the position point P1 and P2 and automatically compare the reference position and pose to get the deviation. Thirdly, we hope that all the automatic recognition and extraction proved to be reliable.

Figure 2 shows the time and speed curve drawn after velocity calculation and processing of the pose data of the reciprocating motion of the mobile robot before the established position points P1 and P2 collected by the infrared motion capture system.

As can be seen from Figure 2, the mobile robot is stationary at position points A and B, which are close to 0. However, due to noise and other external factors in infrared motion capture system, mobile robot itself and environment, the velocity curve presents burr phenomenon. Therefore, the primary goal of data processing is to extract the relative static points in pose data, identify which are reference points, which are test evaluation points, and the corresponding relationship between test evaluation points and reference points.

In this paper, static points in pose data are identified based on speed judgment,and reference points are identified based on time stamps collected and saved by infrared motion capture system when position points are set, and the corresponding relationship between test evaluation points and reference points is based on the sequence of test evaluation points after the reference point.

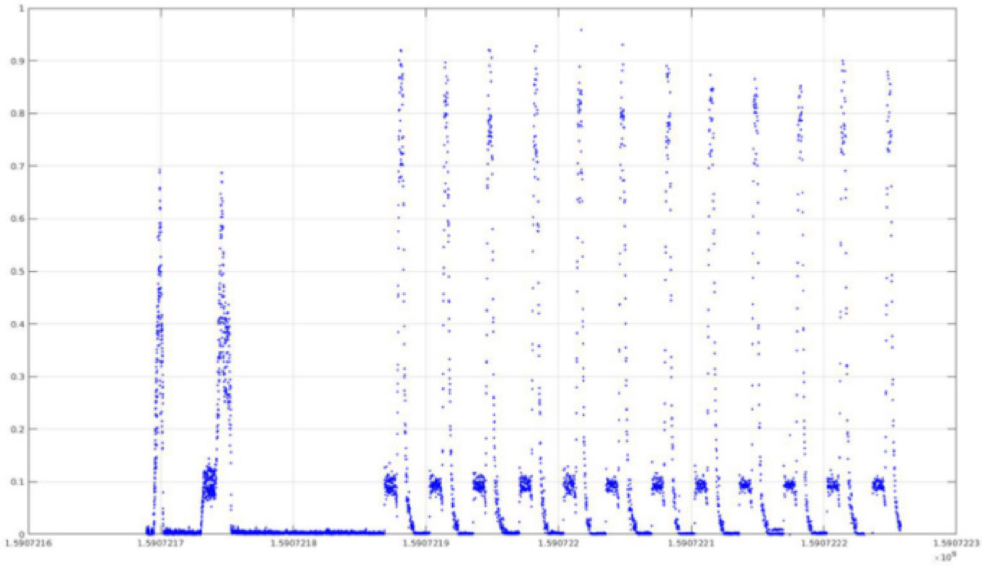

Figure 2. Sample diagram of time velocity curve

The following takes two position points P1 and P2 as examples to discuss data processing methods in detail. Two types of data files are obtained through the data acquisition module: The first type of data file A is the timestamp file of the reference point output by the infrared motion capture system, including the timestamp T1 T2 of the reference point. The second type of data file B is the real-time pose file of the mobile robot collected by the infrared motion capture system, including the timestamp and the pose of the mobile robot at the corresponding timestamp point. The data processing principle is shown in Figure 3.

As shown in Figure 3, the white circles in column (a) represent each data point in data file B. The top to bottom means the temporal sequence. For example, the first circle is the robot's spatial pose at 0 seconds. The second circle is the robot's spatial pose at 1 seconds, and so on. T1, T2 represents the timestamps of the two reference points recorded in data file A.

I. To calculate the linear velocity and angular velocity of each data point in data file B, formulas and calculation methods in existing technology can be adopted for calculation;

II. Set four indicators: THv, number of linear velocity M, THω, number of angular velocity N;

III. Traverse all data points in data file B:

If a data point satisfies both conditions S1 and S2, the point is marked as a rest point. Otherwise mark the point as a moving point.

