AN AUTOMATIC ERROR SURFACE DIAGNOSTICS DURING TURNING MACHINING OPERATION USING LASER SENSOR

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The paper deals with the design of an automated measuring and error detection system integrated into the turning machine. The experimental measuring device is based on a laser sensor with data transfer to the PLC control system. The main advantage of the designed experimental system is the possibility of measuring during the whole production process. The start position for the next product turn is indexed by a binary index laser sensor. The acquired data are transferred to the PC by TCP protocol for the next visualization and basic data representation. Data are stored locally in CSV format for the next knowledge extraction. Stored data is transferred after averaging to the Cloud Platform and can be used as an alarm system for production machine maintenance prediction.

KEYWORDS

Automation, Laser sensors, Quality control, Industry 4.0, Turning

1 INTRODUCTION

Measuring during the production process can significantly improve the quality of the final product, detect failures, and stop production immediately and protect production devices from damage. This is the current trend in connection with the concept of Industry 4.0 and full digitalization. The PLC (Programmable Logic Controller) system can accumulate measured data from the installed measuring system and send this digital data for the next data extraction to the Cloud Platform. The data from measuring in the production process creates many values (100-1000) per second and Cloud Platform works with minimal data rate 1 value per second [Židek 2018]. So there is a need for some data knowledge extraction algorithm integrated into the PLC system to minimize these amounts of data. Some other problems with measuring during the production process are described, for example, in the articles [Zhou 2019], [Martinez 2018], [Zidek 2016].

The newest CNC machines can include measuring devices for tools abrasion or can be extended as the selected option. The production process generates chip continuously and this is the main reason why it is possible to use also contact sensor for measuring. The current trend is contactless measuring and the main technology used is laser and confocal sensors. A laser sensor is a low cost and provides adequate precision for measuring and simple integration to the PLC control system. A confocal sensor provides better precision but with a higher price and more problems with integration into industrial control systems.

Some approaches to in-process dimensional control and measurement were described almost 30 years ago by [Fan 1991], then for example by [Yandayan 1997], [Vacharanukul 2005], [Ko 2007] and [Czarske 2013]. The experiments with measuring in Lathe machines were described, for example, in the works [Jeong 2005], [Kuschmierz 2016], [Zou 2017] and using laser sensors in the articles [Dorsch 1994], [Günther 2009], [Valino 2012] and [Gunther 2013]. New approaches to data acquisition and principles of digital data storage from the production process to industrial Cloud Platforms can be found in the articles [Lu 2019], [Mahmoud 2019], and [Zidek 2020]. Increasing reliability and productivity of the industrial system by sensor implementation is described in [Turygin 2018], [Bozek 2015], [Zidek 2014].

The red laser system based on the triangulation principle was selected for measuring. The designed measuring system can be used for CNC turning machines or classical lathes without digital control. This is one way to integrate older production machines to digitalization within Industry 4.0 concept.

2 THE EXPERIMENTAL MEASURING SYSTEM

In this section, there is described as the experimental measuring system designed for extending the standard lathe machine with continuous dimension measuring during the production process.

2.1 *The main idea of measuring*

The main principle of measuring with the data transfer chain from sensor to Cloud Platform is shown in Fig 1.

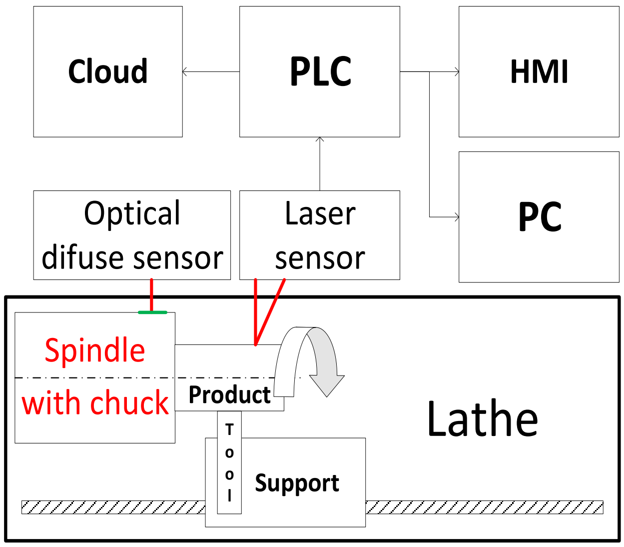

Figure 1. **The principle of interoperation measuring of the produced workpiece**

The measuring chain consists of two sensor devices: the laser triangulation device head and the optical diffuse sensor with a reflection label placed in the spindle with chuck.

