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The analysis of signal disruptions from an optical triangulation measurement sensor

Abstract

The paper presents the analysis of a measurement signal from a measurement triangulation sensor (laser) obtained during the positioning of an industrial robot. The signal is characterised by the range of disruptions. Their character is complex, because it involves the influence of robot position correction signals generated by the drive, free vibrations of the mechanical system caused by its movement and instability of reading the optical measurement sensor. There are presented the components of a test stand as well as the interactions between the robot control system, PLC, the laser controller and the user's HMI. The results of the analysis of the obtained data indicate that the reliable reading in the time shorter than the time of the system relaxation is possible. The presented issue is an element of a wider research program, the aim of which is to determine the correlations between the measurement capability of the method realised with the active use of an industrial robot and the measurement realisation time.

Keywords: laser measurements, Fast Fourier Transformation, low-pass filtering, measurement capability.

1. Introduction

Inspection is one of the most important areas of the plant activity, in which the use of industrial robots has been developed over the last few years. During the performance of typical tasks of the inspection robot, an integrated sensor or a video camera determines whether the quality of an object, a component or a product fulfils the standards. In the opposite situation, the sensor or the camera remains motionless in the area of robot operation, and the working object, taken and transported by the robot, is tested.

Over the last few years the impressive development in the areas of design and production of components for optical measuring systems has been observed [1]. It has caused their increased supply, with simultaneous lowering of their purchase and exploitation costs. Their increasing capabilities open the field for their new applications [2, 3], also in everyday manufacturing practice, not only, as yet, in laboratory conditions. The light source in many solutions constitutes a laser diode of the wavelength of about 660 nm (red colour). Optical measurements are contactless, which is one of their greatest advantages. It enables the measurement of hot, viscous, or delicate or fragile materials. The additional asset is the possibility of avoiding the collision of the gauging point with the measured surface. The assets of optical measurements meet the constantly increasing requirements of quality control. They enable achievement of the goal of measurement automatization by eliminating the human participation in direct control procedures. The important restriction, which should be met by the control systems, is not to extend the manufacturing cycle. That is why the designers of production systems, especially those of large-scale and mass production, try to integrate the measuring activities with the processing or transporting system, to complete the tasks at the same time.

One of the ways of implementation of the above-mentioned ideas is the use of industrial robots equipped with optical sensors or the sensors delivering the measured elements to the measurement zone. The difficult measurement conditions: vibrations, instability of the robot movement trajectory, light interference, noises, etc. should be taken into consideration. Generally, they cause the increase in the measurement uncertainty and extension of the realisation time. Thus, the research programmes have been undertaken to determine the measurement capability of a laser cooperating with an industrial robot, depending on the measurement realisation time.

The laser measuring head used in the research conducts the distance measurement with the use of the optical triangulation method (Fig. 1). A laser beam is emitted by the laser diode. Through the lens it is aimed at the object, reflects it and hits, through an optical unit, a receiver in the form of RC-CMOS matrix. With the use of triangulation method, knowing the distances between the components of the laser head, i.e. LED diode, RS CMOS matrix and the point where the reflected laser beam hits the RS-CMOS matrix, the distance from the object by which the laser beam was reflected, is counted. The laser head is characterised by the working range – i.e. the range of the distances in which the measurement is performed and a "dead zone" – i.e. the minimum distance from the measurement head, below which the reflected beam of light will not be aimed at the receivers scope. The reading repeatability is the highest in the middle of the working range. For the used sensor it was equal to 0.25 μm.

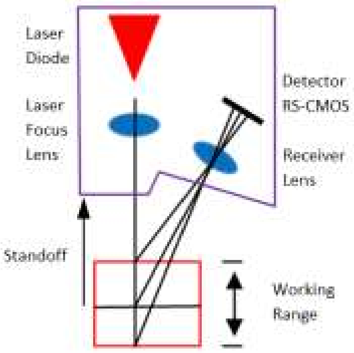

Fig. 1. Principle of laser triangulation measurement

2. Test stand

For the purposes of the research of the positioning repeatability, the test stand presented in Fig. 2 was configured in the Department of Manufacturing Engineering and Automation of ATH. Its base is the modern industrial robot KR 6 R900 AGILUS (1) with the compact controller KR C4 (3) and touch smartPAD (2). The measuring device is the optical triangulation sensor LK-H125 (5) handled by the LK-G5001P controller (6). The access to the parametric configuration of the laser readings as well as visualisation and management of the results is enabled by the LK-Navigator-2 package, installed on PC (7). The stand is supplemented by the PLC SIMATIC S7-1200 controller (4), additionally equipped with optional communicational modules: PROFIBUS and RS232. The controller ensures the synchronisation between the robot positioning programme and the data record in LK-Navigator-2 system.