Where, condition S1 is set as: The linear velocities of M points before and after this point as the midpoint are all less than THv;

Where, condition S2 is set as: The angular velocity of N points before and after this point as the midpoint is all less than the angular velocity threshold THω;

As shown in Figure 3, black circles in column (b) represent stationary points and white circles represent moving points;

IV. Define the stationary segment as a continuous series of stationary points, and define the moving segment as a continuous series of moving points;

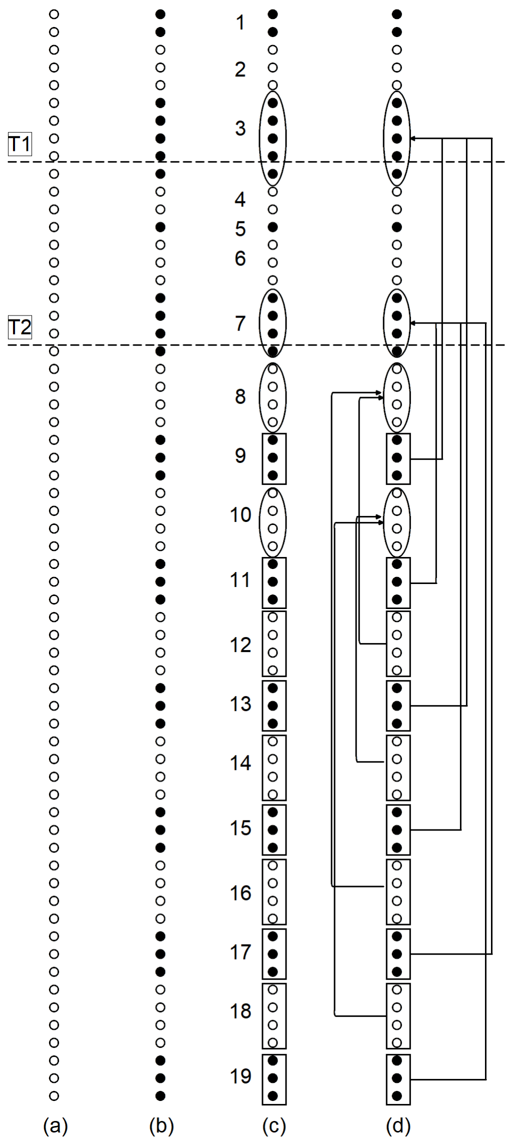

Figure 3. Data processing schematic diagram

V. Screen and classify all stationary and moving segments

Traverse each stationary and moving segment in chronological order:

If a stationary segment contains T1 or T2, that is, the time of the first data point of the stationary segment is less than T1 or T2, and the time of the last data point of the stationary segment is longer than T1 or T2, the stationary segment is marked as a reference segment of positioning accuracy.

The stationary segment containing T1, namely, the pose data of the robot when it first stops at P1, is denoted as the reference segment of the accuracy of the first certain position. The stationary segment containing T2, namely the pose data of the robot when it first stops at P2, is denoted as the second positioning accuracy reference segment. We mark the first, third and fifth stationary sections after the positioning accuracy reference section containing T2 as the first position accuracy to be evaluated. We marked the second, fourth and sixth stationary sections after the positioning accuracy reference section containing T2 as the second positioning accuracy test and evaluation section.

The summary rule is as follows: Assuming that the number of position points is M, the above rule can be summarized as follows: mark the j+(i-1)×m stationary section after the positioning accuracy reference section containing Tm as the Jth positioning accuracy long test evaluation section, where j=(1, 2, 3... , m), I =(1,2,3...). As shown in Figure 3, (c) the circular frame columns is positioning accuracy of the reference period, square box is positioning precision of the test evaluation section, for the convenience of display, all static and movement were numbered from top to bottom, in particular, Figure 3 for the position of the point P1 in the positioning accuracy of the reference period, number 7 for the position of the point P2 positioning accuracy of the reference period and numbers 9, 13 and 17 are the positioning accuracy test and evaluation sections of position point P1, and numbers 11, 15 and 19 are the positioning accuracy evaluation sections of position point P2.