The laser sensor provides the measured distance of the workpiece surface with the possibility to set up zero value. The optical diffuse sensor with a reflexive label on the spindle with chuck provides exact information about the start of the next turn. This sensor provides only binary data to the PLC system.

The next part is digital data processing via standard industrial protocol Profinet and its transfer to the PLC system. Datalog and simple graphical representation are provided by the PC system and desktop application. The whole measuring process can be adjusted and controlled by the HMI touch screen with basic functions for start, stop, and actual value status monitoring which includes critical error on the product. The acquired data provides two information (measured dimension, index of the turn) and must be evaluated for every turn or set of turns. The result is the approximated value of actual precision. The principle of data transfer from PLC to Cloud Platform is based on OPC Server/Client. This data can be also used for tool lifetime prediction or machine maintenance.

2.2 The used measuring device

The Keyence Laser Sensor IL-100 with the measuring range of 100 mm and a resolution of 0.001 mm was used. The digitalized data from measuring is transferred by amplifier via an industrial communication bus Profinet for communication with PLC using the Keyence DL-PN1 signal amplifier. The optical Retro-reflective sensor IFM O5P500 detects the start of turn by pulse with a reflexive label placed on the lathe chuck.

The classic lathe without digital control from company OPTIMUM machines types OPTIturn TU2807V was extended with two sensors. The spindle speed was set up to 162 RPM. The triangulation laser sensor for distance measuring and the optical sensor for the index of the next turn is shown in Fig. 2.

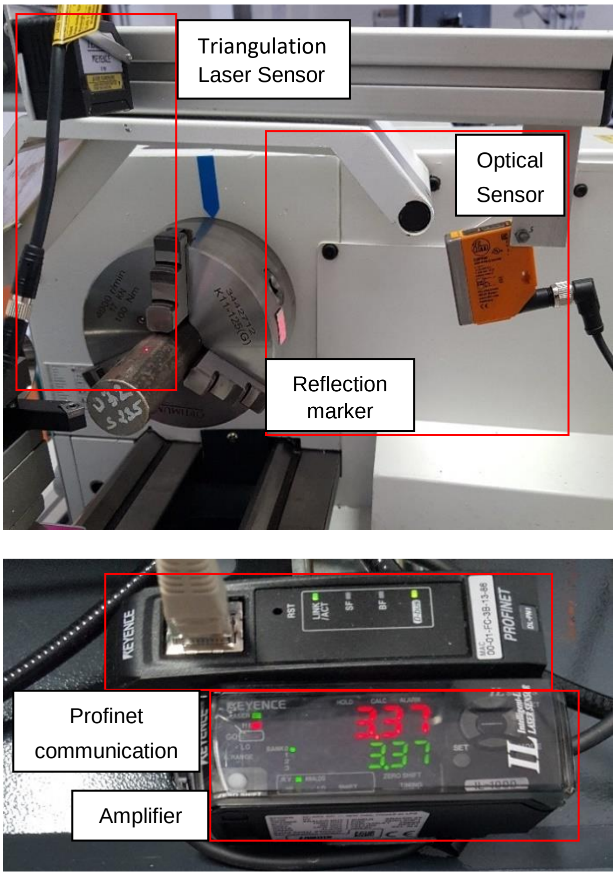

Figure 2. **The laser sensor for distance measuring, the optical sensor as turn index, the sensor amplifier and Profinet communication module**

2.3 The control system and software

The PLC Siemens S7-1500 CPU 1516-3 PN/DP with digital input module for optical sensor and Profinet interface for laser sensor was used for control (Figure 3).

