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An automated quick accuracy and output signal check for industrial robots

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Abstract: - Due to the increasing complexity of application of industrial robots the demand of higher robot accuracy is an important part of modern robotics. This accuracy is needed in offline programming, copying programs or image-processing. The identification of the actual accuracy of one robot and the comparison with the manufacturer informations is in some cases decisive for the purchase. Therefore a quick solution for an accuracy check of an industrial robot is needed to assure the denoted manufacturer values.
This paper illustrates a new developed quick accuracy check according to the european standard EN ISO 9283 and a separate quick signal check of industrial robots, modified by the needs of the customer. After measuring the robot with an external measurement system the data is analysed by a special automated software module, which creates presentation-ready documents with a minimum of user interaction.

Key-Words: - robot accuracy, automated, process capability, static, dynamic, 3D-measurement

1 Introduction

The accuracy of an industrial robot can be divided into two major parts: The static accuracy which determines how exactly the robot can be moved to a 3-dimensional position with several iterations and the dynamic accuracy, which specifies how exactly the robot can move along given trajectories. A high robot accuracy is needed in many different applications like sealing or spot-welding of car bodies.

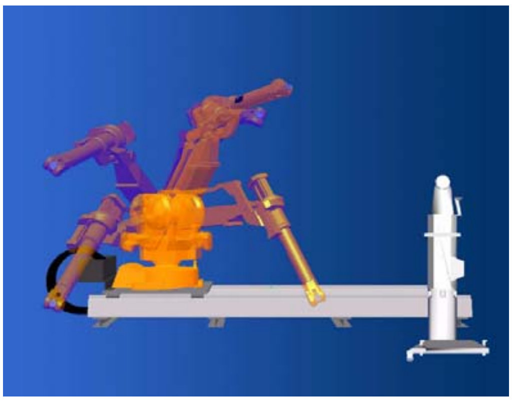

Fig. 1: Robot and 3D-measurement system

In contrast to the required accuracy, in industrial environments many robots are placed on linear tracks, so called 7th axis, to stretch the robots working area according to the largeness of the working pieces. Very important is to determine the static and the dynamic accuracy of the robot, to do some predictions if the analyzed robot is adequate for the planned application. Also relevant for the correct functionality of the planned application is the so called process capability of the robot. This describes, if the timing and scaling of the robots external signals is enough accurate, so that no problems occur with the controlling of additional peripheral parts like spray nozzles for example. For testing the robots process capability, a real-time system for measuring analog and digital signals simultaneously to a 3D-measurement system was developed, which is described in part 3 of this document. From this analyses of the accuracy and the process capability arise various robot-chracteristics, which are either manufacture-depending or robot type-depending. To get proper predictions about the accuracies and characteristics, an objective and automatically interpretation of the measurement data was needed and implemented through a new software tool. This programm generates presentation-ready material including the major facts of the analysis and diagramms for a better overview over the robots characteristics. The structure of this software-tool is described in part 4 followed by some examples given in part 5.

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2 Static and dynamic accuracy of industrial robots

The method explained in this document was developed in a common project with a german car manufacturer to validate robots for planned applications. It is a modification of the industrial patent DIN EN ISO 9283 and is in some ways fitted to the special needs of the applications.

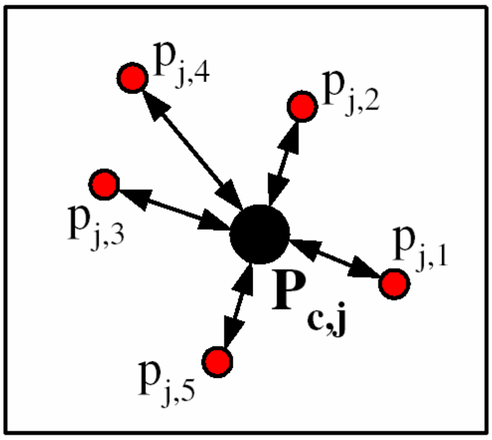

Fig. 2 : Robot moves ($P_{i,i}$) to one Point $P_{c,i}$

To get the static accuracy A_{pj} defined by

$$AP_j = \sqrt{(\bar{x}_j - x_{c,j})^2 + (\bar{y}_j - y_{c,j})^2 + (\bar{z}_j - z_{c,j})^2} \qquad (1)$$

