Using axiomatic design principles for the development of a device to measure the positioning error of an industrial robot

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Abstract. Robots are part of the integrated production process, being widely used in manufacturing processes, including the positioning of parts. One of the factors that influences the accuracy of the products to be machined is related to the errors of positioning the workpiece at each stage of manufacture. To determine the amplitude and the medium value of the positioning error, we used axiomatic design to develop a device capable of measuring positioning errors. The result was a constructive solution for a device capable of taking the positioning data of the end of the robot arm along three axes of a spatial coordinate system. In this way, data are recorded using dial comparators positioned on existing channels in the three walls corresponding to the corner of a cube-shaped box. Statistical processing of measurement results should provide information on the positioning accuracy of a workpiece by an industrial robot.

1. Introduction

The use of industrial robots with arms for positioning and handling objects has already become a common practice for decades that helps increase productivity, by removing the human factor and multiple related risk factors and ensuring repeatability of operations that also involves continuity in the process. production. Over time, they have become increasingly accurate in providing smaller and smaller positioning deviations of manipulated objects.

To measure the positioning accuracy we know several devices, among which, we can use a tool known as a dial comparator. This is a mechanical device is used to measure or verify dimensions and deviations of the parts along a single axis, allowing the measurement of small and very small dimensions, with the help of a feeler rod that slides in the fixing arm in strokes up to about 10 mm, with a micron or micron fractions accuracy. This device has the disadvantage that positioning can be achieved by moving the feeler rod along a single axis and does not provide conditions for evaluating the positioning accuracy of an object by the robot’s arm in a spatial Coordinate System-CS.

Another known coordinate measuring machine provides position measurements along three axes of a Cartesian CS. Measurement subsystems are provided along each axis. The shape of the part or its components is determined through point-by-point mapping in the reference CS. The coordinate values of points on the part are determined using a measuring head via a contact or non-contact method and their data are processed by an evaluation unit. For this machine type the measurement is usually made along a single axis which could be disadvantageous, and depending on the used tool type in measurement and its complexity, the purchase price can be very high. Another disadvantage is that the machine can’t be used to evaluate the positioning accuracy of an object by a robot arm.
In view of these facts, the main goal of this paper is to create a device for evaluating the positioning accuracy of an object by the arm of an industrial robot by taking into account both the customer's requirements and the functional factors.

The main challenge of the desired device must solve is the positioning accuracy evaluation of an object by a robot arm and also the degree of repeatability of the positioning accuracy within a spatial CS.

2. Theoretical aspects concerning the measurement of the positioning accuracy of industrial robots

To further exemplify the use of the Axiomatic Design-AD method, we have briefly presented below the aspects that must be considered in the design process of a device that determines the positioning accuracy of industrial arm robots. For numerically controlled machine tools, after mounting the workpiece, the positioning accuracy can be measured, depending on the type of machine tool or its equipment, through numerically controlled axes with linear displacement (linear axes) or with rotational displacement (rotation) complete and multiple, or oscillation (axes of rotation) using Renishaw tools with palpatory head (figure 1) [2].

![Figure 1. Renishaw with palpatory head [2].](image)

The definition of the parameters, the conditions and the means to perform the measurements, the calculation/evaluation of the characteristic parameters are regulated by generally accepted standards in the world of machine tools, namely (SR) ISO 230-2 and VDI / DGQ 3441. These refer both to the verification linear and circular positioning accuracy [3].

In addition to the classic, well-known solutions of dial comparators (figure 2) a measuring system in polar coordinates can be used that can make measurements in horizontal and vertical directions using a reflector consisting of a system with mirrors that turns the laser beam back to the laser tracker. (figure 3).

Although these systems are accurate, they are complex, requiring a long time for set-up and adjustments, economically disadvantageous, and the measurement is performed on two axes simultaneously [1].

3. Principles specific to Axiomatic Design

Various design methods aim to choose the optimal constructive solution so that it meets all customer requirements. The axiomatic design method and its principles were developed by Korean scientist Nam Pyo Suh in during his time as a professor at the Massachusetts Institute of Technology in Boston, USA [5]. In using the axiomatic design method, the following sequence of activities corresponding to the design is considered:

- knowledge and understanding of customer requirements;
- conceptualizing solutions by using synthesis;
• development of analyzes for the optimization of previously identified solutions;
• verification of the extent to which the results obtained meet the initial requirements of the customer.

And the areas of use are the following:
• the client's domain, where the highlighted client's requirements are located;
• the functional area, where the functional requirements are defined;
• physical domain, where the established design parameters are;
• process domain, where are the determining process variables.

Also, there are some other customer needs to be considered in the production of the device needed; for example:
• the design technology must be adapted to the existing equipment;
• as many components as possible must be made at a single stage, in the realization of the device; if this condition is met, a higher machining accuracy will take place and the time required for the realization of the device will be shorter.
• a simplified shape is preferred to ensure and facilitate the construction of the device and to increase productivity.
• the size, shape, and mechanical characteristics of the device should be established in accordance with the material used.

The practice of design manufacturing technologies proved in time that the problem solved is not simple and first result usually adopt simplifications.

