Positioning Accuracy and Repeatability of a Class of Technological Robots

Daniela Taslakova

Central Laboratory of Mechatronics and Instrumentation, 1113 Sofia

1. Pose characteristics. General description

Command pose – pose specified through teach programming, manual data input or explicit programming.
Attained pose – pose achieved by robot under automation mode in response to command pose.

![Diagram of accuracy scheme](image-url)
Pose accuracy and repeatability characteristics quantify the deviations which occur between a command and attained pose, and the fluctuations in the attained poses for a series of repeat visits to a command pose. These errors may be caused by internal control definitions, co-ordinate transformation errors, differences between the dimensions of the articulated structure and those used in the robot control system model, mechanical faults such as clearances, hysteresis, friction, and external influences such as temperature.

2. Pose accuracy

Pose accuracy expresses the deviation between a command pose and the mean of the attained poses when approaching the command pose from the same direction. Pose accuracy is divided into:
- the difference between a command pose and the barycentre of the cluster of attained points, i.e. positioning accuracy
- the difference between command angular orientation and the average of the attained angular orientation.
The pose accuracy is the maximum deviation obtained in position and orientation.

The positioning accuracy is expressed as follows:

\[ \Delta L = \sqrt{(\bar{x} - x)^2 + (\bar{y} - y)^2 + (\bar{z} - z)^2}, \]

where:

\[ \bar{x} = \frac{1}{n} \sum_{j=1}^{n} x_j; \quad \bar{y} = \frac{1}{n} \sum_{j=1}^{n} y_j; \quad \bar{z} = \frac{1}{n} \sum_{j=1}^{n} z_j, \]

\[ x, y, z \] are the coordinates of the barycentre of the cluster of points obtained after repeating the same pose \( n \) times;

\[ x_c, y_c, z_c \] are the coordinates of the command pose;

\[ x_j, y_j, z_j \] are the coordinates of the \( j \)-th attained pose.

The orientation accuracy is expressed by:

\[ \Delta L_a = (\bar{a} - a), \quad \Delta L_b = (\bar{b} - b), \quad \Delta L_c = (\bar{c} - c), \]

where:

\[ \bar{a} = \frac{1}{n} \sum_{j=1}^{n} a_j; \quad \bar{b} = \frac{1}{n} \sum_{j=1}^{n} b_j; \quad \bar{c} = \frac{1}{n} \sum_{j=1}^{n} c_j, \]

\[ a_j, b_j, c_j \] are the mean values of the orientation angles obtained at the same pose repeated \( n \) times;

\( a, b, c \) are the angles of the command pose and \( a_j, b_j, c_j \) are the angles of the \( j \)-th attained pose.

Starting from \( P_1 \), the robot successively moves its mechanical interface to poses \( P_2, P_3, P_4, P_5 \). Each of the poses should be visited using a uni-directional approach. Paths used during the test shall be similar to those used when programming. For each pose, positioning accuracy (\( \Delta L \)) and orientation accuracy (\( \Delta L_a, \Delta L_b, \Delta L_c \)) are calculated.

3. Pose repeatability

Pose repeatability expresses the closeness of agreement between the positions and orientations of the attained poses after \( n \) repeat visits to the same command pose in the same direction. For a given pose, the repeatability (\( r \)) is expressed by:

- the value of \( r \), which is the radius of the sphere whose centre is the barycentre and which is calculated as below.

- the spread of the angles \( \pm 3S_a, \pm 3S_b, \pm 3S_c \) about the mean values \( a, b, c \), where

\( S_a, S_b, S_c \) are the standard deviations:
\[
\begin{align*}
r &= D + 3S_D, \\
D &= \frac{1}{n} \sum_{j=1}^{n} D_j', \\
D_j' &= \sqrt{(x_j - \bar{x})^2 + (y_j - \bar{y})^2 + (z_j - \bar{z})^2},
\end{align*}
\]
where \(x, y, z\) and \(x_j, y_j, z_j\) are defined in 1.

\[
S_D = \sqrt{\frac{\sum_{j=1}^{n} (D_j' - D)^2}{n-1}}
\]

\[
\begin{align*}
r_a &= \pm 3S_a = \pm 3 \sqrt{\frac{\sum_{j=1}^{n} (a_j - \bar{a})^2}{n-1}}, \\
r_b &= \pm 3S_b = \pm 3 \sqrt{\frac{\sum_{j=1}^{n} (b_j - \bar{b})^2}{n-1}}, \\
r_c &= \pm 3S_c = \pm 3 \sqrt{\frac{\sum_{j=1}^{n} (c_j - \bar{c})^2}{n-1}}.
\end{align*}
\]

The procedure is the same as in 1. For each pose \(r\) and angular deviations \(r_a\), \(r_b\) and \(r_c\) are calculated.