3. The method of eliminating disruptions of measurement results

The measurement conducted with the use of triangulation optical sensor is discrete, thus, in time, there is obtained the point cloud (Fig. 3) of the size depending on the density of the recorded results and the measurement time. It is obvious that the measurement based on the single reading would be, in this situation, vitiated by incidental errors. Thus, one should wait for the end of the whole robot system relaxation period to obtain reliable readings. The relaxation time for the above-mentioned test stand amounts about 5 seconds, and thus waiting will cause the significant extension of the measuring process.

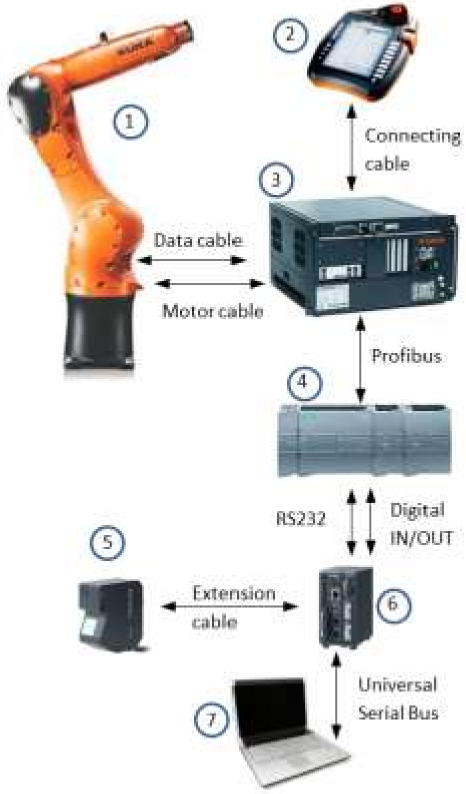

Fig. 2. Bus architecture

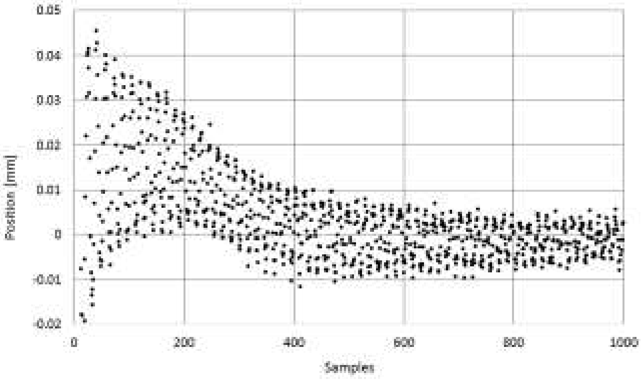

Fig. 3. Example of the series of measurement results, in the form of the point cloud

Figure 4, generated as linear, after connecting the measurement points, shows that the factual measurement signal, if being realised continuously, will have the character of compound oscillations. The compound oscillation signals, containing various disruptions are, in technology as well as outside the purely technological area, very common and there are many advanced methods of its analysis created, e.g. PCA (Principal Component Analysis) or ICA (Independent Component Analysis) [4].

To get acquainted with the character of measurement signal oscillations, the amplitude-frequency analysis was conducted (Fig. 5) with the use of Fourier Fast Transform (FFT) method, using the tools of the Excel package [5]. The Fourier Analysis is based on a simple idea – a complex signal should be presented as a sum of simpler signals, the behaviour of which is easier to observe and forecast. The two characteristic frequencies of the obtained measurement signal can be read from the chart: the first one – slightly below 1 Hz and the second one – about 12.5 Hz.