Figure 3. **The used PLC control system for data processing**

The real-time pulses (4 ms) are generated by PLC for measuring with a laser sensor as it is shown in Fig. 4.

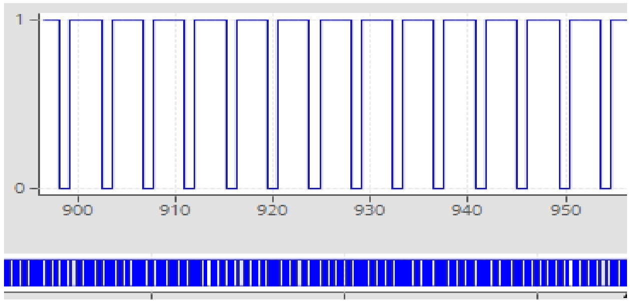

Figure 4. **Track diagram of measuring pulses generated by PLC**

The machine creates 2,7 of turn in one second. The one turn takes about 0,37 of the second.

2.4 The algorithm of data processing

The measuring starts with the first impulse from the index sensor, previous data is not stored and only new data is transferred to the PLC. It is possible to get a maximum of 92 values per second from the laser sensor. The amplifier allows us to set up zero and transfer measured data via the Profinet communication module to the PLC system. The PLC sends raw data to the PC for data log, visualization, and knowledge extraction. The extracted data is sent to the Cloud Platform by the OPC server. The HMI is connected to the PLC by Ethernet and provides basic control and setup with monitoring of actual and critical values. The basic data flow diagram of the simplified algorithm is shown in Fig. 5.

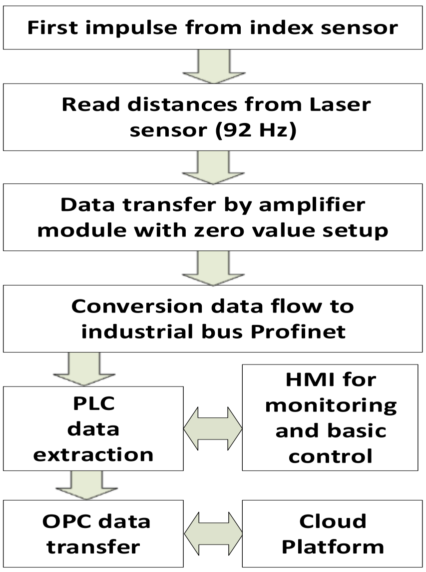

Figure 5. **The data flow diagram from the sensors to the control system and Cloud Platform**

HMI touch panel Siemens SIMATIC Multi Panel MP270 provides basic control and actual data monitoring. It belongs to the product category positioned in the product hierarchy between classic components such as operator panels on the one hand, and industrial computers on the other. Using this device is shown in Fig. 6.

HMI touch panel provides basic functions as:

- start and stop of measurement,
- monitoring of measuring actual values,
- turns to count,
- tolerance range setup,
- checking of critical values.

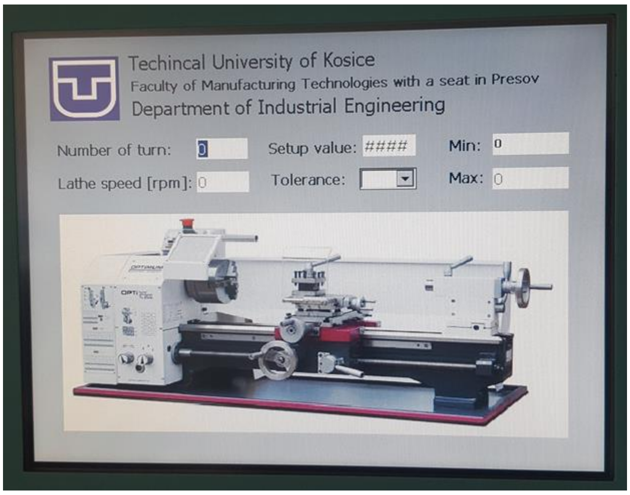

Figure 6. **HMI monitoring and basic control**

2.5 *Experiments*

Data exchange between PLC and PC is realized by client-server communication based on TCP protocol. PLC runs TCP client and PC software written in C# runs TCP server with listening data from PLC. The raw values from the measuring process are stored in PC as structured data in CSV format: time interval, index, displacement (error) as it is shown in Fig. 7.

