Mobile HMI system for the micromachine tool

Bogdan Broel-Plater, Paweł Dworak, Marcin Mikołajczak

Department of Control Engineering and Robotics, West Pomeranian University of Technology

Abstract: In the paper a mobile visualization system of a numerical micromachine tool using mobile devices: tablet and smartphone is presented. The system is implemented and tested in the Department of Control Engineering and Robotics at the Faculty of Electrical Engineering, West Pomeranian University of Technology in Szczecin on the prototype of micromachine tool which has been built in the framework of the grant N R03 0050 06. Apart basic tasks of the human machine interface (HMI) e.g. monitoring of the main machining parameters, the system provides very advanced functionality comprising remote wireless control of the machine (remote pendant), sound, vibration and text messages (e-mail, SMS), a set of diagnostic functions. The system make it possible to detect and inform the operator about destruction of the device (milling cutter), possibility of exceeding the acceptable tool position errors and incorrect temperatures of the spindle. All These situations are detected by a mechanism that uses fuzzy logic inference. Acquisition of process data and all necessary calculations are carried out in the NI LabVIEW environment with the use of CompactRIO and Aerotech controllers and its libraries. The paper presents a functionality and realization of some selected diagnostic functionality: remote communication with operator and the use of fuzzy logic to determine trend of temperature of the spindle.

Keywords: mobile HMI, CNC, diagnostic, fuzzy logic

1. Introduction

Over the years, with the development of portable devices, visualization systems for industrial process evolved. Undeniably significant contribution to this development has made consumer electronics market. The rapid development of smartphones and later tablets, enabled designers to create solutions which, even a few years ago, nobody would have thought. Currently offered on the market mobile devices have the computing power of personal computers similar to the prior 10 years, while remaining within the pocket or hand of the operator. Important in terms of ease of use and intuitiveness of the operation of the visualization system is to provide the portable device with a touch screen which eliminates necessity of use a pointing device which as a mouse, stylus or touchpad.

The first portable devices (panels) were equipped with low resolution monochrome touch screens while the contemporary ones use high resolution color LCD. Device used by us an Acer Iconia Tab W500 tablet is equipped with a screen size of 10.1 in with HD Ready WXGA 1280 × 800 resolution. Given the growth rate of the touch-screen devices they will be soon equipped with full HD resolution screens (Acer A 700, iPad 4 [9, 10]. This allows one to create rich, colorful interface elements through which an operator can with one glance at the screen to assess whether all components are working properly.

In addition to the standard HMI functions (Human Machine Interface) the created system features diagnostics of the machine and micromachining process.

Increasing significantly the safety of the process, reducing downtime and increasing the process quality diagnostic is the most useful feature of the modern monitoring and visualization systems [2, 4, 5]. Unfortunately, they are still rarely used in practice, mainly because of the high degree of sophistication and/or the difficulties in the implementation and configuration especially from the point of view of possible implementation for the a micro machine [1, 3, 6, 8]. Relatively easy to intuitively understand and implement are the methods based on fuzzy logic [5]. Simple rules of fuzzy logic [7] seem to be almost perfect to describe the failure of devices and process abnormalities. In the paper functionality and realization of some selected diagnostic functionality: remote communication with operator and the use of fuzzy logic to determine trend of temperature of the spindle is presented.

The organization of this paper is as follows. In Section 2 a structure of the control and visualization system of the micromachine is described. In Section 3 we present some selected features of the developed HMI system for the micromachine. Section 4 describe a fuzzy logic procedure for the assessment of the state of process. We end the paper in Section 5 with conclusions.

2. Structure of the system

The machine named SNTM-CM-ZUT-1 has been built in the framework of the grant N R03 0050 06. The linear movements of the spindle in the 3-D space allow three linear Aerotech brushless servomotors: ANT95-50-L-Z (axis Y), ANT95-50-L (axis X) and ANT130-110-L (axis Z). The drives allow to move the spindle and object with the resolution of 1 nm, accuracy ±4 µm, and linear velocity of motion up to 350 mm/s. The machine allows to conduct micromilling process with precision on the level up to 1 nm with accuracy ±3.0 µm.