the robot moves five times ($P_{j,i}$) to six different positions $P_{c,i}(x_{c,i}, y_{c,i}, z_{c,i})$ for getting the average values

$$\bar{x}_j = \frac{1}{n}\sum_{k=1}^{n} x_{j,k} \quad \bar{y}_j = \frac{1}{n}\sum_{k=1}^{n} y_{j,k} \quad \bar{z}_j = \frac{1}{n}\sum_{k=1}^{n} z_{j,k} \qquad (2)$$

and calculate AP_j using the robots teached positions $P_{c,j}(x_{c,j}, y_{c,j}, z_{c,j})$ as shown in figure 2. The determination of the dynamic accuracy is done by moving the robot with varying velocities and different reorientations along specified geometrical paths like a straight line, a circle or along the so called "optional test path" from the ISO 9283. The dynamic accuracy in this test is defined by the greatest distance (AT_p) between the robots movement and the given path at a right angle, with a given straight line defined by

$$\frac{x - x_1}{l} = \frac{y - y_1}{m} = \frac{z - z_1}{n} \qquad (3)$$

so:

$$AT_p = \left| \max\left(\sqrt{\frac{[(a - x_1)m - (b - y_1)l]^2 + [(b - y_1)n - (c - z_1)m]^2 + [(c - z_1)l - (a - x_1)n]^2}{l^2 + m^2 + n^2}} \right) \right| \qquad (4)$$

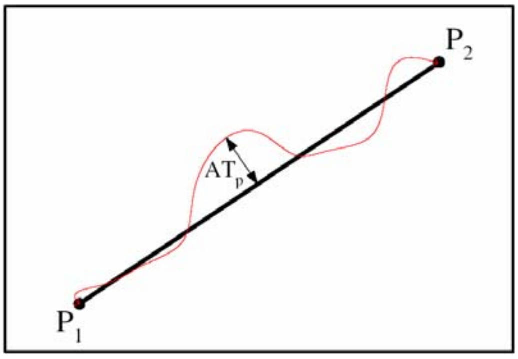

Fig. 3 : Positional error on a straight line

On a given semicircle-line the dynamic accuracy can be calculated from the greatest radial offset of the given semicircle and a circle built through the measured points. Therefore

$$AT_p = \Delta R = \left| R_0 - \sqrt{(x_j - x_0)^2 + (y_j - y_0)^2} \right| \qquad (5)$$

The "optional test path" from the ISO-standard is used in this accuracy test, because it combines straight line-pathes and circular movements to one geometrical figure. More information about this can be found in [1]. The calculation of the different values for the static and dynamic accuracy is done automatically by a new software-tool described in part 4.

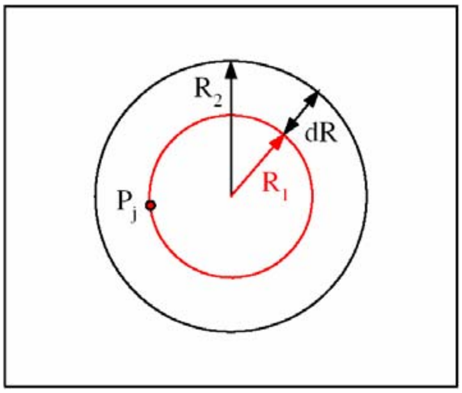

Fig. 4 : Error-calculating at circular movements

The next interesting step in analyzing robots is to find out the process capability.

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3 Analysis of the robots process capability

For controlling its external peripherals industrial robots are able to generate different signals, which can be used as a trigger signal or for getting the current velocity of the Tool-Center-Point (TCP) for example. Two kinds of these robot-generated signals were analyzed to test, if the robot is able to work together properly with additional peripherals, its so called process capability. The first is a digital output signal (0..24V) which could work for example as an power-on/power-off swich of a fluid pump. The second is an analog output signal (0..10V), which is proportional to the robots TCP-velocity and could work as a valve-signal of a fluid