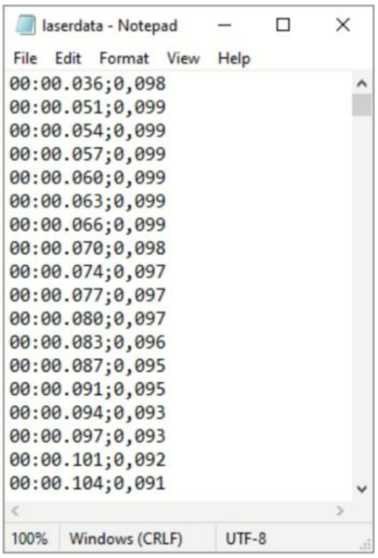
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Figure 7. **An example of data in CSV format stored in a log file**

The visualized data from the txt file in the polar diagram for one turn in the 2D diagram is shown in Fig. 8.

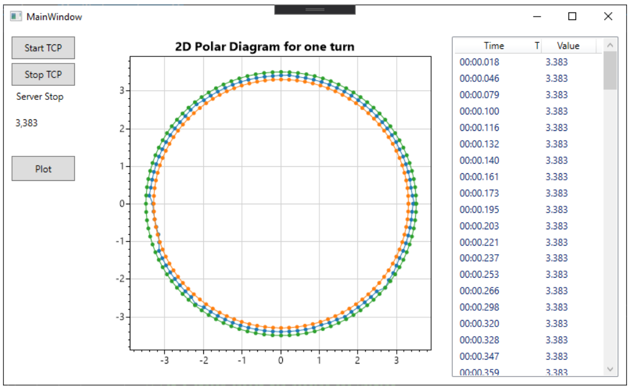

Figure 8. **The visualized measured data in the 2D polar diagram**

The software is written in C# with the WPF library as a graphical interface. 3D diagram of measurement for more turns is shown in Fig. 9.

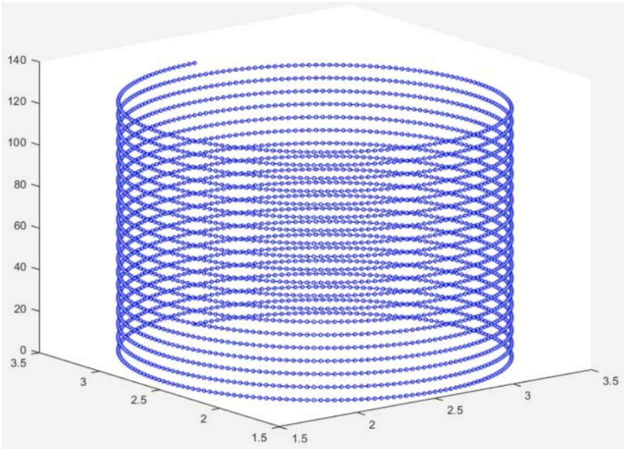

Figure 9. **3D diagram of the measured values during rotation**

It is necessary to isolate stable measurements from the machine turning acceleration and deceleration phase. The critical values can be identified when the number of measurements inside one turn is constant. An example of the measured data with maximal and minimal errors during stop and movements is shown in Tab. 1.

Turn/Value	Max [mm]	Min [mm]	Deviation [mm]	RPM
During turn	0,099	0,091	0,008	92
During stop	0,097	0,096	0,001	0

Table 1. An example of the measured data

During the workpiece movement, the deviation of about 0,008 mm was achieved due to the quality of the machined surface. The measuring device identifies the only deviation from zero position, for real dimension, its value has to be calculated by the equation:

$$D = x + d \pm e, \quad (1)$$

where:

D –the calculated real dimension,

x – the required drawing dimension value,

d – the measured value of deviation,

e – error of the sensor.

