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THE CORRECTION OF THE MEASURING ACCURACY OF THE INDUSTRIAL ROBOT BY USING ARTIFICIAL NEURAL NETWORKS.

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Abstract: Using industrial robots to the measurement tasks in the field of multicoordinate metrology is worth the interest. But it demands performing adaptation process, correcting the measuring accuracy if needed and determining the field of measuring tasks. During the adaptation process it is important to perform analysis of the accuracy of built measurement system. In the case of lack of accuracy it is indispensable to correct this values. The use of software methods like ANN (Artifical Neural Networks) seems to be expedient, because it is not the mechanical interference. The point of the described method is the determination of error in the given spaces. Then it is possible to built the accuracy model of whole robots space.

Keywords: industrial robot, measurement.

1. INTRODUCTION

Using industrial robots in elastic systems of production means much more than using them in simple operations such as material storage, grabbing or handing. By combining programmable possibilities of improving the execution of tasks by the robots and tools with navigation (NC, CNC, DNC), it is possible to design the system of production that gives the industry a very high degree of real flexibility and higher potential efficiency.

The main reason motivating people to use the robots in elastic systems of production is the reduction of direct work costs and increasing efficiency. It can be achieved even by using a single robot in small scale manufacturing, because the machine can do more than a single task.

2. ANALYSIS OF ECONOMICAL RESERVES

Having noticed that assembly and welding are the most frequently robotised tasks, it is essential to analyze the opportunities of using possible economical reserves like stoppage, reorganizing the structure of manufacturing process or using the robots which after changing the production profile became destined to scrapping but still their possibilities and weariness level are sufficient to use them in some production processes.

In [1] there is shown the percentage of using robots in various areas in different countries. As it can be easily noticed, Europe is leading above all other continents in using robots in welding, bonding and operations of navigating technological machines. On the bases of the example of Singapore, it is possible to analyze the tendencies of using robots in countries of Far East, where lots of western companies, mostly of IT branch, started running their factories, in which assembly (and caused by that - manipulation) of electronic devices takes place.

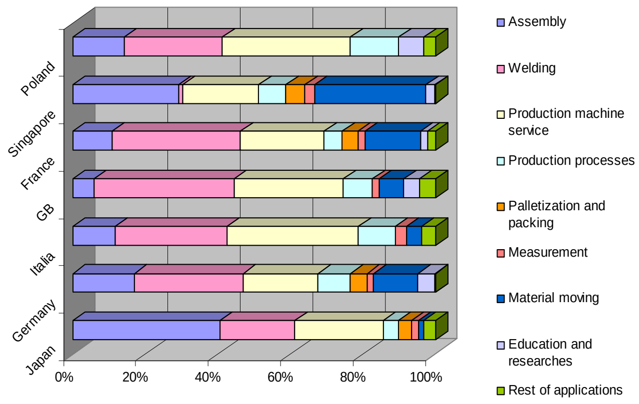

Fig. 1. Percentage participation fields of industrial robots application in selected countries in nineties years of XX century. [1]

The idea of using robots as tools of measurement gives lots of opportunities. Building the kinematical chain of industrial robots, according to their high level of possible manipulation, enables the access to areas hardly accessible or practically inaccessible for conventional measuring devices. Because of that, it is worth analyzing the matter of using industrial robots as measuring devices. But it is also essential to analyze the position and function of the robot in the specific production process.

3. METHODS OF THE CORRECTION OF POSITIONING THE ACCURACY OF INDUSTRIAL ROBOTS.

To achieve the sufficient accuracy level the robots used in production processes need to be calibrated first. That is why elaborated technologies and methods are nowadays being worked out, which helps increasing the accuracy of performing tasks without the necessity of constructional changes of the robot.

The interesting solution in the area of high parameters of accuracy seems to be the use of a hexapod platform, described in [2]. This specific kind of device may be used in the process of calibrating the referential position. The disadvantage of this solution is a still relatively high cost of the system.

Other way of calibration of industrial robots is a laser-tracker method. It is also described in [2].

4. THE ALGORITHM OF THE ADAPTATION OF THE INDUSTRIAL ROBOT TO MEASUREMENT TASKS

In order to say anything about performing measuring tasks by the robot, it is essential to notice the necessity of equipping it with the elements which would enable it to measure values of researched objects. The solution used most frequently is systems of trigerring probe head [3].

