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# PERFORMANCE ANALYSIS METHODOLOGY OF A DIDACTIC MANIPULATOR ROBOT

Marconi Silva Vaz de Mello<sup>1</sup>

Walter de Britto Vidal Filho<sup>2</sup>

Universidade de Brasília, Faculdade de Tecnologia, Depto. de Engenharia Mecânica, Brasília-DF.

<sup>1</sup>marvmello@gmail.com, <sup>2</sup>wbritto@unb.br

**Abstract.** *The use of didactic manipulator robots is important in engineering teaching because the use of industrial manipulators presents risks due to their inertia and high speeds. Due to the high costs of imported didactic manipulator robots, manufacturing them in educational institutions became an attractive option. An additional advantage of the design and manufacture of these manipulators in educational institutions is the systematic design research of these systems. After this initial phase, one possible difficulty is to quantify how much the initial design specifications have been achieved. To solve this problem, it is important to use standardized systems to evaluate the performance of the developed manipulators. The present work aims to study the manipulator robots' performance evaluation systematics and to present a procedure for applying the systematic established to the case of a didactic robot.*

**Keywords:** *robot manipulator, performance, methodology.*

## 1. INTRODUCTION

The teaching of manipulator robotics has been growing due to an increased demand for them in companies. The use of industrial manipulators presents a risk due to their great inertia and speeds which can cause severe injuries when it shocks with the human body. In order to avoid this risk, it is important to use didactic robots. The closed architecture of industrial robots makes it difficult to teach. The cost is also a constraint on the employment of an industrial robot in teaching activities. A didactic robot can cost ten times less than an industrial robot.



Figure 1. Prototype of the didactic robot studied and CAD design (Reis et al., 2016)

The industrial robots' standards have been used to analyze didactic robots' performance (Costa Neto et al., 2012). Some standards establish that the evaluation parameters depend on the main manipulator activity, therefore it is necessary to analyze the performance according to the characteristics required for an activity. Usually the industrial robot's standard methods are adapted to didactic robots. In Costa Neto (2012), it was considered that a didactic robot would have the same requirements of an industrial robot to move parts. It is possible to observe the prototype of the didactic robot studied in this paper in Figure 1. It was developed in Reis et al. (2016). This robot has five degrees of freedom. The maximum range obtained is 627 mm. The robot uses three stepping motors, except for the pulse which employs two servomotors. The structure is made of aluminum alloy plates. The present work aims to study the

evaluation method on robots' performance and present a procedure to apply the systematic to the developed didactic robot.

## 2. SYSTEMATICS OF PERFORMANCE ANALYSIS

The systematics to evaluate manipulator robots' performance must follow a reference in order to be able to generate values which serve as parameters of comparison between different manipulators. Some robot manufacturers have developed their own test conditions, while others adopted tests defined in standards such as those established by the American National Standard Institute (ANSI) or those ones defined by the International Standard Organization (ISO). The Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards - ABNT) does not have a specific standard for manipulators' performance analysis, but adopts ISO standards published in this area (Rosário, 2012). None national standard on industrial robots was found in the ABNT website. The main ANSI standards for robots according to (Costa Neto et al., 2012) and (Rosário, 2010) are: American national standards for industrial robots and robot systems - Point-to-point and static performance characteristics - Evaluation (ANSI R15.05-1, 1990) and American national standards for industrial robots and robot systems - Path-related and dynamic performance characteristics (ANSI R15.05-2, 1992). The first standard measures the parameters of the terminal effector in static positions, while the second one measures the dynamic characteristics during the trajectory.

The mains ISO standards, according to Costa Neto et al. (2012) are: Manipulating Industrial Robots – Performance Criteria and Related Test Methods (ISO 9283, 1998) and ISO TR 13309, Manipulating Industrial Robots – Informative Guide on Test Equipment and Metrology Methods of Operation for Robot Performance Evaluation in Accordance with ISO (ISO TR 13309, 1995). The performance analysis results may vary when calculated by one standard or another. The accuracy calculation methodology according to ANSI indicates a greater precision than when calculated by the ISO methodology (Romano, 2002; Rosário, 2010). While the ANSI repeatability calculation presents a lower value than the one calculated by the ISO standard (Romano, 2002; Rosário, 2010). This shows a difficulty in standardizing a performance appraisal. The ISO standards were chosen as guidance because they are adopted by ABNT (Rosário, 2010).

The ISO 9283: 1998 establishes the test conditions. The starting point is a virtual test cube entered in the robot workspace (fig.2), this is the reference for the pose and paths to be used in the test. This cube with sides parallel to the axes of the robot base coordinate system should be located in the most used part of the workspace and should be as large as possible. Instrumentation uncertainty should not exceed 25% of the magnitude of the characteristic being tested.

