Model of errors of touch-trigger probe installed on the industrial robot

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Abstract. The paper presents the redundant coordinate system consisting of Kawasaki RS010N Industrial Robot (IR) equipped with Heidenhein touch-trigger probe. The probe was mounted on the IR instead of a gripper and it was connected to a controller. This probe generates a binary signal at the moment of contact with a measuring surface. When the probe gives the signal the controller calculates coordinates of a measuring point thanks to encoders mounted in rotary axis. The signal also affects drivers and machine control. In addition, a special program in AS language was written. The program allows for coordinate measurements using this system. As part of the research an attempt to define a mathematical errors model of acquisition points system was made. For this purpose the model first developed by prof. Jerzy Sladek was used. The errors model of the touch trigger probe describes a relationship between an approach vector and a deviation for each measuring point, taking into account the approach from different directions. For this purpose, tests were performed using material standards of size to identify this function, both as measured internally and externally. An attempt was made to model this function using approximation methods based on the artificial neural networks.

1. Introduction
Robotics is now one of the fastest growing areas of technology. From day to day, the number of installed robotized positions on the production line increases. Increasingly, it is assumed that the number of installed robotic and metrology systems determines the degree of development of the company. Industrial robots replace people currently or are their helpers in engineering, construction, transport, agriculture, metrology and medicine.

In 2016, the International Federation of Robotics, reported record sales of industrial robots in the world – 300 000 pieces[1]. The trend developing in the industry of robotics is to provide a safe working together for human and robotic workstation.

Laboratory of Coordinate Metrology has been involved in modeling and evaluation of the accuracy of coordinate measuring systems including industrial robots [2-7].

2. Research object
Research object was the Heidenhein touch-trigger probe having fastened thereto a ruby measuring tip with a diameter of 8 mm (fig. 1). This probe was attached to the robot mechanical interface and connected to the controller of an industrial robot. As a result, detecting deflection of the stylus, the signal, at the input of the robot indicating the contact of measurement with the material is fed.
Tab1. The results of unidirectional positioning accuracy and repeatability of industrial robot in mm

|      | AP_p | AP_x | AP_y | AP_z | S | RP_l |
|------|------|------|------|------|---|------|
| P1   | 0.024| 0.005| -0.022| 0.008| 0.004| 0.022|
| P2   | 0.012| 0.011| 0.003| -0.002| 0.003| 0.021|
| P3   | 0.018| 0.015| 0.007| 0.006| 0.007| 0.036|
| P4   | 0.018| 0.009| -0.001| -0.015| 0.004| 0.025|
| P5   | 0.024| 0.013| 0.004| -0.020| 0.003| 0.019|

It is controlled by Teach Pendant’a with touch screen. It is also possible to control the robot directly from a PC using software KRterm. The robot is suitable for many common industrial applications, e.g. Assembly, palletizing, gluing or sealing.

3. Accuracy and repeatability of positioning of industrial robot studies

The study was conducted using a Leica Laser Tracker LTD 840 (Fig. 2). Cateye reflector was attached to the robot mechanical interface. During the test, Laser Tracker followed the position of the reflector. When the robot with the reflector is stopped and the position of the reflector was stable, then the coordinates of the center of the reflector were read. These points are used to determine the characteristics of the surveyed industrial robot. During the study, Laser Tracker collaborated with measuring software PC-DMIS, which enabled registration point coordinates.

3.1. Research procedure

Accuracy and repeatability of positioning of Kawasaki industrial robot studies have been carried out in accordance with PN-EN ISO 9283 Industrial robots – methods of testing the functional characteristics [3,8]. In the workspace of an industrial robot, the cube with largest possible volume was entered. The sides of the cube were parallel to the basic coordinate system of the robot. The corners of the cube formed the plane on which five points were deployed. Additionally, a single measurement point was adopted in the center of the cube at the intersection of its diagonals. The robot has been taught the position of these five points. These points were used to write a program for industrial robot in AS programming language. Robot, in a single measurement cycle, reached each of these five points from the same direction. At each point, the robot stopped at three seconds, to read, using a laser tracker, the actual position of the point. This measuring cycle was repeated n = 30 times.

