**Trajectory Performances Test for Arc Welding Robot Based on the Non-contact Laser Tracing Measurement Technology**

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**Abstract.** The aim of this paper is to test the trajectory precision of the execution terminal of the industrial robot based on a non-contact laser tracing measurement technique. The target is found in terms of tracing mirror attached in measurement position. This method utilizes the linear motion units and photo detection units to trace the target actively. The measurement of the target coordinates are measured with the laser interferometer linear measurement module and the grating ruler. This system can achieve the trajectory measurement of the planar motion objects without contact in real-time condition and also possesses the high precision. The experimental work and calculation were performed in order to achieve the trajectory precision of the research.

**Introduction**

As industrial robots widely employed in assembly, seam welding, testing, drilling and other fields, more or less stringent requirements are always imposed on these fields. Recently, the position of robot end-effector is obtained through the position information of each joint. There are several serious problems. First, the robot's frame stiffness must be large, because any deflection of arms will lead to misjudge the position of the robot end-effector. The fact will increase the price and weight of machines; meanwhile limit the payload of robot. Second, even with the precision encoder and the solid component, the precision of large robot is low. The robot, which has a working space of 2m and can transport different payload, usually has 1 ~ 2mm of the absolute accuracy. To enable the robot to a high accuracy for those tasks, the measurement which can provide precise location information of robot has been required [1-4].

With wide measurement range, flexible, dynamic and high precision, the laser tracing measurement system can realize high-precision measurement of moving objects in space. Some companies, such as LEICA, API and FARO, have launched commercial laser tracking measurement system based on the spherical coordinate. National Metrology Institute of Japan (NRLM) and the British National Physical Laboratory (NPL) are developing measurement system based on the principle of multilateral laser tracking measurement system [5]; Tianjin University in China has developed laser tracking coordinate mapping system at first based on the multilateral method [6]. In relevant available products, gantry-type coordinate measuring machine has high accuracy, but the move should not be bulky; articulated arm measuring instrument is portable, but its error at 1m is more than 30µm, and generally it requires staff assistance, and it is not be independent Tracking; laser tracker is portable, but its error at 1m is more than 15µm, at the same time, its measurement accuracy is influenced by the accuracy of code disc and increased with the increase of the measuring distance.

In this paper, we study the laser tracing measurement system based on Cartesian coordinates. This system overcomes the former’s precision coupling. Then we use the system to test the trajectory precision of the industry robot.
**Working Principle of Laser Tracing Measurement System**

To track the movement and determine its two-dimensional coordinates of a point in the plane, a target mirror is attached to the robot end-effector. The laser that the laser interferometer sent out reflects to the target mirror through the tracking mirror. Then the laser is divided into two beams to return to the light detection device and the interferometer by the beam splitter. Though the interferometer monitors the changes of the fringes of two beams, the system can realize high-precision non-contact measurement. When the target moves, detection system measures the movement of the target mirror based on the position deviation of the return beam at the light detector. The tracking mirror adjusts the X position to re-aim the target, and we can measure the total displacement and the displacement of X direction through the laser interferometer and a grating ruler respectively in order to achieve the measurement of coordinates. Its working principle is shown in Fig.1.

![Fig. 1 Working principle of laser tracing system](image1)

The system consists of laser interferometer measurement system, tracking system, light detection system, control system and other subsystems in Fig.2. Its composition and spatial assembly relationship are shown in Fig. 3.

![Fig. 2 System components](image2)

![Fig. 3 Laser tracking measurement system](image3)

**Test Plan for Position Precision**

The results at home and abroad showed that the flow in structural and moving parameters of the robot extends to the precision of end-effector. In this paper, load, position and velocity are the primary considerations. This paper takes welding robot as the example, analyses the position precision of the robot. The testing cube is selected in that portion of the working space with the greatest anticipated use. And the edges of the cube are parallel to the base coordinate system.
**Trajectory Test.** Based on the off-line programming, the arc welding robot executes the order again and again to meet the requirements of manufacturing line. Arc welding process requires the trajectory performance of the robot end-effector to satisfy certain precisions. When the track precisions beyond technical requirements, the arc welding may lead to reduce the weld strength because of the deviation of weld center, and ultimately affect product quality. Thus, according to ISO9283 standard [7], the major testing paths for the arc welding robot are lines and square. Selected cube is located in that portion of the working space with the greatest anticipated use, and its edges are parallel to the base coordinate system of robot. The test path is at the test plane of the cube, as is shown in Fig. 4.

The accuracy, repeatability and error of robot along rectangular path are considered. The rectangle is in horizontal plane i.e. height of the robot end-effector is constant from earth level. The vertex coordinate, length and width of rectangle for the robot are defined. Orientation of the robot end-effector is tangent to path. When the robot end-effector moves in this path, some position datum was taken from the end-effector by the laser measurement technology, and was transformed to global reference coordinate, as is shown in Fig. 5.

**Test Velocities.** According to the requirements of ISO9283, test velocity can be chose 10% welding speed. And tests could be carried out at the maximum velocity achievable between the specified poses, i.e. with the velocity override set to 100%, in each case. And additional test velocities are at 50% and/or 10% of this velocity. The research found that welding velocity is influenced by welding conveyor angle, plate thickness, and other factors, such as whether there is filler. In general, welding velocity is between 1.5m/min ~ 6m/min. So test velocity should be between 0.15m/min ~0. 6m/min, that is 1.5m/min ~ 6m/min. In this study, we select 5mm / s as the test velocities.