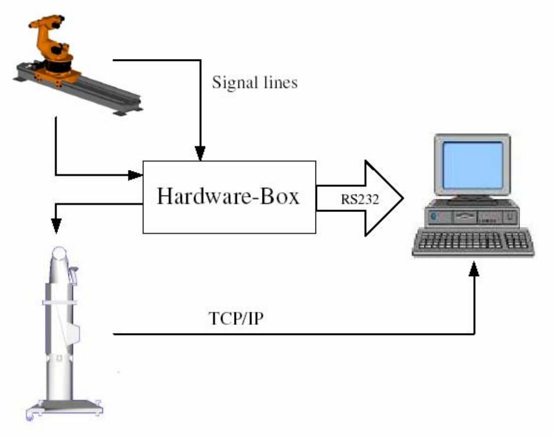

Fig. 5 : Configuration of the measuring-system

pump. Important aspects of these two signals are the timing-accuracy and at the analog signal even the amplitude-accuracy. Errors in the signals amplitude would at a fluid pump cause that too much or too few fluid is delivered and the accuracy of the whole application sinks. Even crucial is the proper timing of the signals, so that its correctness is given even when the robot moves slower, around edges for example.

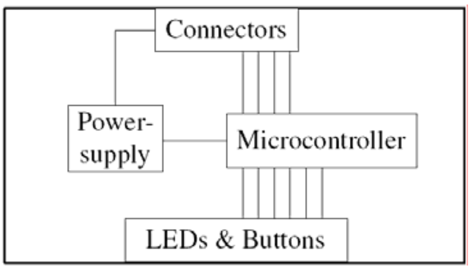

Fig. 6: Configuration of the Hardware-Box

For analyzing the robots external signals a special hardware was developed which does the controlling of the 3D-measurement system and the reading of the signal-values in realtime. Therefore it is connected with the 3D-measurement system over TCP/IP, with the robots signal lines and with a PC over RS232. At a sampling rate of 250 Hz the 3-

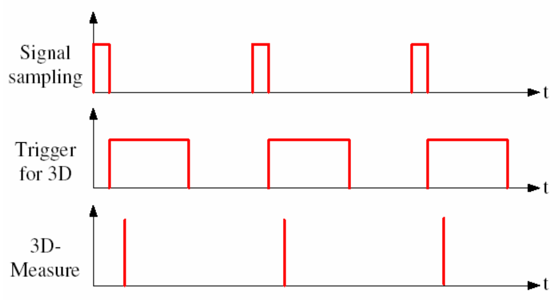

Fig. 7 : 3D-measurement over slave-trigger

dimensional position of the TCP and the corresponding signal value are measured and stored in different memories at the PC. Inside the Hardware-Box a Microcontroller with integrated RS232 and A/D-Unit converts ever sampling cycle the input signal into byte-values and sends it via the RS232 to the PC.

One problem on the signal-analyzing is to synchronize the 3D-measurement system and the signal-sampling. In this case a special feature of the used 3D-measurement system, a Leica LTD800 laser-tracker, is used. This special feature is the possibility of triggering the measurements of the system with an external clock signal. With help of this external triggering, it is possible to build up a self-synchronizing system by using the measure-ment system as slave after the sampling hardware. Due to the self-synchronizing measurements, the timing jitter between measurement of the external signal and measurement of the robots TCP-position reduces to the sampling time of the microcontroller because of successive approximation and the delay of a 3D-measure after triggering. These two delays added result a very small and even constant timing-error and permit a nearly exact measurement of both, the external signal and the robots 3D-position at the same time.

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4 Software-tool for automated interpretation of the measurement results

For an automated and objective interpretation of the generated measurement results, a new software-tool was developed in which the user is able to open existing measurement files, fill in additional informations and create presentation-ready material in PDF-Format. The tool is special fitted to the customer needs and lists all for this field of application relevant accuracy values of the robot. Beneath figures about the positional errors at the fix points or during dynamic movements, one kind of illustration of the robots movement along a

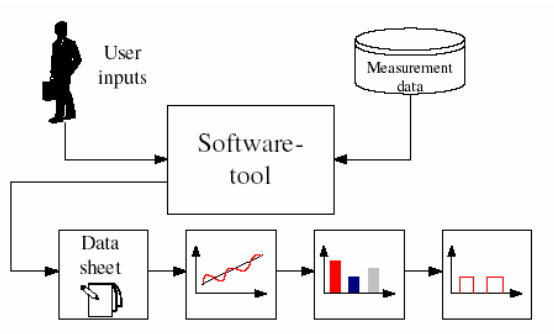

Fig. 8 : Configuration of the SW-Tool

straight line differs from common illustrations of error-functions. Therefore, the coordinate-system in which the measurement data are taken is transformed, so that the viewer has a look along the straight path, what means that the z-axis of the coordinate system is rotated into the direction of the straight line.