The probes below are only useful for measuring sticking elements, when a sticking probe does not cause the deformation of the touched surface. The alternative solution for the sticking probes with restrained possibilities, like impossibility of measuring elements such as a sponge or easily deformed ones, are non-sticking heads.

To sum up, the large number of available probe heads gives a wide spectrum of possible usage.

4.1. Elaborated method

To determine the accuracy of measuring by the industrial robot COMAU SMART 3S a method was used, which was created on the bases of the system of artifacts. Coordination of the ball midpoints lying in the coordinate sub-system - ball-artifact system - was assigned as a result of measuring the artifact on PMM 12106 Leitz. During the measuring the values of temperature gradients and the temperature of the artifact were collected.

Measuring the artifact in only one position restrains the possibility of noticing the expansion of error values only to the under-space of artifact, which is included in the operational measuring sub-space of the adapted robot. To increase the range of corrected area there was a system elaborated to moving the ball-artifact, which is schematically shown in the figure below. To achieve the data set, the ball-artifact is moved along each axis of the basing coordinate system of the robot.

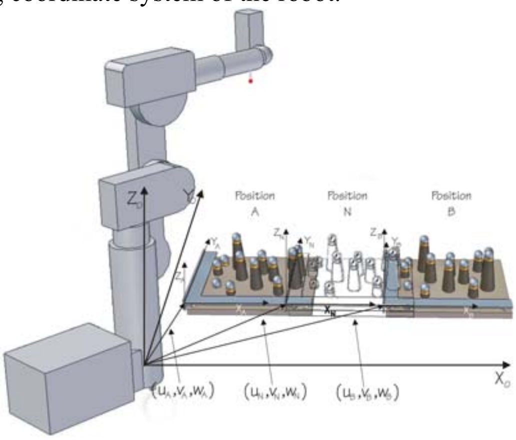

Fig. 2. Diagram of artifact moving during the creation of ANN teach set

Because of the elaborated and built up position it became possible to move the ball-artifact along each axis of the basing co-ordinate system of the robot. Using the slideways with the rectilinear error up to ±2 μm/m it is possible to determinate the master values of spatial ball-artifact with the use of the laser interferometer.

The measuring system was equipped with a set of sensors and a weather station SC 10 which was set to monitor the conditions which can influence the results of the measure in real time.[5]

It should be noticed that components of the error are caused either by interferometer and models WMP are omittable relating to results of the measuring performed by adaptated robot, which has an positioning error ±0.1 mm.

There was a measurement performed to receive information about errors in determining values of movements. It was ran as it follows. In the ball-artifact one ball was chosen as a referring ball, included during the movement of pattern moved along the slideway. Change of placing as a master value was identified by a laser interferometer. Determined data were included in process of creating teaching sets for Artifical Neural Networks (ANN) gained as a result of measuring the spatial ball-artifact moved along each coordinate axis using slideways simultaneously. The values determined in measurement on PMM 12106 - the values in local coordinate system as a model can be expressed as it follows: (Fig 2)

$$\begin{bmatrix} x_{P_1} & y_{P_1} & z_{P_1} \\ \vdots & \vdots & \vdots \\ x_{P_{13}} & y_{P_{13}} & z_{P_{13}} \end{bmatrix} \quad (1)$$

where:

$x_{P_i}, y_{P_i}, z_{P_i}$ - are values of balls midpoint coordinate for $i := 1..13$,

Transformation of the values of local coordinates to basing system of the robot is being made due to the dependence:

$$\begin{bmatrix} x_{P_1} & y_{P_1} & z_{P_1} \\ \vdots & \vdots & \vdots \\ x_{P_{13}} & y_{P_{13}} & z_{P_{13}} \end{bmatrix} + \begin{bmatrix} u_A & v_A & w_A \\ \vdots & \vdots & \vdots \\ u_A & v_A & w_A \end{bmatrix} =$$

$$= \begin{bmatrix} x_{0P_1} & y_{0P_1} & z_{0P_1} \\ \vdots & \vdots & \vdots \\ x_{0P_{13}} & y_{0P_{13}} & z_{0P_{13}} \end{bmatrix} \quad (2)$$

where:

u_A, v_A, w_A - the vector linking the origin of coordinates and the origin of local coordinate system in position "A"

The dependence described above is describing the transformation for the position "A".