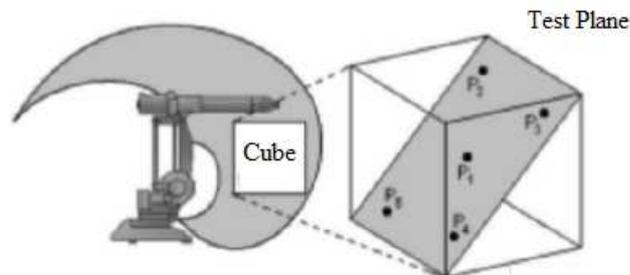


Figure 2. Test cube in robot workspace (Romano, 2002).

The Pose is understood in the ISO standard as the end-effector's spatial position ( $x, y, z$ ) and its orientation (roll, pitch, yaw). Pose accuracy (AP) is the difference between the commanded pose and the average of the attained poses that can be divided into positioning and orientation. Each cycle corresponds to positioning an end-effector point at the cube points from P5 to P1 (fig.2). The standard recommends that 30 cycles should be performed. Pose repeatability (RP) expresses the proximity between the positions achieved for the same commanded pose after several repetitions or cycles. It is given by the radius of the sphere centered on the baricenter of the group of attained points and by the range of three standard deviations ( $3\sigma$ ) of angular measurements around the average values of the orientation angles. Distance accuracy (AD) and repeatability (RD) quantify, respectively, the error in the distance between command pose and attained postures, and fluctuations in the distance for a series of repeated movements between the two postures. For this test, positions P2 and P4 in the cube were used. The minimum posing time is another variable that corresponds to the time between the end-effect leaving one pose and reaching another pose. Stabilization time is characterized by how quickly the robot can stop in an attained pose. Position Overshoot measures the robot's ability to make smooth and precise stops at the attained poses, measures the maximum oscillation length of the end-effector when it reaches the commanded pose. Static flexibility corresponds to the displacement of the effector when subjected to workload.

### 3. EXPERIMENTAL ANALYSIS

Several measurement techniques and devices can be used, depending on the desired tests, according to the ISO standards. For static measurements, the following systems can be used in addition to the devices for dynamic measurements:

- Cube-cradle sensor system;
- Tracking laser system;
- Laser scanning system;
- Digital theodolite system;
- Two-camera imaging system;
- Inertial system;
- Coordinate measuring machine system; and
- Measuring arm system.

Coordinate's measuring machines, as shown in fig. 3, have already been employed to measure the performance of didactic robots (Costa Neto, 2012). These machines greatly limit the volume that can be analyzed in the robot's workspace.



Figure 3. Coordinate Measuring Machine (MMC, 2018).

The Metrology Laboratory of the University of Brasília (UnB) has a coordinate measuring machine, as used in Costa Neto et al. (2012), however it was decided to use a coordinate measuring arm (fig.4), because it was observed that a measuring arm allows measurements at some points difficult to reach by a Cartesian machine. The available measuring arm is Romer © (fig. 4).

The characteristics of this arm are probing error uncertainty of  $\pm 16 \mu\text{m}$ , uncertainty of volumetric measurement of  $\pm 60 \mu\text{m}$  and 6 mm probe diameter.



Figure 4. Coordinate Measuring Arm.



The software used on the measuring arm allows a point, line and plane to set a new coordinate axis for reference. Thus, points belonging to the robot's base plane were selected, so that the reference for measurement is the same used in the manipulator modeling. This facilitates data handling to obtain performance characteristics. The didactic robot was placed on a level table in the metrology lab, as well as the measuring arm. The coordinate systems were adjusted. The coordinates of the cube points P1 to P5 were calculated within the manipulator workspace according to the guidelines of the ISO standard.

#### 4. RESULTS ANALYSIS

The following equations are used in the calculation of accuracy and repeatability of pose according to ISO 9283. The ISO standard establishes that for each posture acquired, a measurement must be performed, however due to the technical constraints, only 1 measurement every 5 cycles has been performed.

$$AP_p = \sqrt{(AP_x)^2 + (AP_y)^2 + (AP_z)^2} \quad (1)$$

$$AP_x = \bar{x} - x_c \quad (2)$$

$$AP_y = \bar{y} - y_c \quad (3)$$

$$AP_z = \bar{z} - z_c \quad (4)$$

Where  $\bar{x}$ ,  $\bar{y}$  and  $\bar{z}$  are the means of the positions obtained and  $x_c$ ,  $y_c$  and  $z_c$  are the positions commanded. The repeatability of the positioning is calculated as:

$$RP_l = \bar{l} + 3S_l \quad (5)$$

$$\bar{l} = \frac{1}{n} \sum_{j=1}^n l_j \quad (6)$$

$$l_j = \sqrt{(\bar{x} - x_j)^2 + (\bar{y} - y_j)^2 + (\bar{z} - z_j)^2} \quad (7)$$