VI. Positioning accuracy based evaluation

The average position and angle of the robot in the positioning accuracy reference section of position point P1 and position point P2 were obtained.

The average position and Angle of the robot in the positioning accuracy test and evaluation section of position point P1 and position point P2 were obtained.

Calculate the distance between the average position of the robot in the test and evaluation section of P1 positioning accuracy and the average position of the robot in the reference section of P1 positioning accuracy (specifically, Euclidean distance, Manhattan distance and other spatial distance calculation methods can be selected) to form the position deviation array of P1.

The difference between the average angle of the robot in the test and evaluation section of P1 positioning accuracy and the average angle of the robot in the reference section of P1 positioning accuracy was calculated to form the angle deviation array E_{a1} of P1.

In the same way to get solution to E_{l2} and E_{a2}, namely, E_{l1} and E_{a1} are the position and Angle deviation between the positioning accuracy test evaluation section and the positioning accuracy reference section of position point P1 in column (d) numbered 9, 13 and 17 respectively. E_{l2} and E_{a2} are the position and angle deviation between the positioning accuracy test evaluation section of position point P2 and the positioning accuracy reference section of position point P2 in column (d) numbered 11, 15 and 19 respectively. Conduct statistical analysis on $E_{l1}/E_{a1}/E_{l2}/E_{a2}$, such as on average value, standard deviation, maximum value, minimum value, etc. to complete positioning accuracy evaluation.

4. Experiment

In order to verify the effectiveness of the positioning accuracy test method proposed in this paper, all modules including test configuration module, data acquisition module, data processing module and result display module are implemented using Python.A complete automatic testing system for positioning accuracy was formed, and experiments were carried out in the actual environment on the logistics robot chassis prototype of Zhejiang Xinyihua Intelligent Technology Co., LTD., as shown in Figure 4.

The prototype is a differentially driven wheeled robot that can transport goods back and forth between points based on lidar positioning and navigation after mapping and setting up points.

The pose measurement tool based on the test is the infrared motion capture system developed by Beijing Nokov Technology Co., LTD., as shown in Figure 5.

The graphical pose measurement tool can track the logistics robot by capturing the marker reflective ball placed on the robot body during the process of transporting goods between the set position points, and output the pose data of the logistics robot in real time.

Figure 4. Chassis prototype

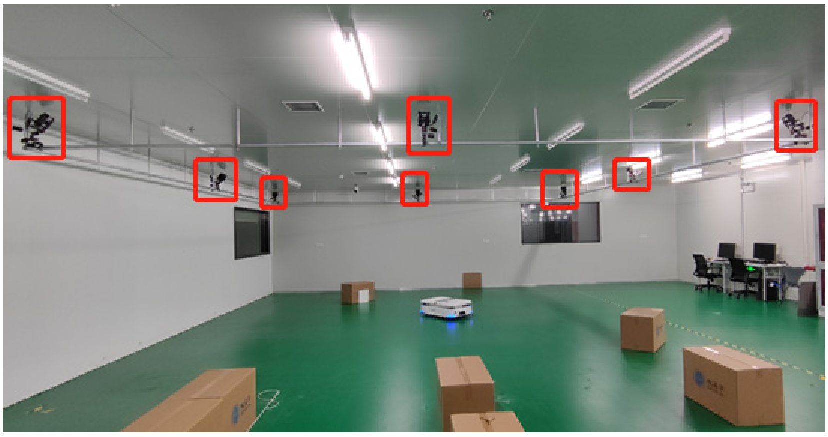

Figure 5. Infrared motion capture system

4.1 Test configuration

The test configuration interface is shown in Figure 6.