4. Functional requirements and design parameters of the device for measuring the positioning accuracy of an industrial robot

As it has been mentioned before, a device meant to measure the positioning accuracy of an industrial robot was designed taking into consideration the Axiomatic Design method to find the best-suited version of the device. To give an easier understanding of the way of using the principles of Axiomatic Design, have been applied some assumptions concerning the constructive solution. Further, will be mentioned some of the customer needs:
CN1: the device must be made relatively easy into a laboratory for mechanical machining, adaptable on machine tools and including by FDM printing;

CN2: for conclusive experimental results the device must have the possibility to measure objects of different dimensions and shapes;

Following the customer needs mentioned before, the main functional requirements are:

FR1: Ensure the movement of the measuring devices;
FR2: Secure the measuring instruments;
FR3: Ensure the position of the device;

Moving to the identification of functional requirements corresponding to the second level, consideration could be given to:

FR1.1: Ensure the movement of the measuring devices on several axes;
FR1.2: Ensure the movement of the measuring devices from 3 measuring directions;
FR2.1: Secure the measuring instrument on support;
FR2.2: Insert and prefix the support with the help of its sole that will enter the guide channel located on the wall of the device;
FR2.3: Fix the support on the device with a screw with nut;
FR2.4: Prefix the screw on a guide channel located on the wall of the device;
FR3.1: Ensure the position of the device by building it in one piece;
FR3.2: Ensure the position of the device by fixing it on a board;
FR3.3: Ensure the device on the board providing both the device and the plate with threaded holes.

Following the above-mentioned functional requirements, the following design parameters (DPs) were identified:

DP1: Procedures used to build the exterior case of the device;
DP1.1: lathe/drill / 3d printing machine used to process the wall of the device;
DP1.2: lathe/drill / 3d printing machine used to process the wall of the device;
DP2: Procedures used to fix the measurement device;
DP2.1: drill/3d printing machine;
DP2.2: prefix channel;
DP2.3: screw with nut for fixing;
DP2.4: prefix channel;
DP3: Procedure used to fix the fix the device;
DP3.1: 3d printing machine;
DP3.2: tightening screw;
DP3.3: threading machine.

The functional requirements and design parameters from above will be included in Table 1, to check the validity of the independence axiom. The correspondence between the functional requirements FRs and design parameters DPs can be written as a matrix relation:

\[
\{FR\} = [A] \{DP\},
\]

where A is the design matrix by which the transfer functions FR and DP are taken into consideration.

In the case of the identified device, the relation (1) could be written by using Table 1.

In accordance with the Axiomatic Design theory, as it can be seen from the table 1, the design matrix is a diagonal matrix and it can be considered as an uncoupled matrix. This can be considered a result of a good design. The device resulted using the axiomatic design method can be seen in the figures below.
Table 1. Functional requirements and design parameters.

| FRs          | DPs        | Design parameters corresponding to the first level | Design parameters corresponding to the second level |
|--------------|------------|---------------------------------------------------|---------------------------------------------------|
| First order FRs |           | DP1 | DP2 | DP3 | DP1.1 | DP1.2 | DP2.1 | DP2.2 | DP2.3 | DP2.4 | DP3.1 | DP3.2 | DP3.3 |
| FR1.1        | X          |     |     |     |       |       |       |       |       |       |       |       |       |
| FR1.2        | X          |     |     |     |       |       |       |       |       |       |       |       |       |
| FR2.1        | X          |     |     |     |       |       |       |       |       |       |       |       |       |
| FR2.2        | X          |     |     |     |       |       |       |       |       |       |       |       |       |
| FR2.3        | X          |     |     |     |       |       |       |       |       |       |       |       |       |
| FR2.4        | X          |     |     |     |       |       |       |       |       |       |       |       |       |
| FR3.1        | X          |     |     |     |       |       |       |       |       |       |       |       |       |
| FR3.2        | X          |     |     |     |       |       |       |       |       |       |       |       |       |
| FR3.3        | X          |     |     |     |       |       |       |       |       |       |       |       |       |

Figure 4. Principal view of the proposed device.
Figure 5. Lateral view of the proposed device.

Figure 6. Section A-A of the proposed device.
According to figures 4-6, the device has as a basic part a base plate 1, located on an assembly A within the range of an arm B of an industrial robot. At the base plate 1 are joined, for example by welding, two walls 2 and 3, which, together with a wall 4, secured to walls 2 and 3, form a so-called corner. In each of the three walls 2, 3 and 4, of square shape, there are two perforated rectilinear channels a and b, the channel a being arranged along a diagonal of the square wall, and the channel b being parallel to this diagonal and at a certain distance from the respective diagonal. A disc 5 holding rod 6 in the form of a disc can move freely in the channel a. In the channel b a rod 8 supporting a part 9 can be moved and immobilized in a certain position using a nut 7 in which a guide bush 10 will be attached to guide the rod 5 supporting the probe 6 in the form of a disc to each of the three dial comparators, C, D and E.

5. Conclusion
Using the axiomatic design method, we obtained a device that measures the positioning accuracy of industrial arm robots in a spatial coordinate system such as the level of repeatability of spatial coordinates determined by several attempts to estimate the positioning accuracy of the object by the robot arm.

Another direction of research development can be the verification of the level of repeatability of the spatial coordinates of the positioned object by repeated measurements and the interpretation of the recorded data.

References
[1] Macovei M I, Laser tracker procedures for experimental evaluation of the performance parameters for RI KAWASAKI FS10E (in Romanian), Student Scientific Session, 2016, Politehnica University of Bucharest. http://www.imst.pub.ro/Upload/Sesiune/ComunicariStiintifice/Lucrari_2015/06.12/12_L07.pdf
[2] Renishaw - Elements of a CMM system, https://www.renishaw.com/en/elements-of-a-cmm-system--45561
[3] Gornic C, Checking machine tools. Measurements and interpreting the results, T&T, 2012, https://www.ttonline.ro/revista/masini-unelte/verificarea-masinilor-unelte-xvi-effectuarea-masurarilor-si-interpretarea-rezultatelor
[4] Grozav I, Improving quality through axiomatic design (in Romanian), Bulentinul AGIR, 1-2, 2008, https://www.agir.ro/buletine/341.pdf
[5] Suh NP 1990 The principles of design (New York: Oxford University)