The spindle is driven by the DC motor 4015 with the servo inverter e@syDrive 4425 and the e@syDrive 4428 feeder, all provided by Syco Tec. It allows to achieve the rotary velocity up to 100.000 rpm, and max torque value 0.04 Nm. The object is oriented perpendicular with reference to the base and the operations are conducted in vertical and horizontal orientation. The depth of operation is obtained in line with the base.

The machine control system consist of three controllers: Aerotech for linear motion, Sycotec spindle controllers and National Instruments CompactRIO control for measurement, diagnostic and supervisory control algorithms. It is complemented by the workstation and some mobile devices used to visualization and remote control of the process. The scheme of the control and visualization system of the micromachine is presented in fig. 1.

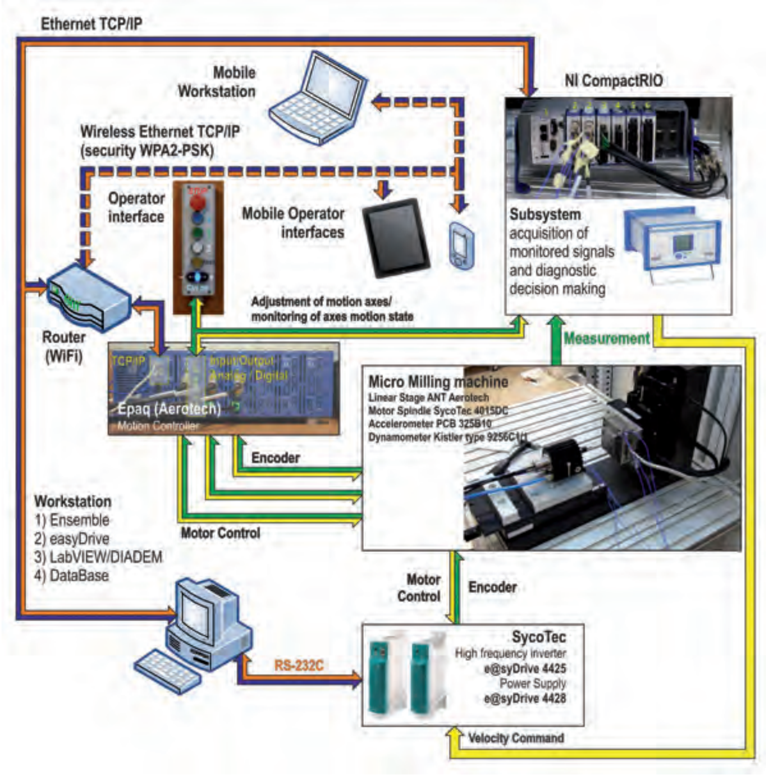


Fig. 1. Scheme of the control and visualization system of the micromachine

Rys. 1. Schemat systemu wizualizacji i sterowania mikrofrezarką

Communication within the system is realized via Ethernet TCP/IP, except from spindle controller connected to the workstation by RS-232C. The main node of the communication system is then a router, to which an workstation and Epaq and CompactRIO controllers are connected. Its WiFi function allows one to connect to the system a few additional mobile devices e.g. tablets, smartphones or laptops. This communication channel is coded with WPA2-PSK protocol.

The heart of the system is a workstation, which monitors all system components and the process of machining. It is here where more diagnostic calculations are performer and from where the instructions to the controllers of the devices and process data to operator panels are sent.

Remote HMI systems can be divided into those based on web interface and autonomous, working on mobile devices using Wi-Fi to communicate with the base station controlling the process. While working on a prototype of the numerical micromachining visualization system we focused on the second of these systems. Web-based interface, despite the many advantages in our case does not fulfill the tasks put before him. Due to the many hours' time in cut material, the operator should be able to move around the factory floor at the same time having the ability to track and stop a remote process from any place and using any device (HMI implementation). That is also why we decide to implement the HMI system in the National Instruments LabVIEW environment. Possibility to control the Aerotech devices, the LabVIEW flexibility, high level language power and many tools and mechanism provided makes this environment ideal for implementation of the prototype HMI system.

In the implementation an advanced variable-sharing mechanism LabVIEW Shared Variable Engine (SVE) has been used. It allows to share the process variables between the workstation and mobile devices [11].