The value of errors as a difference between the model values $x_{0P_i}, y_{0P_i}, z_{0P_i}$ and the values measures by an adaptated robot in position "A" can be expressed like that:

$$\begin{bmatrix} x_{0P_1} & y_{0P_1} & z_{0P_1} \\ \vdots & \vdots & \vdots \\ x_{0P_{13}} & y_{0P_{13}} & z_{0P_{13}} \end{bmatrix} - \begin{bmatrix} x_{A_1} & y_{A_1} & z_{A_1} \\ \vdots & \vdots & \vdots \\ x_{A_{13}} & y_{A_{13}} & z_{A_{13}} \end{bmatrix} =$$

$$= \begin{bmatrix} \Delta x_{A_1} & \Delta y_{A_1} & \Delta z_{A_1} \\ \vdots & \vdots & \vdots \\ \Delta x_{A_{13}} & \Delta y_{A_{13}} & \Delta z_{A_{13}} \end{bmatrix} \quad (3)$$

where:

$\Delta x_{A_i}, \Delta y_{A_i}, \Delta z_{A_i}$ - component values of errors of determining the midpoint of the balls in global coordinate system.

Analogously the values of errors are being determined for the position "B" - see the figure 4. Thus determined in positions "A" and "B" the values of errors were used to create the teaching set for ANN. Wide preliminary analyze of the matter of the measuring correcting gave the necessity of enriching the set with the values of temperature gradients around the analyzed measured space and the temperature of the model, figure 5. The temperature is the factor, which greatly influences on the measuring value. It should be remarked that though the influence of the temperature on the model parameters, or on the characteristic of the tool, which is in the case measuring system of the industrial robot and probe head.

The research on the influence of temperature on the accuracy of the measure show undoubtedly that it should be included in the process of creating correctional sets for the adapting robots.

Achieved data set - teaching set for ANN included groups of data: **incoming** - nominal coordinates of points, temperature of the model and temperature gradients; **outcoming** - the values of errors in nominal points.

The analyze of available literature and experience gained during preliminary research have given the corollary that best results of adaptation the net to determine the errors in the function of coordinate position and temperature are given when they are each spread along the axis of basing coordinate system. That's why the prepared teaching set was implemented due to each components of the error. As the teaching set for analyzing the task the values were prepared, which were expressed as data vectors. For example: to determine the component Δx of the error:

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$$\begin{bmatrix} x_{A_1}, y_{A_1}, z_{A_1}, gradTx_{A_1}, gradTy_{A_1}, gradTz_{A_1}, Tw_{A_1}, \Delta x_{A_1} \\ \vdots \\ x_{A_{13}}, y_{A_{13}}, z_{A_{13}}, gradTx_{A_{13}}, gradTy_{A_{13}}, gradTz_{A_{13}}, Tw_{A_{13}}, \Delta x_{A_{13}} \\ x_{B_1}, y_{B_1}, z_{B_1}, gradTx_{B_1}, gradTy_{B_1}, gradTz_{B_1}, Tw_{B_1}, \Delta x_{B_1} \\ \vdots \\ x_{B_{13}}, y_{B_{13}}, z_{B_{13}}, gradTx_{B_{13}}, gradTy_{B_{13}}, gradTz_{B_{13}}, Tw_{B_{13}}, \Delta x_{B_{13}} \end{bmatrix} \quad (5)$$

where:

$gradTx_{A_i}, gradTy_{A_i}, gradTz_{A_i}$ and $gradTx_{B_i}, gradTy_{B_i}, gradTz_{B_i}$ - gradients of temperatures during the measurement in positions "A" and "B"

Tw_{A_i}, Tw_{B_i} - temperatures of the artifact during the measurement in positions "A" and "B"

Analogously for the Δy and Δz error components is described.

