TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special II, April, 2024

EXPERIMENTAL RESEARCH ON POSITIONING ACCURACY OF EDUCATIONAL ROBOTS

Dragos-Florin CHITARIU, Teodora-Maria AGACHE, Cătălin-Gabriel DUMITRAS, Mihăiță HORODINCĂ. Florin-Daniel EDUTANU, George-Gabriel CHIRIAC

Abstract: *The aim of the paper is to develop and test an adapted programming methodology for educational robot, for reducing positioning deviations. Experimental work was performed on determining the main precision characteristics of educational robots, which also are applied to industrial robots. There are few tools available to the robot user to improve accuracy. A programming methodology was proposed and the positioning accuracy on the X axis was measured with a laser interferometer. In addition, an own procedure was created to compensate for positioning deviations and introduce them into the programming process. Form the performed experiment resulted that cross-direction compensation reduces positioning errors. After the robot compensation, the positioning accuracy improves but the repeatability remains at closed values.*

Key words: *positioning accuracy, repeatability, industrial robot.*

1. INTRODUCTION

Industrial robots show a high flexibility in terms of end effector manipulation, but with a high capacity to reach all points in the precise and repeatable workspace [1, 2]. Among the main uses of industrial robots we mention: general material and parts transfer, such as parts, tools, injection molding, stamped parts in order to transfer or stack and more complex operation that include welding, grinding, deburring, and assembly [1, 2]. Other operation performed by robot include 3D printing mainly in construction field [3], typical machining applications such milling or grinding using various spindle attachments [5, 6, 7]. 3D printing of small construction with the help of robot can be feasible and the entire construction is made by continuous concrete pouring and in this case the tolerances are usually in centimetres on the other hand in the case of CNC machining, parts the tolerances are in micrometers. An area of machining where robots can present advantages over CNC machines is the machining of large parts, where robot flexibility, ease of deploy and cost are superior to CNC machine.

When using robots for machining the inherit problem of the low stiffness occurs and it can amplify the effect of chatter. The rigidity of a robotic arm is depended of the arm kinematics, considering also the tolerances from machining and assembly, joint rigidity from backlash and flexure in the gears link rigidity affected by the flexure of the arm castings [2, 10, 11].

Performance of the industrial robots can be assessed by using the International Standard ISO 9283: 1998 were the following elements are analyzed: pose accuracy and repeatability of the robot, pose accuracy variability of different directions, path length accuracy and repeatability weaving deviations [8]. The precision of the industrial robot refers to the rate of obtaining the position of the end effector in a programmed point in its workspace. The industrial robot accuracy repeatability refers to the capability of the robot to reach a programmed point over and over again [1].

Robot performance is indicated by the accuracy and repeatability.

The accuracy of a robot can be affected by computational errors, robots components machined accuracy, elastic deformations of links under gravitational and workloads, gear backlash, thermal effects, wear, joint transducer errors, and other static and dynamic effects [1, 2, 13].

Industrial robot repeatability is dependent of the resolution of the controller, referring to smallest displacement, linear of rotation, which can be detected [1]. The industrial robot resolution depends on robots control system. It is related to the smallest increase in motion that may be achieved by the robot.

Control resolution is refers to the smallest variation of displacement that can be detected by the encoders [14 -15].

In industrial robotics domain, the repeatability is used only with the meaning of unidirectional repeatability - the robot capacity to return to previous position on the identical direction in order to reduce the effect of backlash. In nominal values the multidirectional repeatability can have double the values of the unidirectional repeatability [9, 10, 11, 12]. Also, the value of repeatability can be affected by thermal expansion and in some cases robots must be pre-warmed before operation, Vocetka determined that repeatability can be approximately 25 μm at any temperature with proper compensation and without approximately 200 μm [11].

The largest effect of a robot's accuracy comes from length of the robot links and the tolerances involved. The difference between the zero positions of the kinematic coupling reported by the robot controller and the reached zero position has an effect on the accuracy of the robot [16]. For some industrial robots the repeated positioning accuracy can even reach 0.01 mm and the absolute positioning accuracy (APA) can be beyond 1 mm or worse [7].

Alongside research focus on the evaluation of precision considering the mechanical construction industrial robots, the different compensation methods are used to program and adapt the robot trajectory usually be employing offline programming software. Machine learning is considered a viable alternative being an adaptive method for compensating for positioning errors and reducing vibrations [16].

Positioning performance evaluation of robots or machine tools is difficult to accomplish and can be done with only with high performance measuring systems. Some basic tests can be accomplished with common indicator gauges and reference or tooling ball [17]. In robot calibration the accustomed measuring equipment is the laser tracker [17, 18, 19] and some particular cases laser interferometer or machine tool probes [20]. Also, special measuring equipment’s can be adapted for robot use, such as ball bar measuring fixture, usually used in machine for machine tools precision measurements [22].

