Comparison of position repeatability of a human operator and an industrial manipulating robot

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Abstract

Robot performance criteria of position repeatability are studied. Weight-to-payload ratio is in manipulating robots significantly higher than in human operators. Bracing strategy improving the robot performances is introduced in the paper. The strategy copies human behavior during fine motion operations. A comparison is made between the robot and the human operator performing approximately the same manipulating task. Contactless measurements of position repeatability were accomplished with the OPTOTRAK® motion analysis system. The results of tests demonstrate considerable improvement of robot and human operator’s position repeatability when using bracing. © 1998 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Modern robot manipulators replacing human operator in assembly tasks [1] are usually designed in accordance with the principles encountered in humans and their arms and hands. The main goal of developing a mechanical counterpart to human operator is achieving of improved performances such as speed, payload capacity, position accuracy and repeatability. However, when the loads are not exceeding 3 kilograms, weight-to-payload ratio found in robots is reported to be ten times higher than the same ratio assessed in human operator [2]. The reduction of this ratio is highly related to overall robot efficiency from technical and economical point of view. Traditional principles for improving this ratio are introducing lighter materials [3], new construction solutions and design of new actuators.

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In a special case, it is possible to increase the robot absolute accuracy and repeatability by using appropriate bracing [4]. The method of bracing [5] is a direct copy of human behavior where the adaptation to higher accuracy and repeatability requirements during the fine motion operation is required. A human operator, when performing precise manipulation tasks, often finds supports for his forearm, wrist or elbow like in many working situations watch-makers are practicing. The same simple idea can be transferred into robotics.

Apart from some estimations, there was no explicit comparison made between human operator and adequate robot performances. The aim of this investigation was to make concise technical comparison of robot and human operator performance with and without bracing.

2. Method

Position repeatability tests were performed in accordance with ISO 9283 standard for manipulating industrial robots [6]. The cube with maximum volume was located in the workspace of the most frequent anticipated use. Five points \((P_1–P_5)\) were located on the diagonals of the selected plane as shown in Fig. 1. Contactless OPTOTRAK®/3010 motion analysis system was used for measuring of the actual positions (see Fig. 2). Measurements were taken at the poses \(P_1, P_2, P_3, P_4\) and \(P_5\). The position repeatability expresses the closeness of the attained positions after 30 repeated visits to the same commanded position, as required by the ISO 9283 standard. The repeatability is calculated by the following equations:

\[
r = \bar{D} + 3S_D,
\]

\[
\bar{D} = \frac{1}{n} \sum_{j=1}^{n} D_j,
\]

\[
D_j = \sqrt{(x_j - \bar{x})^2 + (y_j - \bar{y})^2 + (z_j - \bar{z})^2},
\]

Fig. 1. Definition of the measuring points \((P_1–P_5)\) inside the robot workspace.
where $x_j, y_j, z_j$ represent nominal positions, $\bar{x}, \bar{y}, \bar{z}$ mean actual positions and $S_D$ is the positional standard deviation.

The repeatability tests were made for (1) robot, (2) braced robot, (3) human operator and (4) human operator with his forearms braced. In cases (1) and (2) the nominal poses were commanded by the robot program. The same standard requirements were involved in the tests with human operator. The nominal poses were commanded by a wire frame with five ring targets which were positioned into the working space of the operator. The operator held in his hand the same measuring rigid body as the robot. Approximately the same volume of the working space was chosen for the operator as for the robot.

A saddle shaped support body was used in case (2). In case (4) a horizontal bar was used to support the human operator’s forearm. The four measuring situations are shown in Fig. 3.

3. Testing and results

Asea Irb 6 industrial manipulating robot was tested in our experiments. Additional segment was attached to the robot enabling bracing against the support body. For the case (1) (Fig. 3a) the weight of additional segment was 1.65 kg, while in the case (2) (Fig. 3c) it was 2.15 kg. The difference was due to the construction details of a bracing segment. The weight of the measuring rigid body held by human operator was 0.8 kg. Three persons were tested. 5% of the total human operator’s weight was assumed as arm weight. Additional dummy weight with the mass of 0.9 kg was attached to the human’s hand simulating the same tool as held by the robot. Approximate weight-to-payload ratios were (a) free robot 82, (b) human operator 2.4, (c) braced robot 62, (d) human operator with bracing 5.
Fig. 3. Four types of measurements (a) free robot, (b) human operator, (c) braced robot and (d) human operator with braced forearm.

Fig. 4. The results of the repeatability test in free robot and braced robot.
In the next four histograms (Figs. 4 and 5) the results of the position repeatability for the four specified types of testing are presented.

The repeatability of the braced robot as compared to the free robot was improved for approximately 50%. The same improvement in the human operator was for about 25%. Note, that the weight-to-payload ratio for robot was more than $10 \times$ higher than for human operator.

4. Conclusion

Applying bracing strategy during robot manipulation is a copy of human behavior. Position repeatability performance criteria were studied. Repeatability measurements according to ISO 9283 were performed with industrial manipulating robot. For the first time, the same measurement of position repeatability under condition of ISO 9238 standard was used in the test of a human operator performance. The results show significant improvement of position repeatability in cases when the robot and the human operator are braced against the supporting body. The comparative study encouraged researchers for further investigation of bracing strategy [7]. Same approaches to human operator position repeatability assessment could be applied also in ergonomic studies.

5. Summary

The industrial manipulating robots are usually more or less accurate structural copies of human operator’s arms and hands. Structural copying of the natural mechanisms alone does
not always give satisfying results, hence the modern robotic manipulators with maximum rated loads below 3 kg are mechanically inferior to human operators. Bracing strategy which is used for improving particular robot performances is the combination of the structural and functional copying of natural human behavior. A human operator, when performing precise manipulation tasks often finds supports for his forearm, wrist or elbow like in many situations watch-makers are practicing. The same simple idea can be transferred into robotics with the aim of temporarily improvement of robot characteristics such as accuracy, repeatability, stiffness, payload capacity and mechanical vibrations.

The objective of our research was to get concise technical comparison between the robot and human operator’s performances concerning positional repeatability. ISO 9283 standard for manipulating industrial robot performance criteria and related test methods was the basis for the comparative study. The testing equipment was built around the contactless 3-D motion analysis system OPTOTRAK®/3010 (Northern Digital). The position repeatability tests were performed for the robot Asea Irb 6 and the human operator accomplishing similar manipulating task under the same conditions. Human and robot operations in free and braced condition were tested. Position repeatability of the braced robot as compared to free robot was improved for approximately 50%. The same improvement in human operator was about 25%. Weight-to-payload ratio for robot was more than 10\times higher than for human operator. The results of the study encouraged researchers for further investigation of the kinematics of a braced robot. The potential use of the obtained results in ergonomic studies is suggested.

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References

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