**Other Test Parameters.** All tests are executed with no test load, and with a test load equal to 10% of rated load conditions. However, because the reflective component of test system are required to install at the body of the robot end-effector, the experimental load for arc welding robot is actually a 1kg and 6kg.
From the above, we can see trajectory precision of robot is calculated by the test data from looping execution. Measurement system tracks the target mirror. At the same time, it snatches the feedback data from the functional units rapidly. Collection interval is approximately 15ms. Although such a data acquisition speed can guarantee the tracking performance and the request of real time, but result in large gathering samples. Take testing a square track of side length 200mm as an example, test velocity is 5mm / s, the number of loops is 30, there needs to collect about 400k double-precision data, and file size is about 20Mb. So huge amount of data Not only causes read difficulty, and conventional computer configuration cannot acquire the data quickly in execution unit of the system, even leads to memory leak. Considering inefficient analysis of a huge number of data, the system limit the number of loops not more than 10 times one group. In this test, the number of cycles we selected is 3.

**Path Characteristics.** For continuous path applications, path characteristics are more important than pose characteristics. Path characteristics include path accuracy and repeatability. Their definitions are independent of the shape of the command path. In this paper, the ISO approach has been adopted. ISO defines path accuracy characterizes the ability of a robot to move its mechanical interface along the command path in the same direction n times. Path accuracy contains two parts: positioning path accuracy and orientation path accuracy. Path accuracy mentioned in this paper is positioning path accuracy. Its value is the maximum deviation from the commanded path obtains from the same path several times in the same direction. It is calculated as follows:

\[
AP_p = \max \sqrt{(x_i - x_{ci})^2 + (y_i - y_{ci})^2 + (z_i - z_{ci})^2}, \quad i = 1, \ldots, m, \tag{1}
\]

where
\[
x_i = \frac{1}{n} \sum_{j=1}^{n} x_j,
\]
\[
y_i = \frac{1}{n} \sum_{j=1}^{n} y_j,
\]
\[
z_i = \frac{1}{n} \sum_{j=1}^{n} z_j.
\]

When calculating \(AP_p\), we selected 11 points along the command path and corresponding normal planes. \(x_{ci}, y_{ci}\) and \(z_{ci}\) are the coordinates of the \(i\)-th point on the command path. \(x_j, y_j\) and \(z_j\) are the coordinates of the intersection of the \(j\)-th attained path and the \(i\)-th normal plane.

Path repeatability expresses the closeness of the agreement between the attained paths for the same command path repeated \(n\) times. Just the same as path accuracy, path repeatability also contains two parts: positioning path repeatability and orientation path repeatability. And path repeatability mentioned in this paper is positioning path repeatability. Its value is the maximum \(RT_p\) which is equal to the radius of a circle in the normal plane and with its centre on the barycentre line. It is calculated as follows:

\[
RT_p = \max RT_{pi} = \max \left[ \bar{l}_i + 3S_y \right], \quad i = 1, \ldots, m, \tag{2}
\]

where
\[
\bar{l}_i = \frac{1}{n} \sum_{j=1}^{n} l_y,
\]
\[
l_y = \sqrt{(x_y - \bar{x})^2 + (y_y - \bar{y})^2 + (z_y - \bar{z})^2},
\]
\[
S_y = \sqrt{\frac{\sum_{j=1}^{n} (l_y - \bar{l})^2}{n-1}}.
\]
Measured results

The accuracy, repeatability and error of robot along rectangular path are considered. The rectangle is in horizontal plane i.e. height of the end effector is constant from earth level. The vertex coordinate, length and width of rectangle for the robot are defined. Orientation of end-effector is tangent to path. When the end effector moves in this path, a number of dates are acquired from the end-effector by laser tracking measurement technique.

According to the data of the end-effector, Mat lab is adopted to calculate the path characteristics. As, the robot end-effector position in Z direction doesn’t vary, the amount of error in Z direction is considered to be zero. We select AB and CD as the test paths, as is show in Fig. 5. The experimental results of path accuracy and path repeatability are shown in Table 1. Fig. 6 and Fig. 7 respectively showed the trajectory errors at 11 different points along straight line BC and CD in 3 circles. Fig. 8 and Fig. 9 respectively showed the closeness of 3 attained paths for straight line BC and CD.

| command path | path accuracy | path repeatability |
|--------------|---------------|--------------------|
| BC           | 0.2604mm      | 0.2351mm           |
| CD           | 0.3709mm      | 0.1119mm           |

Fig. 6 Trajectory error along straight line BC

Fig. 7 Trajectory error along straight line CD

Fig. 8 Closeness of 3 attained paths for straight line BC

Fig. 9 Closeness of 3 attained paths for straight line CD
Conclusions

To determine and improve the position precision of the industry robot, the laser tracking measurement system is studied in the paper. The work overcomes the coupling of Spherical coordinate system, and establishes a Cartesian coordinate-based laser tracking measurement system. And we employ this system to measure trajectory precision of arc welding robot. The result showed that, it is convenient and correct to employ the laser tracking measurement system to measure the positions of manipulators. The method can also provide the foundation for the robot pose process control. Based on the measurement results, it is clearly that the robot path accuracy along straight line BC is higher along straight line CD. The robot path repeatability along straight line BC is lower along straight line CD.

Acknowledgements

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