The laser tracker operation is fast and reliable, by using Spherically Mounted Retroreflector (SMR) on the robot flange the tracker can determine distance with angles and data position in the robot work space [22, 23].

The volumetric accuracy and repeatability of laser trackers is reduces compared to the very precise laser interferometer that is the standard in machine tool calibration an verification. However, this type of measuring instrument is not presented in the ISO 9283 standard [8, 14, 13,].

According to Slamani a laser interferometer can be used to evaluate the linear repeatability of industrial robot [10, 15].

A series of researchers use a laser interferometer in order to evaluate alternating linear precision (3 paths) and perform bidirectional tests [16, 17, 18].

The aim of the paper is to develop and test an adapted programming methodology for educational robot, with stepper motor and reduced number of joints, for reducing positioning deviations. The proposed programming methodology is verified by experiments.

2. MATERIALS AND METHODS

The robot used in this work is a Dobot Magician (model DT-MG-4R005-02E), manufactured by Shenzhen Yuejiang Technology Co., Ltd. It was designed to play the role of an industrial robot but on a much smaller scale, so that it can be used on the desk, having a bearing load of 500 grams and a repeatability of ± 0.2 mm.

The joint J1, J2 and J3 are rotational and control the position of point R, and their positive direction is clockwise. If a servo end effectors is installed (such as a vacuum suction cup) then the Dobot acquires a 4th axis of rotation, J4, which is used to control the azimuth of the P point of the pivot, as presented in figure 2. J4 is always kept on the vertical axis [20, 21].

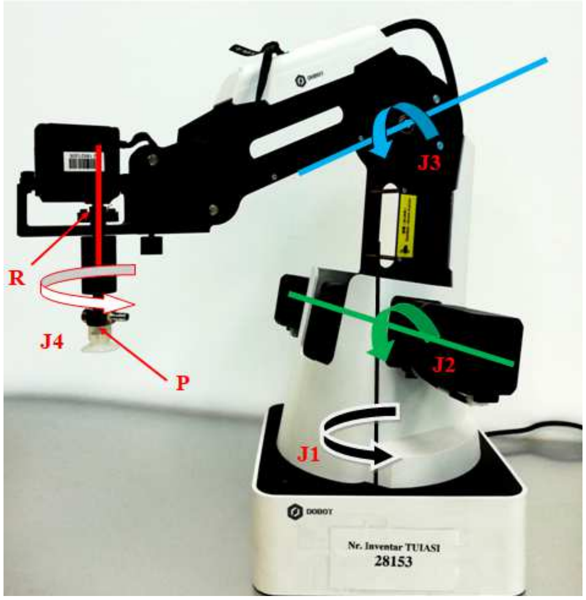

Fig.1. The local coordinate system and the rotation axes

In this paper the Renishaw XL-80 laser interferometer is used in order to determine and analyze the parameters that indicate the precision of the robot such as: Repeatability and one-way positioning precision on x (Rp_x, Ap_x) and Repeatability and one-way accuracy of positioning distance on x (RD_x, AD_x).

The Renishaw XL-80 laser interferometer is mostly used for machine tools calibration. The system consists of the XL-80 laser unit, the XC-80 environmental compensation unit (temperature, humidity, pressure) and optical accessories.

The laser measuring beam that comes out of the Renishaw XL-80 laser interferometer (1) it reaches the beam splitter and is split into two: a reflected beam, with a fixed length, and a transmitted beam, with a variable length. The two beams are reflected back through the splitter in order to form an interference beam at the detector, which is found within the laser head. The only moving element is the reflector (2), which will be mounted on the flange of the robot (3), as presented in figure 2.b.

If the optical path difference varies, the sensor captures a signal that sweeps between the extremes of constructive and destructive interference. These variations (fringes) are counted and used to determine the change in variation between the two path lengths. The length measured by the detector obtained by the number of fringes read and multiplied by half the approximate wavelength of the laser beam 0.317 um (0.000317 mm), this setup remains unchanged during the experiments [21].

A setup for measuring linear displacements used in own experiments is presented in figure 2.