An example of the real dimension calculation:

- the required dimension: 30 mm,
- the measured value of deviation: 0,008 mm,
- the error of the sensor: 0,004 mm,

D = 30,008 ± 0,004 mm.

The Cloud Platform provides only a minimum 1-second store interval, so it was possible to store in Cloud Platform only one value for three turns. For the reliable storage, it was selected 1 value per 5 turns of the workpiece, because RPM can be increased over nominal. The simple average function was selected to store a representative value from a set of measured values. An example of data transferred to the Cloud Platform Mind Sphere from the OPC server is shown in Fig. 10. There are shown: a course of the measured values (green polyline), the minimal (yellow line), and maximal (black line) tolerance.

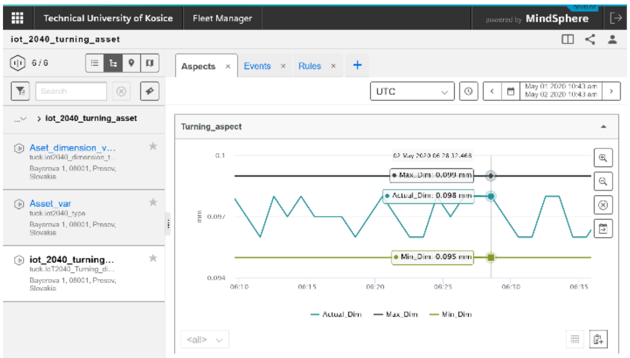

Figure 10. **An example of data in Cloud Platform for prediction or alarm message.**

The next task was to increase machine security using the RFID system to minimize injuries of unauthorized persons in the laboratory. The separate checking system based on an Arduino board with an RFID reader has been used. The only person with a registered RFID card can activate the machine. The machine is operated only with a valid RFID card placed on the reader. An implementation of the laboratory security system to the machine power supply is shown in Fig. 11. The security system is based on Arduino Uno with text display and NFC reader MFRC-522 NFC/RFID Module. The turning machine on/off function is realized by two relays of different voltage levels.

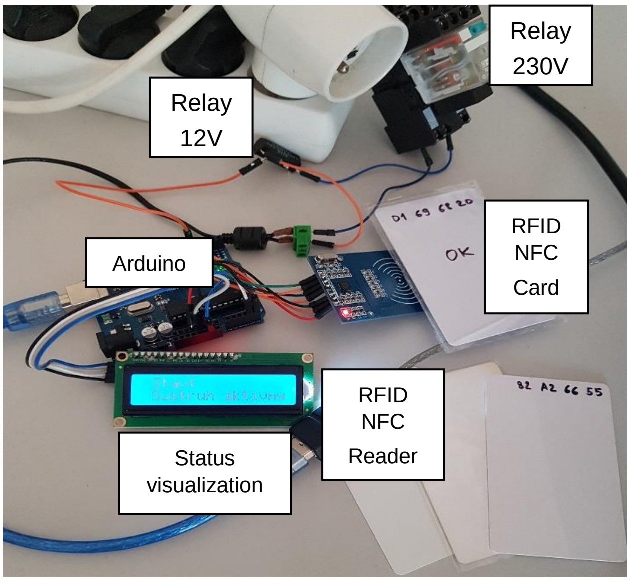

Figure 11. **The laboratory security system is based on RFID technology to ensure security.**

Conclusions

In the article, there was presented an experimental measurement system based on the Laser triangulation sensor for non-CNC Lathe production machines with data digitalization for Industry 4.0 concept. The continuous diagnostics of the product surface during or after machining operation was achieved. The surface visualization is realized in 2D space as a polar diagram designed in C# application and by 3D visualization tested in the MATLAB software as a helical spiral. It is possible to stop production and identify critical dimension limits with an automated alarm system and data backup to the Cloud Platform. The lathe machine was also extended by a security RFID NFC system to ensure the security of unauthorized access.

This solution can be used as a universal maintenance prediction system for other production machines (Lathes, Flat grinder machines, milling machines) or as tool maintenance prediction.

The next works will continue with the implementation of a more precise confocal type sensor integrated into the existing solution.

ACKNOWLEDGMENTS

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