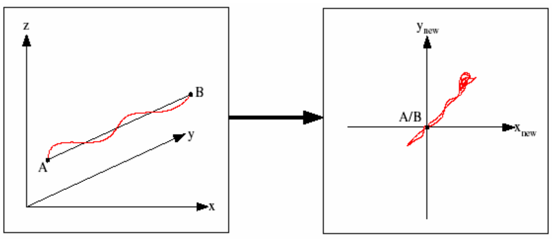

Fig. 9 : Coordinate system transformation

Mathematically (using quaternions):

$$\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \times \begin{pmatrix} l \\ m \\ n \end{pmatrix} = \begin{pmatrix} -m \\ l \\ 0 \end{pmatrix} = \vec{\vartheta} \qquad (6)$$

For $\vec{\vartheta}$ as rotating axis and

$$\alpha = \arccos\left(\frac{n}{\sqrt{l^2 + m^2 + n^2}} \right) \qquad (7)$$

for the angle of rotation. After rotating the coordinate system we get a projection of the 3-dimensional movement into a 2-dimensional plane. The length of the vector to a specified point on the robots movement line gives the orthographical positioning error to the straight line and the density allocation of the points shows the main movement zone of the robots TCP.

5 Example analyses

The depicted interpretations of measurement results should give an overview of the possibilities of documentation using the developed software-tool. Company names of the manufacturers and robot types are leaved out for data security.

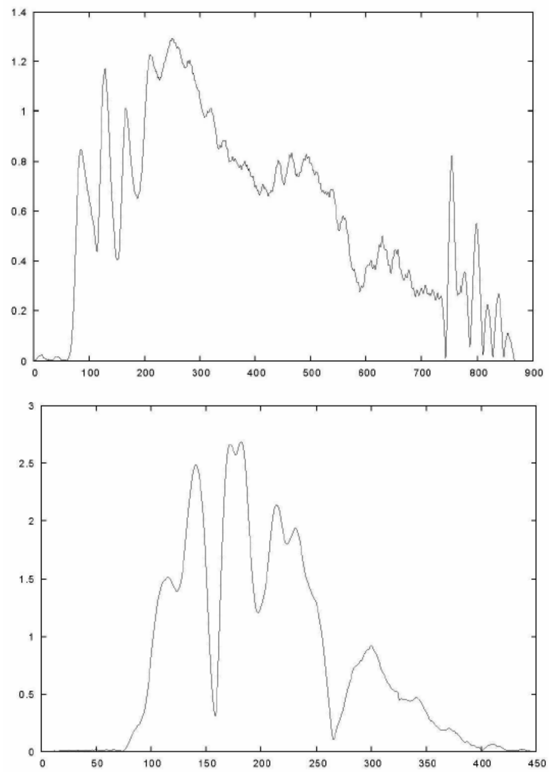

Fig. 10 : Accuracy in mm at 400 and 1500 mm/s

In figure 10 you can see the dynamic accuracy along a given straight path. Depicted is the perpendicular error along the given path moved with 400 mm/s (above figure) and 1500 mm/s. As you can see the inaccuracy of the robots TCP is greater at faster movements. One interesting effect are the error peaks during start and end of the robots movement. Due to the acceleration forces the flexibilities of the robot arm cause additional error components.

Transforming the coordinate systems of these two measured straight line movements so that the start and end point of the given line is in (0/0), you get figure 11. Here the length of the vector to one point of the measurement data is the same as the perpendicular error of the corresponding point shown in figure 10. The benefit of this representation is that you can see a density allocation of the meaured points. For example in the lower diagramm of figure 11 you can see that the robot was pending to one side during the movement.