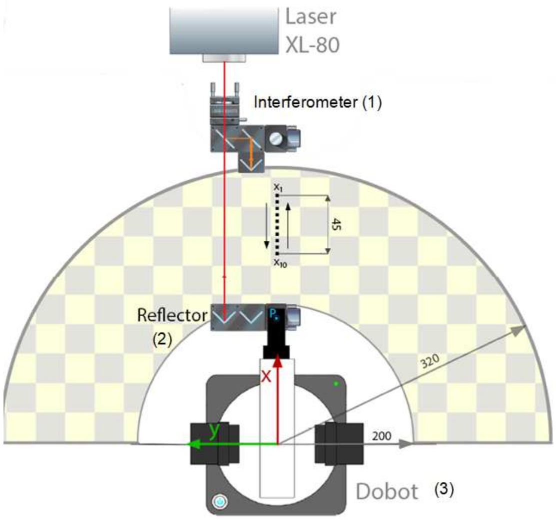

Fig.2. Positioning of the robot and Renishaw equipment to perform a linear measurement on the X-axis, bi-directionally, through 10 points

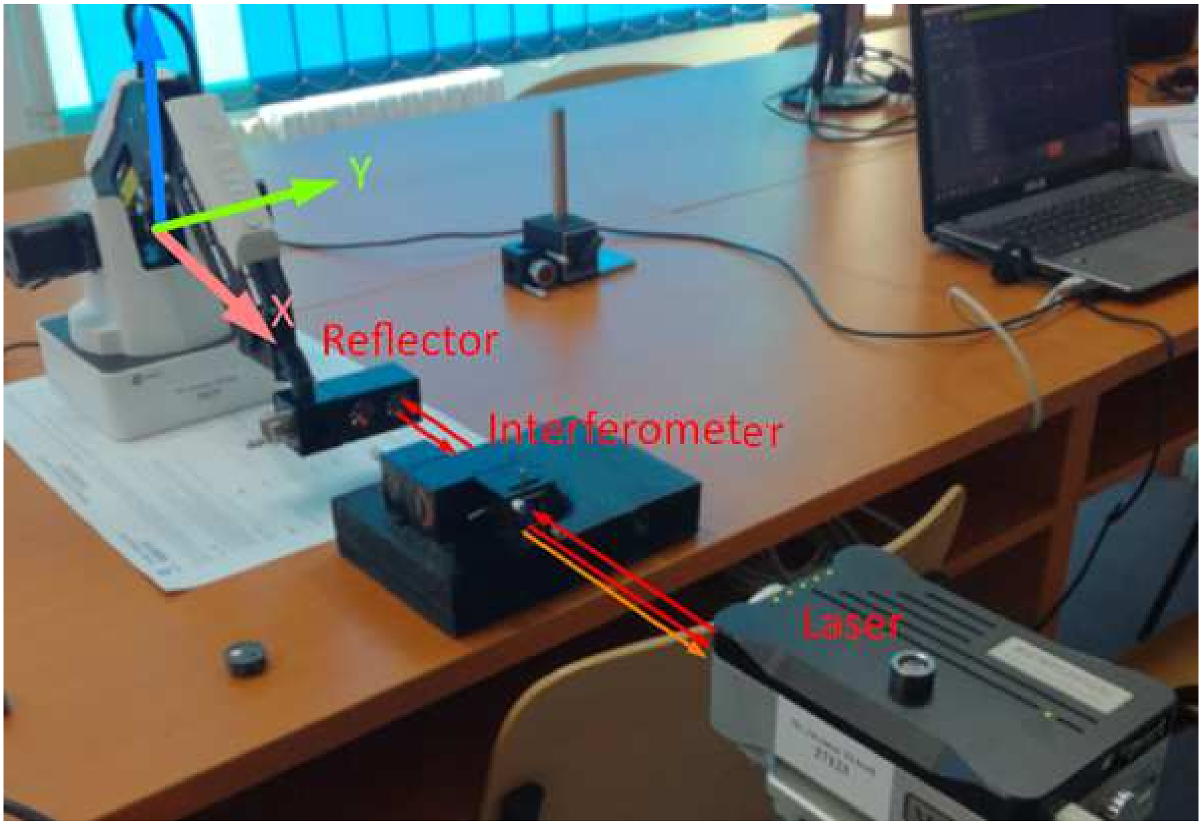

Fig.3. View of the experimental setup

The definition of the starting position was determined by the size of the measuring equipment used and the work space of the robot. In the experiments the robot will perform a bidirectional linear path 5 times, stopping at 10 target points, spaced by 5mm offset, with a 376 gram workload (moving optical element and clamping block), the measuring cycle is presented in figure 4.

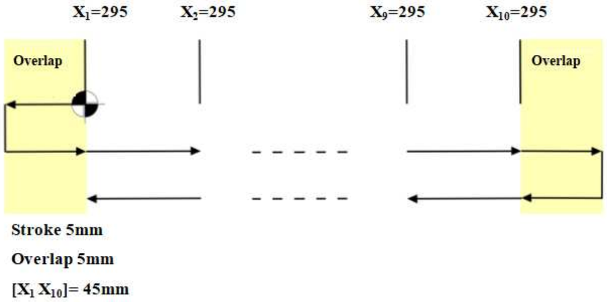

Fig.4. A directional measuring cycle in 10 points

Setting the origin is done so that the reading on the Renishaw for the first coordinate corresponds to the one on the Dobot, in this case it is x1 = 295 ordered. Starting from the origin, the robot will perform a 5 mm overshoot movement towards the laser and back towards target 1, thus triggering automatic target registration in the Carto Capture program.