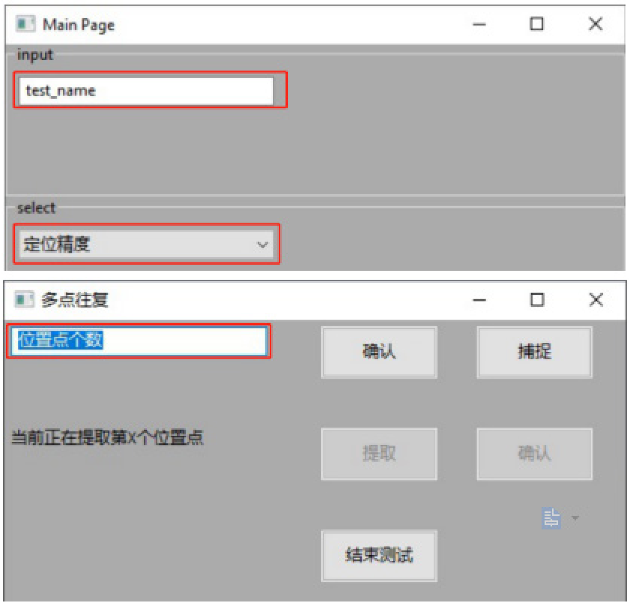

Figure 6. Test configuration interface diagram

Through the test configuration interface, set the name of this experiment and select this experiment as the positioning accuracy test. The number of position points is 2, that is, reciprocating before the two position points.

4.2 Data collection

As discussed in Chapter 3 of this paper, data processing needs to deal with two types of files: The first type of data file A is the timestamp file of reference point output by infrared motion capture system, including the timestamp T1 and T2 of reference point.The second type of data file B is the real-time pose file of the mobile robot collected by the infrared motion capture system, including the timestamp and the pose of the mobile robot at the corresponding timestamp point. Data collection methods in the two types of data files are described below.

4.2.1 Timestamp data collection

Start the infrared motion capture system, record the initial timestamp Ts, and control the logistics robot to reach the position point P1. The logistics robot control system can be used to complete the establishment of position point P1, and record the timestamp T1 at the current position. The logistics robot was controlled to reach P2, and P2 was established through the logistics robot control system, and timestamp T2 was recorded at the current position. After more than 6 seconds, the end timestamp Te is recorded at position P2. All timestamp records are saved in timestamps.txt.

4.2.2 Robot based real-time pose acquisition

After the timestamp data collection is completed, the task "P1<->P2" is created through the logistics robot control system, and the residence time of the robot after reaching the position point P1 and P2 is set to 10s. Set the running mode of the robot to cycle mode and activate the task to make the robot run autonomously between P1 and P2. After running for a certain number of times, such as 109 times, the pose collection is terminated, and the dataset1.htr file collected by the infrared motion capture system is obtained.

4.3 Data processing

The collected dataset1.htr file is preprocessed to remove invalid points. The speed curve obtained by using the data processing method proposed in this paper is shown in Figure 7, and the sample position curve relative to the reference point is shown in Figure 8.