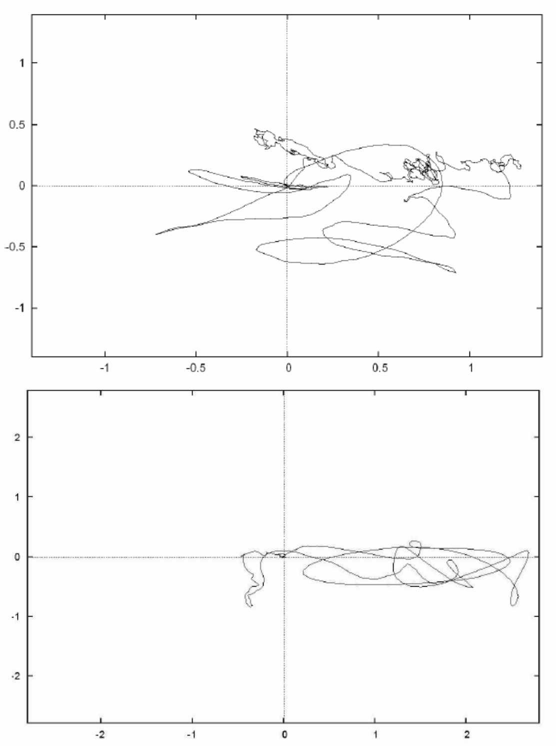

Fig. 11 : Same lines in transformed systems

Switching from linear movements to movements along given geometrical paths like the optional ISO path taken from [1] figure 12 shows one movement part cut out of the whole optional ISO path.

It is a good example for showing the behaviour of robot movements along edges. In the figure you can see the given path and the measured real robot movement along this given path. Obviously the robot did not move along the given path but uses a special 'rounded' movement. This is a typical behaviour and is one of the most error causing effects during robot movements.

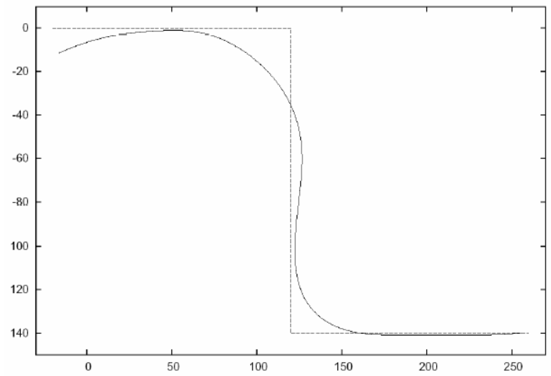

Fig. 12 : One part of the "optional path"

The last figure 13 shows an analysing of a digital signal check where you can see the switching points of the digital signal drawed as small crosses in the 3D-movement data. With this you can easily identify whether the switching points are in the correct positions of the robot movement or not. All units of figure 11-13 are given in mm.

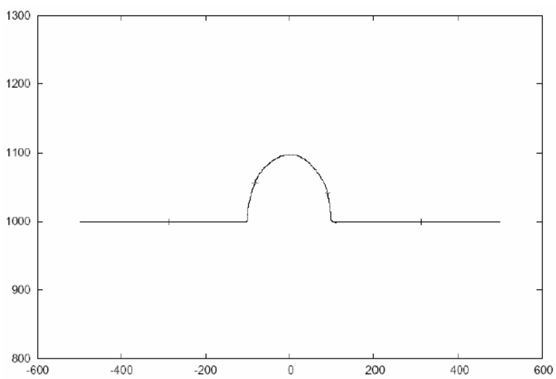

Fig. 13 : Digital I/O matched on 3D-data

6 Conclusion

With increasing complexity of modern industrial applications, accuracy and process capability analyses become more and more important. This method shows one way of analysing different robots, fitted on special customer needs. It is used by DaimlerChrysler for validating different robot types from ABB, KUKA and DUERR. Also the software-tool is extensively used and reduces the time for getting useful measurement interpretation at a fraction of the time before. Different implementations of analyzing methods may occur in the future and the necessity for a clear and objective interpretation of measurement results will increase. As future steps there is planned, to build a fully automated measurement mode with minimal user interaction during the measurements. With this the grafical user interface of the software wll be redesigned, switching from a dialog-based to a window-based software. As extension the analysing of the robot swinging and the zone behaviour at points with non-exact reaching will be included.

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