Passing through each target will be accompanied by a 10 second waiting period, during which the laser beam stabilizes and the actual measurement is performed. In this case a period of 10 second is considered sufficient to cover both robot relaxation time and laser beam stabilization. From previous test a minimum time period for robot stabilization is 3.5 seconds. The robot relaxation time is similar to the research performed by Stryczek [22].

A view of the measuring point distribution on X axis is presented in figure 4.

The experimental methodology used to perform the experiment is presented in figure 5.

In this paper, manual levelling calibration was used, in order to achieve best possible positioning accuracy.

Table 1.

Environmental conditions

Temperature	26 ˚C
Pressure	1007 mbar
Humidity	52 %RH

Environmental conditions during the experiments were recorded by the XC 80 compensator with Carto Capture software and presented in table 1.

The movements of the educational robot can be controlled and edited from a computer that uses a Dobot Studio software interface. The available features are teaching and playback and also the option to run of a script written in Python visual programming language using Blockly programming platform.

Blockly is a programming platform based on Google Blockly that uses puzzle-like elements to combine sequences of instructions to build a program.

The Blockly module is accessed from the Dobot Studio program.

Position accuracy is the difference between a commanded position and the average of positions reached when attempting to approach the commanded position from previous direction.

Position accuracy is divided into:

a) positioning accuracy - the difference between the point of a control point and the barycentre of the achieved positions.

b) orientation accuracy – the angular variation between the orientation of a commanded position and the average of the achieved orientations.

In compliance with ISO 9283, the positioning accuracy is calculated as:

$$AP_p = \sqrt{(\bar{x}-x_c)^2 + (\bar{y}-y_c)^2 + (\bar{z}-z_c)^2} \qquad (1)$$

Where, (x_c, y_c, z_c) are the target coordinates, $(\bar{x},\ \bar{y},\ \bar{z})$ are the average positions achieved. Each of the positions should be reached using a one-way approach.

The repeatability of the positions expresses the degree of closeness between the positions reached after n repeated positioning cycles at the same commanded position on the same working direction.

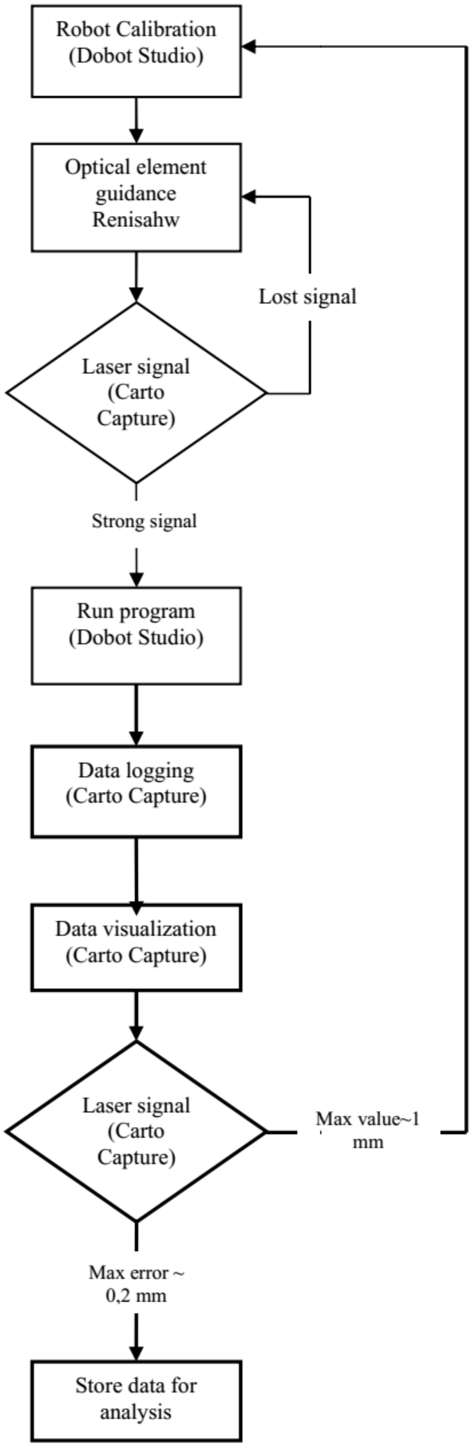

Fig.5. Experimental methodology used to perform the experiment

In compliance with ISO 9283, the positioning repeatability is calculated as:

$$RP_l = \bar{l} + 3S_l \qquad (2)$$

$$\bar{l} = \frac{1}{n}\sum_{i=1}^{n} l_i S_l = \sqrt{\frac{\sum_{i=1}^{n}\left(l_i - \bar{l}\right)^2}{n-1}} \qquad (3)$$

$$l_i = \sqrt{\left(x_i - \bar{x}\right)^2 + \left(y_i - \bar{y}\right)^2 + \left(z_i - \bar{z}\right)^2} \qquad (4)$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i, \bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i, \qquad (5)$$