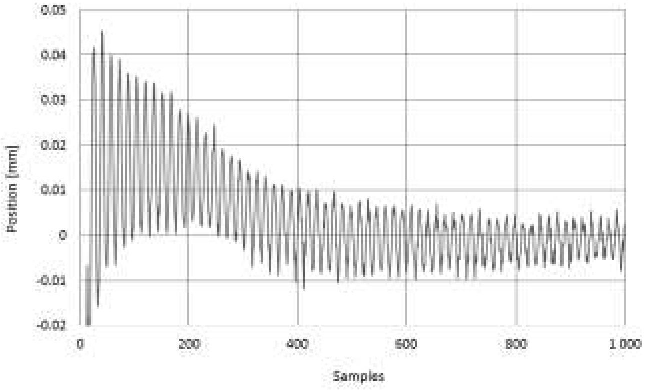

Fig. 4. Example of the series of measurement results in the form of a vibration chart

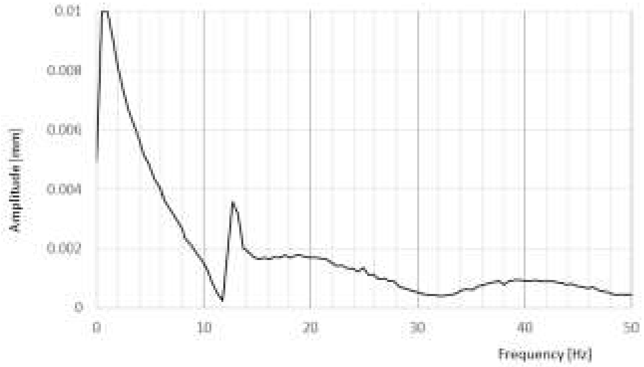

Fig. 5. The measurement signal spectrum obtained with the use of the FFT method

To be able to decompose the signal more precisely, transformations were performed on the shorter time section (1÷1.3 s), involving iterative averaging of the sample values in accordance with the simple formula:

$$X'_n = 0.25(X_{n-1} + 2X_n + X_{n+1}), \tag{1}$$

where:
X'_n – value of the sample n for the subsequent iteration,
X_{n-1} – value of the sample n-1 after the previous iteration,
X_n – value of the sample n after the previous iteration,
X_{n+1} – value of the sample n+1 after the previous iteration.

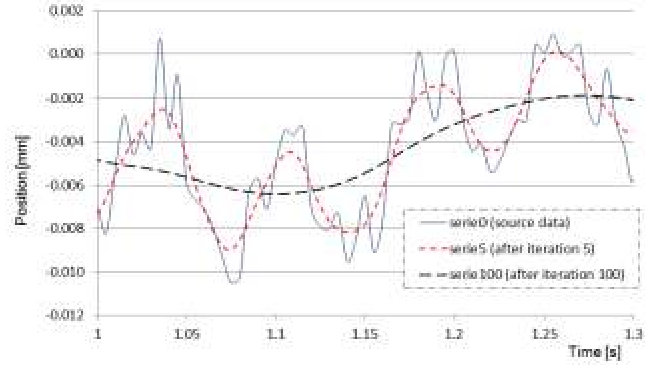

Fig. 6. Effects of signal filtering with the use of averaging method

Figure 6 enables comparison of the source signal with the averaging operation results. According to the conclusions from Figure 5, two courses, of the frequency, respectively, 12.5 and 1 Hz, were searched for. The disruptions above the frequency of 12.5 Hz were treated as noise, caused by the reading instability, occurring also after the expiry of manipulator relaxation period.

After performing simple arithmetic operations (2, 3):

$$Serie_3 = Serie_0 - Serie_5, \tag{2}$$

$$Serie_4 = Serie_5 - Serie_{100}, \tag{3}$$

the disruptions were extracted from the source reading (Fig. 7). *Series*$_3$ presents the chaotic vibrations of the measurement signal of the amplitude not exceeding 3 µm. *Series*$_4$ correspond with the vibrations of fading amplitude, characteristic for a non-ideally stiff manipulator.