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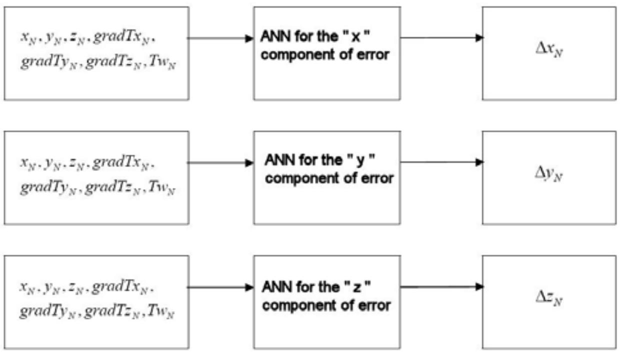

Fig. 3. Definition of error components procedure for the "N" position

After reaching the assumed condition, application stops the process of teaching the net. As a preliminary verification of a quality of taught net - fixing how the net represents the reality - there is a diagram created which present fitting the values gained from the taught net in the relation to data values in the teaching set.

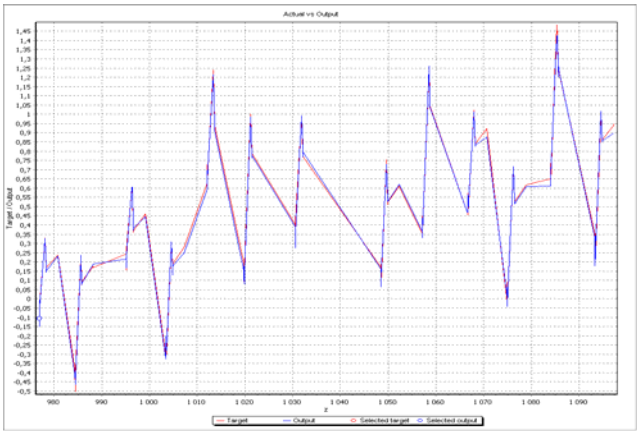

Fig. 4. Comparing values indicated by net (*Output*) with testing set correction values (*Target*) – for *z* error component.

The taught nets are used to analyze and prediction of the errors in position "N" (figure 4). Due to the taken assumption that for the given set of data net is being taught in the direction of predicting only one component of the error it became necessary to analyze the data in direction "N" three times by specifically taught nets. It can be expressed as it shown on figure 6.

The determined component values of error $(\Delta x_N, \Delta y_N, \Delta z_N)$ in the position "N" were noted as errors of determining the midpoints for each ball of the ball-artifact:

$$\begin{bmatrix} \Delta x_{N_1} & \Delta y_{N_1} & \Delta z_{N_1} \\ \vdots & \vdots & \vdots \\ \Delta x_{N_{13}} & \Delta y_{N_{13}} & \Delta z_{N_{13}} \end{bmatrix} \tag{6}$$

Basing on the determined by taught nets matrix of the error, it was corrected along the dependence:

$$\begin{bmatrix} x_{NP_1} & y_{NP_1} & z_{NP_1} \\ \vdots & \vdots & \vdots \\ x_{NP_{13}} & y_{NP_{13}} & z_{NP_{13}} \end{bmatrix} =$$

$$= \begin{bmatrix} \Delta x_{N_1} & \Delta y_{N_1} & \Delta z_{N_1} \\ \vdots & \vdots & \vdots \\ \Delta x_{N_{13}} & \Delta y_{N_{13}} & \Delta z_{N_{13}} \end{bmatrix} + \begin{bmatrix} x_{N_1} & y_{N_1} & z_{N_1} \\ \vdots & \vdots & \vdots \\ x_{N_{13}} & y_{N_{13}} & z_{N_{13}} \end{bmatrix} \tag{7}$$

where:

$(x_{N_i}, y_{N_i}, z_{N_i})$ - values of globes midpoints coordinates determined in the process of measuring in position "N",

$(x_{NP_i}, y_{NP_i}, z_{NP_i})$ - corrected values of model ball midpoints coordinates in position "N"

The elaborated method of the correction of the measuring accuracy of the adapted industrial robot was verified according to the ISO 10360-2 standard. Procedures described there are to determine the accuracy CMM by measuring the maximum permission error - MPE values acceptable for the adapted robot in assumed area.