Given that the command positions are P_{c1}, P_{c2} and the obtained positions are P_{1j}, P_{2j} the positioning distance precision is the distance difference between P_{c1}, P_{c2} and P_{1j}, P_{2j} and the distance repeated n times.

$$AD_x = \overline{D_x} - D_{cx} \qquad (6)$$

$$\overline{D_x} = \frac{1}{n}\sum_{j=1}^{n} D_{xj} \qquad (7)$$

$$D_{xj} = \left|P_{ij} - P_{2j}\right| = \sqrt{\left(x_{ij} - x_{2j}\right)^2} \qquad (8)$$

$$D_{cx} = \left|P_{c1} - P_{c2}\right| = \sqrt{\left(x_{c1} - x_{c2}\right)^2} \qquad (9)$$

Where x_{c1}, x_{c2} are the coordinates of the point P_{c1}, P_{c2}, x_{1j}, x_{2j} are the coordinates of the point P_{1j}, P_{2j}, n is the number of repetitions.

Where (x_i, y_i, z_i) are the "i" positions reached$(\bar{x}, \bar{y}, \bar{z})$are the average of the positions and S_l is the standard deviation from "l".

Positioning distance accuracy

The positioning distance accuracy represents the orientation and position deviation from the imposed distance and the average values of the achieved distances.

3. RESULTS

Our experiment was performed two hours after starting the robot and involved the use of the XC 80 compensator. The calibration of the robot was carried out according to the specific methodology of the Dobot Studio software for the orientation of the robot flange so that it is parallel to the XY plane. The feed rate of the robot was set to 50% and 100% respectively.

Results of bidirectional X-axis measurements under different compensation conditions

In our experiment a position offset was performed at each target point, using the average of the position errors, and as seen in the figure below, we obtained 3 sets of graphs, labelled A, B and C in figure 6 :

- Values Set A- No compensation.
- Values Set B - Bi-directional compensation: the average of the bi-directional positioning errors at the target points was introduced.

Thus, we managed to reduce the positioning errors obtained for a second set of measurements. As in the previous figure, the difference between the two runs in different directions remains, having a close value (~63µm).

- Values Set C- One-way compensation: the average of the one-way positioning errors, at the target points, has been introduced:
  - o for the movement in the positive direction of the X-axis,
  - o for the movement in the negative direction of the X-axis.

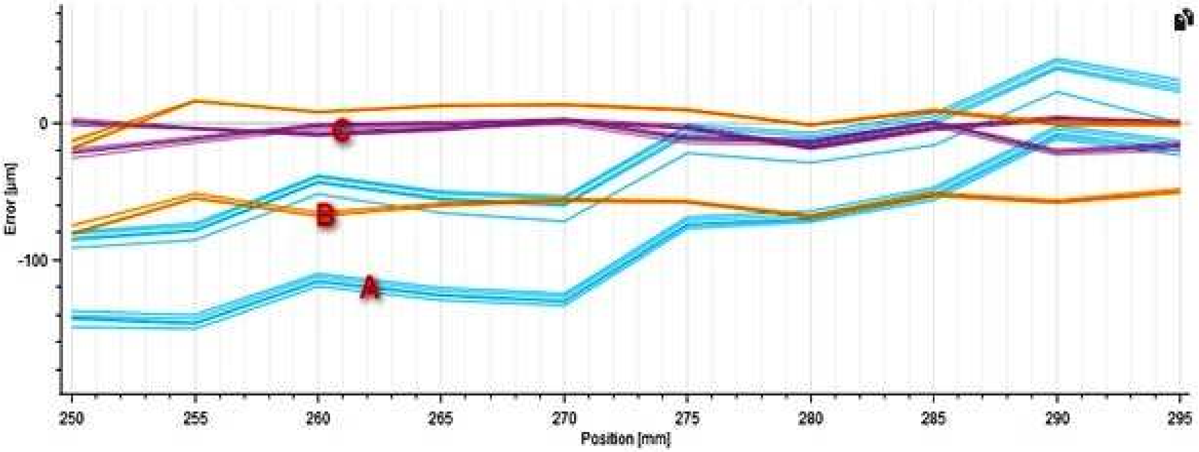

Fig.6. Results of bidirectional X-axis measurements under different compensation conditions