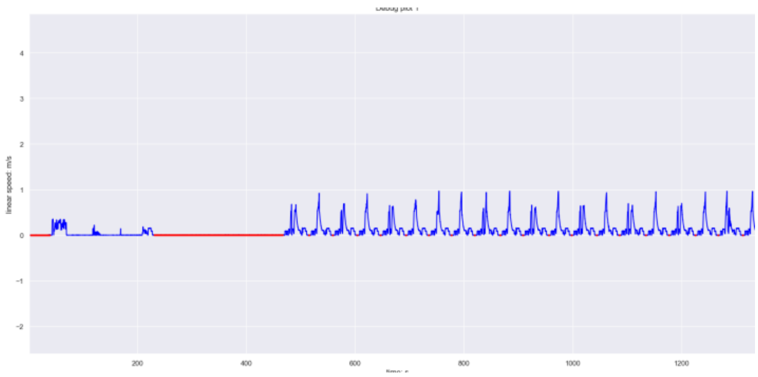

Figure 7. Velocity curve

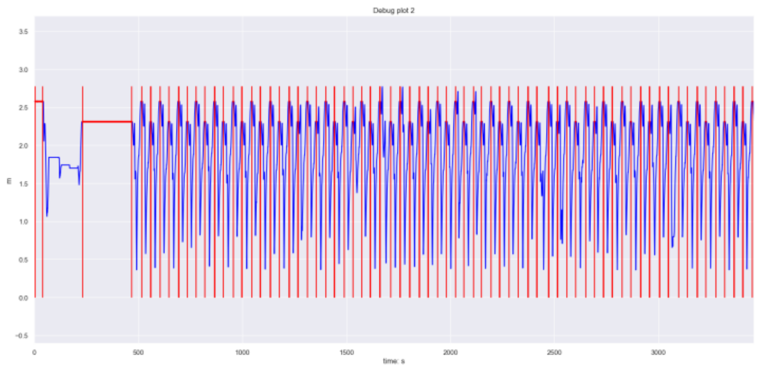

Figure 8. Curve of relative position

The position marked as red horizontal line in Figure 7 is the stationary point identified by the system. The first red horizontal line is the position point P1 when the reference point is initially established, the second red horizontal line is the position point P2 when the reference point is initially established, and the subsequent red horizontal line is the position point

P1, P2 when the robot runs in a cycle.

The position marked as red vertical line in Figure 8 is the position point P1, P2 identified by the system. The first red vertical line is the position point P1 when the reference point is initially established, the second red vertical line is the position point P2 when the reference point is initially established, and the subsequent red vertical line is the position point P1, P2 when the robot runs in a cycle

It can be seen that the speed curve in Figure 7 and position curve in Figure 8 have consistent correspondence with the actual robot movement, and the speed curve in Figure 7 and position curve in Figure 8 also have consistent correspondence, so the system recognition is reliable.

4.4 Results display

The positioning accuracy test results of Position point P1 and Position point P2 after the positioning accuracy evaluation are shown in Figure 9. The positioning accuracy test results of Position point P1 and Position point P2 are output respectively. The total number of test times of Position point P2 is 109, and the Position Pass number is 109. The angle Pass number is 109. Besides, maximum error Max, minimum error min, average error median, root mean square error RMse, and the maximum angle error Rx_max, minimum error Rx_min,as well as average error Rx_median, root mean square error Rx_rmse are displayed.

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 'Position %: ': 0.0,
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 'Position %: ': 0.0,
 'Position Pass number: ': 109,
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Figure 9. Test results of positioning accuracy

In terms of result display, graphical display of position deviation and angle deviation was carried out along with the above data display, as shown in Figure 10 and Figure 11