3.2. The results of the accuracy and repeatability of the industrial robot

The results of unidirectional positioning accuracy and repeatability of linear movements of industrial robot in five points (P1 to P5) are shown in table 1, wherein:

AP_p – unidirectional positioning accuracy,
AP_x, AP_y, AP_z - unidirectional positioning accuracy in axis x, y, z
S – experimental standard deviation,
RP_l – unidirectional positioning repeatability.

The resulting value of unidirectional positioning accuracy of Kawasaki industrial robot is AP_p = 0.024 mm, and the value of unidirectional positioning repeatability is RP_l = 0.036 mm.
4. The research of robot with mounted touch probe

4.1. Measurement of reference sphere

To collect the data to a mathematical model of the contact probe, the measurements of reference sphere with dimension of 25 mm were carried out. The reference sphere was measured at 17 points evenly distributed over the entire hemisphere. One point was measured on top of the ball, eight points were measured 45 degrees below the tip of the ball and 8 points on the equator. Horizontally, points were spaced every 45 degrees.

Diameter value, at this stage of the analysis, was not subjected to radial correction. The obtained values show a relatively low variability in the case of coordinates X and Y, coordinate Z and the diameter are characterized by higher volatility. This is due to distribution of measuring points, which were distributed on the upper hemisphere of the standard. In addition, the variability of shape deviation for the set of spheres is in the range of 0.15 mm - 0.09 mm.

The next step was to determine the variability of the deviations of individual measurement points. The results were presented in the boxed graph (Fig. 3).

![Fig 3. Deviations for individual points (median - the horizontal line, rectangle range: 50% of the population, the extent of vertical lines: 99% of the population, black points are the outlier points, the variability of the mean deviation for each point is highlighted in blue)](image)

Conclusions from the analysis of the data are as follows. The data are highly volatile. Systematic influence is also visible and marked here the blue line. Many points, the value of which exceeds the 99% coverage of the population, is visible as well as appearing skewness of a distribution of measurement points manifesting a significant difference between the median selected by horizontal line and the average value - blue point on the graph.

Conclusions from the analysis of the data are as follows. There is no visible dependence, confirming the function of head of errors. The maximum point is the point of the pole, the minimum point is his neighbor.

Therefore, in order to develop a model of head errors, polynomial model has not been applied, which assumes a suitable mathematical model. In this case, neural networks have been used.

4.2. Construction of the model

In founded mathematical model, according to previous work carried out in the Laboratory of Coordinate Metrology, an error of measuring head was dependent on the inroad vector of measuring point [2]. In the case of industrial robots, we are dealing with a similar situation as for CMMs equipped with a touch-trigger probe, where it is possible to control the orientation of the measuring head.

Therefore, important invasions were presented on a head and not in a main robot. For this purpose, determinated inroads were multiplied by a matrix of the Euler angles.

A neural network has been adapted to the amount of information of training set. In this case it is 17 records of inroads for individual points and an average deviation.
To network simulation the library FANN [9] was used. Its advantages include a large number of software languages with which it works. Information about the form of the network is stored in a text file which gives the possibility to use the same neural networks in a variety of applications.

The acceptable level of differences between the network response and the values of the training set was defined as a half of the average volatility of the deviations in the individual points. What has been achieved.

Modeled head errors are presented on Fig. 4 using a trained neural network. This model was used for correction of the point position all 20 measurements performed on the calibration sphere. According to equation

\[ P'_k = P + c \cdot N(3) \]

Where \( P'_k \) – corrected point, \( N \) – approach vector, \( c \) – correction deviation calculated by artificial neural network. Results of the correction is presented on the Fig 5.

![Fig 5. Results after correction, red line mean values of the uncorrected errors, blue mean of corrected errors](image)

5. Conclusions
The application of robots in a control stations is now a fact. The control station consisting of a robot Kawasaki and Heidenhain probes was developed as a part of the research work conducted in the Coordinate Metrology Laboratory. The accuracy of the robot has been estimated in accordance with EN ISO 9283: 1998, accuracy (AP) was 0.025 mm and repeatability (RP) was 0.036 mm. Use of artificial neural networks has reduced errors of 50%. Research is ongoing on the implementation of the correction system in the robot control system and the development of appropriate interfaces to communication with metrology software systems.

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