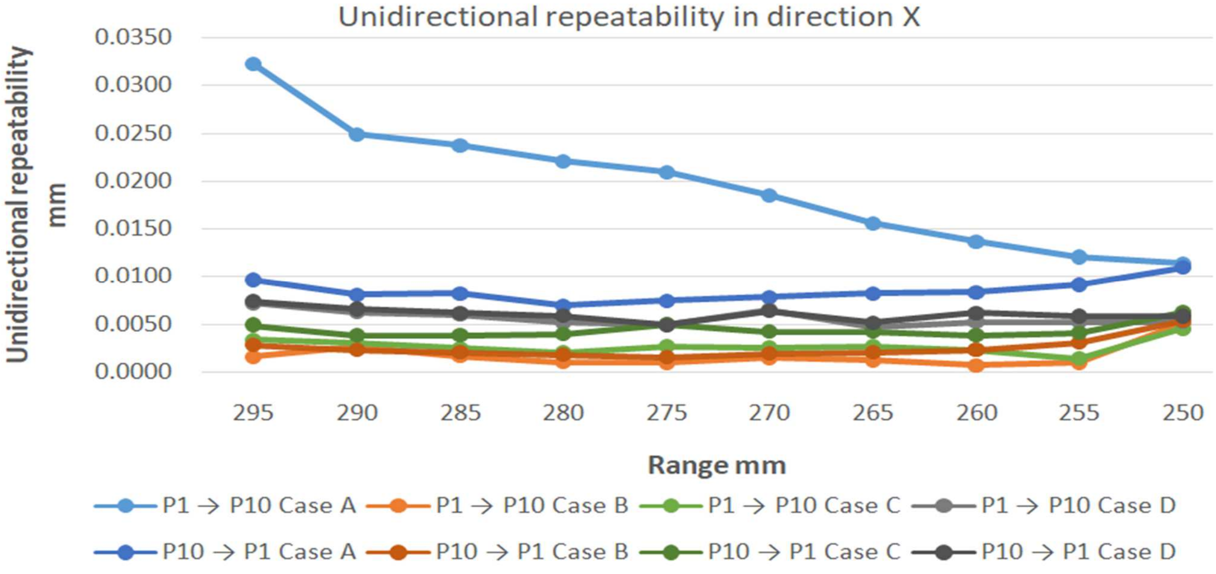

Fig.7. Results of Unidirectional repeatability Rp in direction X, before and after compensation

The graph from figure 7 presents the one-way repeatability Rp values for both directions. The graphs form figure 7, for unidirectional Rp, confirm that better values are obtained for the direction P10 → P1 (Robot→Laser), the best values being for the 50% feed rate in both directions.

In this case, the data were recorder for the target points P1 and P10, under the test conditions specified in table 2, and were used for the calculation of positioning accuracy and repeatability.

Table 2.

Testing parameter for positioning distance accuracy

Load	Feed rate	Positions	Number of repetitions
75.2 %	50%	P_1, P_{10}	30

If it is considered that n=60, which is 30 bidirectional repetitions; thus we obtain the following values for positioning distance precision AD_x and positioning distance repeatability RD_x. The calculated values are:

$AD_x = 116.9\ \mu m$, $RD_x = 19.8\ \mu m$.

Unidirectional positioning repeatability has much closer values at 50%, 100% feed, but not at 20% feed where the extremes are 10.6 µm (for the negative X-axis direction) and 3.9 µm (for the positive X-axis direction).

The calculated Backlash has values of approximately 63 µm.

The bidirectional compensation reduced the positioning errors, the difference between the two runs in different directions remains, having a close value (~63µm).

Cross-direction compensation reduces both positioning errors and backlash. After the robot compensation, the positioning accuracy improves but the repeatability remains at close values.

The drift of the end effector is observed in the positive direction of the X axis, at each unidirectional run, at the advance of 50%, between two points, on the interval of 45 mm.

The accuracy of the positioning distance is 116.9 µm and the repeatability of the positioning distance is 19.9 µm

The experiments described illustrate two aspects of precision that are common to most manipulators. First, the repeatability of the manipulator is very good compared to the positioning accuracy, and according to Mooring, it is not unusual for the positioning accuracy to be much lower than repeatability. Second, repeatability has a constant value throughout the imposed path, while positioning accuracy can vary significantly [23].

4. CONCLUSIONS

The accuracy and repeatability of a robot are difficult to determine because of computational errors or mechanical errors that characterize the components found in the robot structure.

The proposed method allows making linear measurements, on the direction of the X-axis and on the direction of the Z-axis. The Y-axis cannot be approached because the end effector of the robot keeps its coordinates on the Y-axis but not the orientation.

After robot calibration: the positioning accuracy improves considerably from ~1.2 mm to ~0.2 mm for the cases where the feed rate is 50% and 100%, respectively. After robot calibration, unidirectional repeatability improves for a 50% feed rate, from 5.1 - 5.5 µm to 2.2 - 1.8 µm, respectively.