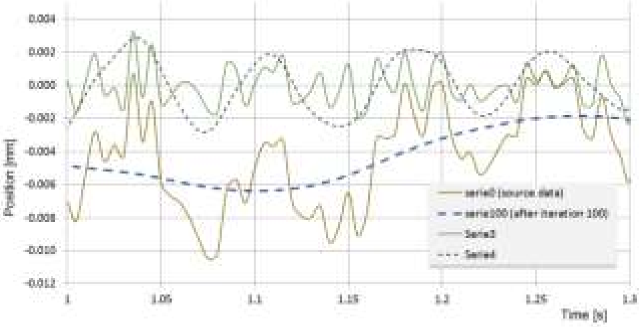

Fig. 7. Extraction of measurement signal disruptions

To sum up, the amount of the source signal can be presented as the sum of:

$$Serie_0 = Serie_{100} + Serie_5 - Serie_3. \tag{4}$$

The further research focused on the analysis of the system that had been hardware filtered with the use of a low-pass filter of the cut-off frequency equal to 1 Hz. In other words, the changes of the measuring system in the frequency range of 0÷1 Hz are of interest. Figure 8 presents the scatter plot (*Serie*$_2$) of the hardware filtered measurement signal on the background of the point cloud (readings of the laser probe).

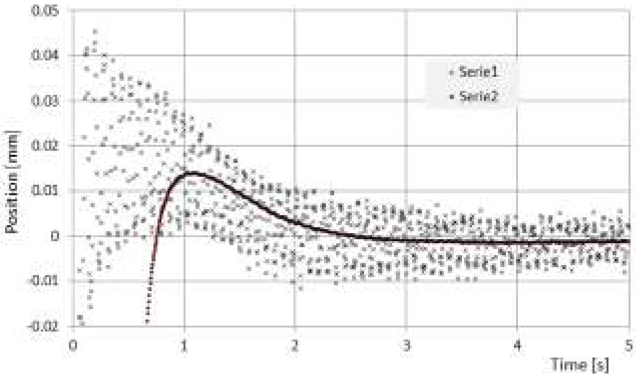

Fig. 8. Averaged process of the indications (Series 2) after using the low-pass filter for cut-off=1 Hz

A visible horizontal shift of the scatter plots is characteristic for filtration taking place simultaneously with the sampling. In the following time cycles only the results of the samples already collected can be taken into account, which results in the averaging process effects being visible only after a certain delay. This is an unfavourable phenomenon. It should be noted though, that its elimination would be connected with waiting for the next samples set collection; the longer, the smaller the frequency of the cut-off frequency for the low-pass filter.

The key issue at the moment is to answer the question about the repeatability of averaged trajectories of indications obtained with the use of a low-pass filter as in the example above. Figure 9 presents the results of five consecutive positioning trials, with identical movement parameters, i.e. location of the starting point, accelerations, velocity, road length and the positioning direction. The results indicate that in just 0.6 s the reading can be conducted with 0.01 mm repeatability. What is more important, however, is that in 0.99 s time, the repeatability of the reading amounts 0.0015 mm. Of course, the translocation (about 0.015 mm) should also be taken into consideration. However, when the displacement is known and controlled, it will not affect the uncertainty of measurement.

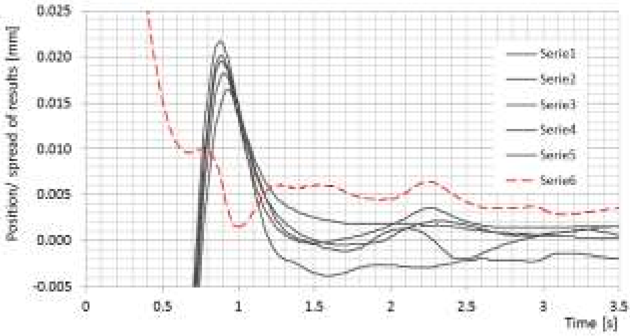

Fig. 9. Dispersion of measurements (Series 6) for five subsequent trials of robot positioning (Series 1÷5)

4. Conclusions

In industrial conditions, the cycle time of a machine (CNC machine, industrial robot, etc.) performing technological operations is of great importance. Thus, in the processes involving control-measurement tasks, the key issue is to determine compromise between the anticipated measurement accuracy and the measurement realisation time. The tests performed indicate that, to achieve low dispersion of measurements results, there is no need to wait for the full relaxation of the robot system to read the results. With the knowledge of the course of averaged indications of an average measurement sensor, the reading may be made already after about 1 second from the "stop" signal, when the full relaxation time in the conducted trials varied from 3 to 5 seconds. Of course, measurements should take place in comparable conditions and movement parameters should be constant. The aim of the further research continuing the issue in question will be the confirmation of the above conclusions with consideration of the impact of the manipulator dynamics (accelerations), the positioning movement realisation speed, the length of positioning route and different run-up directions (perpendicularly, parallel or at a different angle to the measured surface).

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