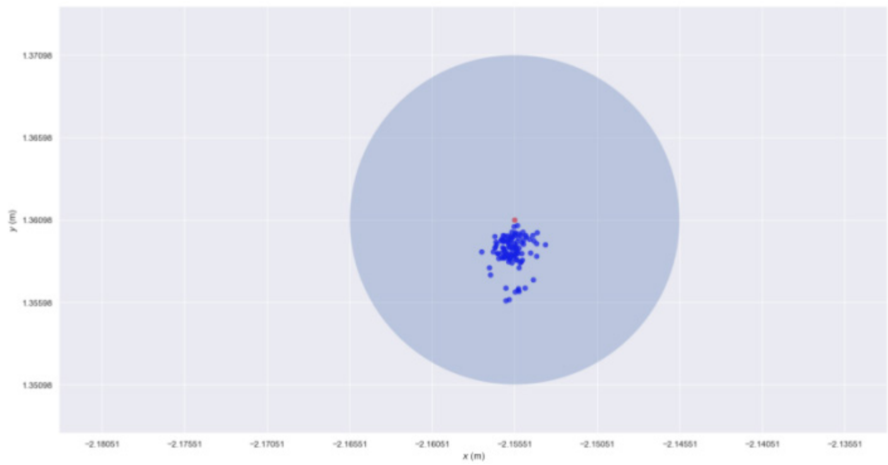

Figure 10. Position deviation diagram of position point P1

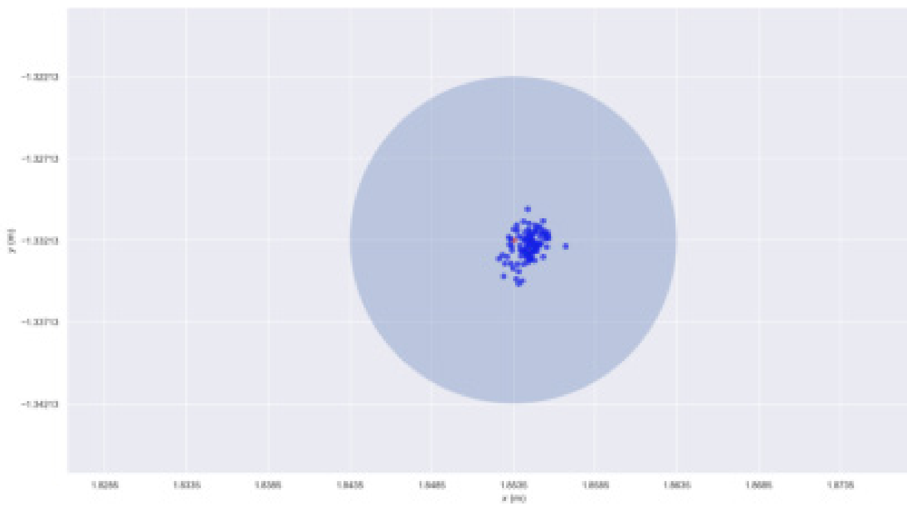

Figure 11. Position deviation diagram of position point P2

In Figure 10 and Figure 11, the center of the red circle represents the position of the reference point, and the radius of the circle is the allowable error range of the positioning accuracy of the logistics robot product index. The blue points are the positions of each test evaluation point

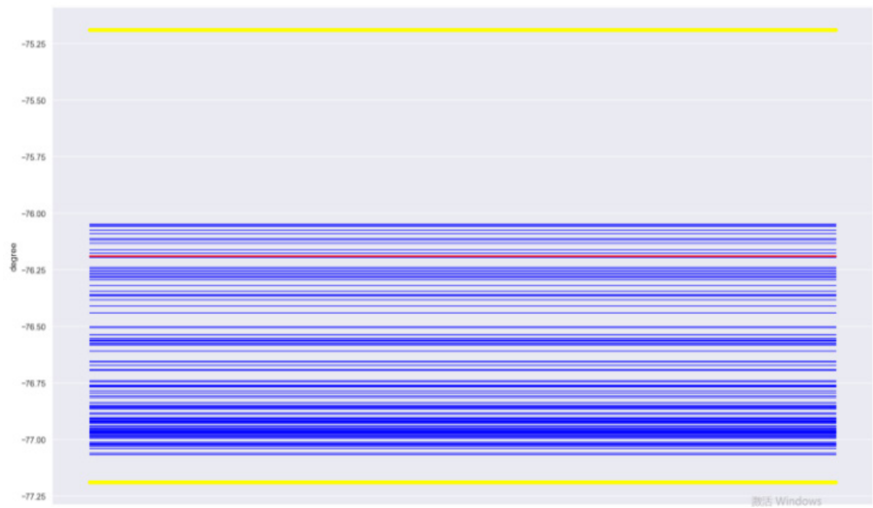

Figure 12. Position deviation diagram of position point P2

Figure 13. Angle deviation diagram of position point P2

In Figure 12 and Figure 13, the red line represents the attitude of the reference point.The upper and lower yellow horizontal lines are the error range of positioning attitude accuracy of logistics robot product indicators, the blue horizontal line is the attitude of each test evaluation point, and the higher the aggregation degree of the attitude of each blue test evaluation point from the reference point of the red horizontal line, the better the positioning attitude accuracy effect.

It can be seen that the test results can be displayed more intuitively through graphical output.

5. Conclusion

In this paper, a positioning accuracy testing method of mobile robot is proposed. The testing method can process the pose data output by pose measurement equipment. Combined with the idea of automatic testing, test configuration, data acquisition, data processing and result display are effectively integrated into a testing system. The experiment proves that this method is feasible. The follow-up work is mainly to continue to expand the application scope of this method and further optimize it for different application scenarios.

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