For the data achieved in this way there was an area determined for the MPE of the adapted robot just before the correction of its accuracy, which can be expressed as follows:

$$MPE = \pm(200 + \frac{L}{22})\mu m \tag{8}$$

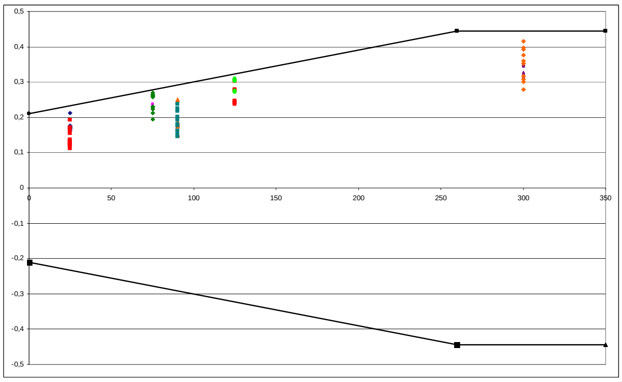

Fig. 5. MPE for adapted robot COMAU SMART 3S – before correction

In the same way there was a measurement taken for the robot already corrected. Which confirmed the efficiency of the method. As a result of applying the elaborated mechanism of correction with the use of ANN to the adapted robot there was a great development of the accuracy of the tool. The equation of MPE corrected the use of ANN can be noted like that:

$$MPE = \pm(60 + \frac{L}{100})\mu m \tag{9}$$

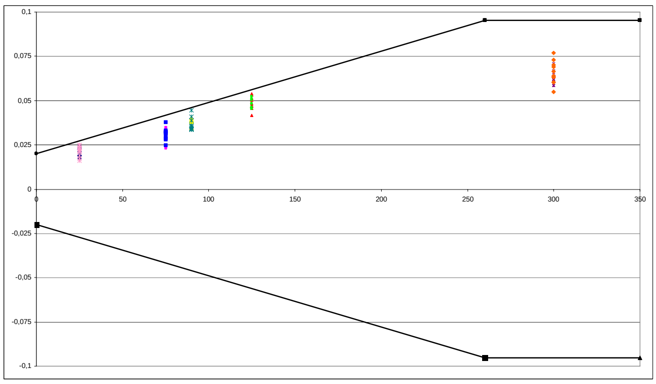

Fig. 6. MPE for adapted robot COMAU SMART 3S – after correction (using built ANN model)

The described procedure for the accuracy calibration and its assessment was repeated for the whole corrected area.

Fig. 7. Artifact posiotioning during measure in a corrected robot space of according with [4]

The calibration was performed for the artifact area and the space of the size 1m × 1m × 1m as well, determined by the length of the used step artifact KOBA - step 1020.

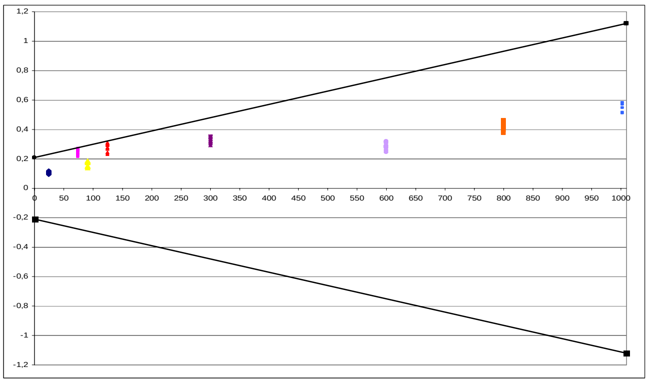

Fig. 8. MPE for adapted robot COMAU SMART 3S determinated using a KOBA-step artifact – after correction and extending corrected space

5. CONCLUSION

In the presented method, the departure from defining individual components and origins of all measuring errors was suggested. The innovative approach is based on the fact that the measuring system, which combines the industrial robot, the probing head and software, is treated as a joint system, which is subjected to the mechanisms of correction by the use of models together with the training sets for ANN, developed during the projection stage.

The use of spatial artifacts of an appropriate configuration makes it possible to define the error value for the selected positions of the robot.

The method of the assessment of the accuracy, based on determining maximum permission errors (MPE) using the test measurement of length, is appropriate for the industrial robots adapted to the tasks of multicoordinate measurement.

The devised methodology of modelling and checking accuracy on the basis of test measurement of length has shown that it is possible to adapt the ISO 10360-2 standard to assess the accuracy of measuring devices with rotational kinematics pairs.

The devised method of the correction of the accuracy can be applied to other operations performed by the industrial robots, such as operations of drilling or assembly, where high accuracy is essentially required.

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