$$S_l = \sqrt{\frac{\sum_{j=1}^n (l_j - \bar{l})^2}{n - 1}} \quad (8)$$

The accuracy and the distances repeatability are calculated, respectively, as:

$$AD_p = \bar{D} - D_c \quad (9)$$

$$RD_p = \pm 3 \sqrt{\frac{\sum_{j=1}^n (D_j - \bar{D})^2}{n - 1}} \quad (10)$$

Where  $\bar{D}$  is the average of the distances obtained,  $D_c$  is the distance commanded and  $D_j$  is the  $j$ th is the distance obtained. Similarly, accuracy and repeatability orientation are calculated:

$$AD_b = \bar{b} - \theta_b \quad (11)$$

$$RD_b = \pm 3 \sqrt{\frac{\sum_{j=1}^n (D_{bj} - \bar{D}_b)^2}{n - 1}} \quad (12)$$

The table 2 shows the results of tests performed for accuracy and repeatability, values are expressed in millimeter and degrees.

Table 2. Accuracy and repeatability

Pose	Pose accuracy [mm]	Pose repeatability [mm]	Orientation accuracy [°]	Orientation repeatability [°]
P5	$AP_y = 2.2189$ $AP_x = -0.3811$ $AP_z = -1.405$ $AP_z = 2.1858$	RP = 23.7215	$AP_\theta = 1$	$RP_\theta = \pm 2.76$
P4	$AP_y = 3.6637$ $AP_x = -2.323$ $AP_x = 2.3957$ $AP_z = 1.5093$	RP = 33.992	$AP_\theta = 0.14$	$RP_\theta = \pm 4.01$
P3	$AP_y = 7.4497$ $AP_x = 0.7953$ $AP_x = -7.0515$ $AP_z = 2.2679$	RP = 39.9517	$AP_\theta = 3.28$	$RP_\theta = \pm 5.18$
P2	$AP_y = 4.0306$ $AP_x = -1.8179$ $AP_x = -2.7942$ $AP_z = 2.2679$	RP = 43.1565	$AP_\theta = 3.28$	$RP_\theta = \pm 5.18$
P1	$AP_y = 2.5745$ $AP_x = -1.4335$ $AP_x = 3.0591$ $AP_z = -1.7517$	RP = 37.2627	$AP_\theta = 6.71$	$RP_\theta = \pm 5.18$

The table 3 presents the results of accuracy and repeatability distance tests. These values measure the error in the commanded distance and measured between two poses.

Table 3 - accuracy and repeatability distance test results

$AD_\theta$ [mm]	$RD_\theta$ [mm]	$AD_b$ [°]	$RD_b$ [°]
19.5804	28.1406	2	0.82

The Minimum posing time and Static Compliance were also measured.

Table 4. Static compliance

	+x	-x	+y	-y	+z	-z
<b>Distance [mm]</b>	8,413951	8,344464	7,080973	7,888557	8,690022	10,38052

To obtain the displacements due to Static Compliance, a force equivalent to the workload was employed in the three coordinates (x, y, z). The Table 4 show that Robot stiffness is low, which results in a high displacement when subjected to load. This rigidity is not only due to the structure, but also due to the transmission elements and actuators.

## 5. CONCLUSION

Difficulties to apply the ISO standard to evaluate the performance of a didactic robot were observed. One difficulty is to use the measuring system to measure the parameters according to the adopted standard. It was observed that the manipulator developed in Reis et al.(2016) did not achieve the expected performance. The robot has a satisfactory accuracy for didactic applications in the accuracy test, between 2 and 7 mm. However its repeatability represents a dispersion of the measurements in a very large radius, between 23 and 43 mm. The results obtained in Costa Neto et al. (2012) show an accuracy of 7.5 mm and a repeatability of 2.78 mm. The robot studied in Costa Neto et al. (2012) is a robot manufactured by a specialized company, while the robot studied in this paper is a robot manufactured in the UnB educational institution. A comparative study allows some conclusions. A good accuracy indicates that the kinematic modeling and the control system were done correctly, however the low repeatability indicates errors mainly in its assembly or manufacture, mainly in the mechanical system (structure, transmission elements and actuators). A more detailed analysis of the structure and transmission element will be done in future work. However, backlash in the transmission elements are the main causes of low repeatability. The studied robot can be used in didactic applications, despite the low repeatability, because the principal activity studied is handling. For teaching applications it is important to use lower cost measuring techniques and devices. A future work to be done is the development of a systematic approach that employs a low cost measuring device that meets the degree of precision to be measured.

## 6. ACKNOWLEDGEMENTS

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## 8. RESPONSIBILITY NOTICE

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