3. Examination of the positioning accuracy and pose repeatability of robot REM 10–01

The object of exploration is the manipulation robot REM 10–01 (Fig.4). The regional structure of the robot is type SCARA, \(R \parallel R \parallel T\). The actuators of the rotational pairs are DC motors, and the translational pair is pneumatic with two fixed positions—up and down. For measuring the accuracy of the robot, it is taught for five points, which are in its working field. The working field is defined by the angles \(R_1 - 200^\circ\), and \(R_2 - 155^\circ\), and represents a part of plane, perpendicular of the axes of rotation.

The control system is realised on the basis of the universal controller 84 EA. The controller gives the possibility to control up to four DC servo axes. The method of control is “point to point”. The maximal velocities of the two axes are 0.958 rad/s and 1.57 rad/s.
The experimental device consists of electronic apparatus for linear measurements with analogue output - "TESA MODUL", memorise measuring oscilloscope, camera and personal computer. The oscilloscope is Tektronix 2230, the camera - SHARP 12 and the PC is type 486DX-2/60 with a videoblaster.

The manipulation robot is taught in five points. According to the requirements for carrying out the measurements, the positioning points are forming a square in the working area, as the intersection point of its diagonals is point \( P_1 \). The joint co-ordinates of the taught points are shown in Table 1.

<table>
<thead>
<tr>
<th>Point</th>
<th>Joint Coordinates, rad</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_1 )</td>
<td>1.17  1.79</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>1.06  0.9</td>
</tr>
<tr>
<td>( P_3 )</td>
<td>1.77  0.79</td>
</tr>
<tr>
<td>( P_4 )</td>
<td>2.11  2.236</td>
</tr>
<tr>
<td>( P_5 )</td>
<td>0.345 2.215</td>
</tr>
</tbody>
</table>

They have been executed 30 measurements with maximum load - in this case 10 kg in the taught points. The results for the positioning accuracy are illustrated in tabl. 2. The data, presented in the table are written in \( \mu m \).

<table>
<thead>
<tr>
<th>( \Delta )</th>
<th>( P_1 )</th>
<th>( P_2 )</th>
<th>( P_3 )</th>
<th>( P_4 )</th>
<th>( P_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta L_x )</td>
<td>-8</td>
<td>-5.7</td>
<td>-1.5</td>
<td>1.07</td>
<td>3.46</td>
</tr>
<tr>
<td>( \Delta L_y )</td>
<td>6.9</td>
<td>1.4</td>
<td>-1.1</td>
<td>-1.1</td>
<td>-2.3</td>
</tr>
<tr>
<td>( \Delta L )</td>
<td>10.56</td>
<td>5.78</td>
<td>1.86</td>
<td>2.24</td>
<td>4.15</td>
</tr>
</tbody>
</table>

The obtained data show that the positioning accuracy of the robot is between 0.01 and 0.02 mm.

The measurements for pose repeatability are similar to the positioning accuracy ones and the procedure is the same. According to the equations for the pose repeatability, they have been made calculations after the tests. The results are shown in tabl. 3. The data, presented in the table are written in \( \mu m \).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>( P_1 )</th>
<th>( P_2 )</th>
<th>( P_3 )</th>
<th>( P_4 )</th>
<th>( P_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D )</td>
<td>2.48</td>
<td>1.47</td>
<td>2.16</td>
<td>4.1</td>
<td>2.99</td>
</tr>
<tr>
<td>( S_d )</td>
<td>1.36</td>
<td>0.94</td>
<td>1.05</td>
<td>1.97</td>
<td>1.33</td>
</tr>
<tr>
<td>( r )</td>
<td>6.56</td>
<td>4.56</td>
<td>10.7</td>
<td>2.24</td>
<td>6.98</td>
</tr>
</tbody>
</table>
4. Conclusion

The described experiments are intended for use mainly when checking the individual characteristics of robots and for new constructive solutions as well. The precise determination of the positioning accuracy and pose repeatability under different conditions of work, manipulation of objects with different mass, their positioning in different points of the working area with different velocity, is important in order to define the possibility of application of the robot for proper industrial task.

References

1. ISO/DIS 9283

Точность позиционирования и позиционная повторяемость одного класса технологических роботов

Даниела Таслакова

Центральная лаборатория мехатроники и приборостроения, 1113 София

(Резюме)

В статье обсуждается методика испытаний манипуляционных индустриальных роботов. Методика позволяет определение специфических характеристик роботов, которые воздействуют на их работу, дает способ их определения и процедуры измерения. Исследованы две из самых важных характеристик роботов – точность позиционирования и позиционная повторяемость. В соответствии с предлагаемой методикой исследован манипуляционный робот REM-10-01.