After robot calibration, unidirectional repeatability for 100% feed does not show drastic changes from 5.7 - 6.1 µm to 6.6 - 5 µm, respectively. The best repeatability values are obtained in the direction P10 → P1, i.e. on the positive direction of the X-axis, at 50% feed.

From the graphs presented, the positioning accuracy improved but the repeatability remained at close values. The experiments described above illustrate two aspects of precision that are common to most manipulators.

First of all the repeatability of the manipulator is very good compared to the positioning accuracy and the positioning accuracy is found to be to be much lower than the repeatability.

The proposed compensating method managed to reduce by 96% the positioning error obtained for a second test after compensation, on a reduce federate, from 1.2 mm to 0.2 mm for a feed rate of 50%. For a feed rate of 20% the best positioning accuracy is obtained.

The proposed measuring method allows performing linear measurements, on the X axis and on the Z axis, a different laser reflector can be used to perform angular measurements.

In the future a more complex compensating algorithm will be employed to determine the educational robot trajectory accuracy.

5. REFERENCES

[1] Spong, M. W., Hutchinson S., Vidyasagar M. *Robot Modeling and Control,* 1st ed.; ISBN: 978-1-119-52404-5, John Wiley & Sons, Inc., , U.S., 2006.

[2] Bruno, S., Sciavicco, L., Villani, L., Oriolo, G. *Robotics Modelling, Planning and Control*, Springer-Verlag London, ISBN 978-1846286414, UK, 2009.

[3] Zhang, X., Li M., Lim, J., H., Weng, Y., Wei Y., Tay D., Pham, H., Pham, Q.-C. *Large-scale 3D printing by a team of mobile robots,* Autom. in Construction, Elsevier, pp. 98–106 , 10.1016/j.autcon.2018.08.004 95, 2018.

[4] Leonesio, M., Villagrossi, E., Beschi, M., Marini, A., Bianchi, G., Pedrocchi, N., Molinari, L., Grechishnikov, V., Ilyukhin, Y., Isaev, A. *Vibration Analysis of Robotic Milling Tasks*, Procedia CIRP, 67, Elsevier, pp. 262-267, 10.1016/j.procir.2017.12.210, 2018.

[5] Gao, Y., Gao, H., Bai, K., Li, M., Dong, W. A *Robotic Milling System Based on 3D Point Cloud*, Machines, 9, 355, pp. 1-20, MDPI, https://doi.org/10.3390/machines9120355, 2021.

[6] Verl, A., Valente, A., Melkote, S., Brecher, C., Ozturk, E., Tunc, L. *Robots in machining,* CIRP Annals, 68, 2, .https://doi.org/10.1016/j.cirp.2019.05.009, 2019.

[7] Chen. Y., Dong F. *Robot machining: recent development and future research issues*, Int J Adv Manuf Technol, Springer, pp. 489–1497,10.1007/s00170-012-4433-4, 2013.

[8] International Standard ISO 9283: 1998 - *Manipulating industrial robots — Performance criteria and related test method.*

[9] Gursel, A., Shirinzadeh B. *A systematic technique to estimate positioning errors for robot accuracy improvement using laser interferometry based sensing,* Mech. and Machine Th., 40, 8.Elsevier, pp. 879-906, https://doi.org/10.1016/j.mechmachtheory.2004.12.012, 2005.

[10] Slamani, M., Nubiola, A., Bonev, I. *Assessment of the Positioning Performance of an Industrial Robot.* Ind. Robot. Int. J. Robot. Res. Appl., Emerald, pp. 57–68, 39. 10.1108/01439911211192501, 2012.

[11] Vocetka, M., Bobovský, Z., Babjak, J., Suder, J., Grushko, S., Mlotek, J., Krys, V., Hagara, M. *Influence of Drift on Robot Repeatability and Its Compensation.* Appl. Sci., MDPI, pp. 1-15, https://doi.org/10.3390/app112210813, 2021.

[12] Chen, T.; Lin, J.; Wu, D.;Wu, H. *Research of Calibration Method for Industrial Robot Based onError Model of Position.* Appl. Sci., 11(3), MDPI, pp. 1-15, https://doi.org/10.3390/app110312872021,

[13] Bucinskas, V., Dzedzickis, A., Sumanas, M., Sutinys, E., Petkevicius, S., Butkiene, J., Virzonis, D., Morkvenaite-Vilkonciene, I. *Improving Industrial Robot Positioning Accuracy to the Microscale Using Machine Learnin g Method.* Machines MDPI, pp. 1-15, 10 (10), 940; https://doi.org/10.3390/machines10100940. 2022.

[14] International Standard ISO/TR 13309. *Manipulating Industrial Robots – Informative guide on test equipment and metrology methods of operation for robot performance evaluation in accordance with* ISO 9283. 1995.

[15] Slamani, M., Nubiola, A., Bonev, I.A. *Modeling and Assessment of the Backlash Error of an Industrial* Robot. Robotica, Cambridge University Press, pp. 1167–1175 https://doi.org/10.1017/S0263574711001287, 2012.

[16] Bleicher, F., Puschitz, F., Theiner, *A. Laser Based Measurement System for Calibrating Machine Tools in 6 DOF.* In R. Neugebauer (Ed.), Parallel Kinematic Machines in Research and Practice, pp. 617–634, Verlag, http://hdl.handle.net/20.500.12708/65454, 2006.

[17] Garnier, S., Subrin,K., *A metrological device for robot identification*, Rob. and Comp.-Integ. Manuf., Elsevier, 73, 10.1016/j.rcim.2021.102249, 2022..

[18] Sanjuan De Caro JD, Rahman M, Rulik I.; *Forward kinematic analysis of Dobot using closed-loop method.*, IAES Int J Robot Autom., pp. 153-160, IJRA, IAES, http://doi.org/10.11591/ijra.v9i3.pp153-159, 2020.

[19] *Dobot Magician User Guide 2020,* Issue: V1.9.0, Shenzhen Yuejiang Technology Co., Ltd., China, https://www.dobot-robots.com/service/download-center .

[20] Wu, L., Yang, J., Zhang, X., Chen, Y. *Multi Manipulator Cooperative 3D Printing Based on Dobot Manipulator,* IOP Conf. Series. Ma. Sci. and Eng., , Iss. 4.10.1088/1757-899X/382/4/042040, Bristol, 382, 2018

[21] XL80 training manual (Part 1) 2008., H-2000-1096-01-A, Renishaw plc., New Mills, UK, https://www.renishaw.com/resourcecentre/en/details/User-guide-XL-80-laser-system.

[22] Stryczek R., Dutka P., *The analysis of signal disruptions from an optical triangulation measurement sensor*, MAM, 10.14313/PAR_222/59 , Vol. 62, No. 02, 2016.

[23] Mooring, B., Roth ZS, Driels MR. *Fundamentals of manipulator calibration.* Wiley, 0-471-50864-0, New York, 1991.

Cercetări experimentale privind precizia de poziționare a roboților educaționali

Obiectivul lucrării este realizare și verificarea unei metodologii de programare a roboților educaționali pentru reducerea erorilor de poziționare. Determinările experimentale au urmărit creșterea poziției de poziționare a roboților educaționali și s-au utilizat metodele de testare folosite pentru roboții de uz industriali. Metodele de testare a precizie de poziționare necesita echipamente foarte complexe și scumpe. În cadrul lucrării s-a propus o metodologie de programare proprie și s-a determinat precizia de poziționare pe axa X, folosind un interferometru laser. Suplimentar s-a realizat o procedură proprie de compensare a abaterilor de poziție prin considerarea acestora în procesul de programare a robotului. Din analiza rezultate experimentale reiese că compensare bidirecțională reduce eroarea de poziționare. După realizarea procedurii de compensare are loc o creștere a preciziei de poziționare dar repetabilitate nu se îmbunătățește peste un anumit nivel.

Dragos-Florin CHITARIU, PhD Associate Professor, Faculty of Machines Manufacturing and Industrial Management; "Gheorghe Asachi" Technical University of Iasi, 700050 Iasi, Romania, dragos-florin.chitariu@academic.tuiasi.ro

Teodora-Maria AGACHE, PhD Student, Faculty of Machines Manufacturing and Industrial Management; "Gheorghe Asachi" Technical University of Iasi, 700050 Iasi, Romania, teodora-maria.agache@student.tuiasi.ro

Cătălin-Gabriel DUMITRAS, PhD Professor, Faculty of Machines Manufacturing and Industrial Management; "Gheorghe Asachi" Technical University of Iasi, 700050 Iasi, Romania, catalin-gabriel.dumitras@academic.tuiasi.ro

Mihăiță HORODINCĂ, PhD Professor, Faculty of Machines Manufacturing and Industrial Management; "Gheorghe Asachi" Technical University of Iasi, 700050 Iasi, Romania, mihaita.horodinca@academic.tuiasi.ro

Florin-Daniel EDUTANU, Ph.D Student, Faculty of Machines Manufacturing and Industrial Management; "Gheorghe Asachi" Technical University of Iasi, florin-daniel.edutanu@student.tuiasi.ro

George-Gabriel CHIRIAC, PhD Student, Faculty of Machines Manufacturing and Industrial Management; "Gheorghe Asachi" Technical University of Iasi, george-gabriel.chiriac@student.tuiasi.ro