SVE allows one to share data between loops on a single diagram or between VIs across the network and further on multiple devices among others. PAC controllers, industrial computers and wireless operator panels. In contrast to many existing data sharing methods in LabVIEW, such as UDP/TCP, LabVIEW queues, and Real-Time FIFOs, one typically configure the shared variable at edit time using property dialogs, and do not need to include configuration code in the application.

Communication between devices is performed on an Ethernet network through a protocol NI-PSP (National Instrument Publish and Subscribe Protocol). Simplified diagram of the system data exchange in the visualization system is presented in the fig. 2.

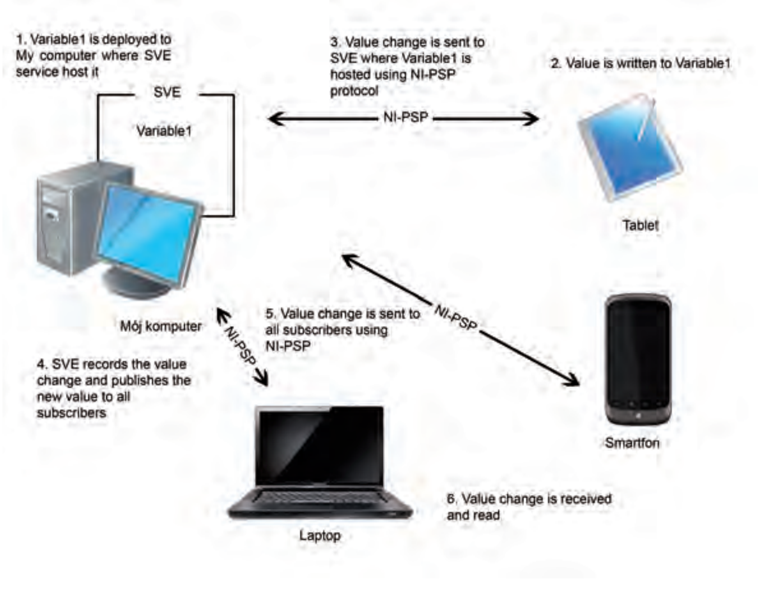


Fig. 2. Diagram of the data exchange using Shared Variable Engine

Rys. 2. Schemat funkcjonowania mechanizmu Shared Variable Engine

3. Functions of HMI system

Some of the main goals of newly created HMI systems are the possibility of implementation in the portable device, easiness of modification, configuration and maintenance of the system and easy adjustment of the interface to user demands. These requirements has been met and the system implemented with the use of the high level language G and the National Instrument LabVIEW environment.

Basic functions of the implemented system are:

- process data presentation,
- data logging In a Citadel 5 database,
- alarm of the process abnormalities,
- historic data presentation,
- CNC program management,
- remote pendant (manual control of the motors),
- diagnostics of the state of the tool, temperature of the spindle and prediction of the exceeding of acceptable machining errors.

The whole HMI system consists of three elements: full application run on the workstation, which controls the process, slightly reduced implementation on a tablet and very simplified ones run on a smartphone.

4. HMI interface on the workstation and tablet

Due to necessity of the continuous and uninterrupted process control and data logging some functions implemented in the workstation and tablet differ slightly, e.g. some functions are realized and configured only in the workstation. Apart of that the GUI (graphical user interface) for the workstation and tablet implementation looks like the same (see fig. 3).

We can distinguish three basic areas of the screen: header, main part (tabs) and footer. The header and footer areas contain always the same selected process parameters. Thanks to the tabs in the main GUI area we gain access to detailed processing parameters, historical data, remote pendant and others.

In the header the most important process parameters are presented such as axis status, position and velocity commands and errors. Additionally the right part of the header is dedicated to present the main diagnostic parameters, which allows the operator to quick assessment of the state of machining. Apart to the numerical indicators a multicolor led indicators are applied. Three colors used are: green, yellow and red depicting a proper machining, higher probability of machining failures and alarms, respectively. The most important state from the point of view of the secure operation is the "yellow state". It allows the operator to prevent errors which may deteriorate the machining performance or failure of the cutter. Parameters presented in this area are: position errors in axis X, Y and Z, velocity errors in axis X, Y and Z and spindle temperature indicator. Additionally an emergency stop button is placed there.

In the footer of the GUI a two combo box lists and numeric indicators are placed. Each list contains a set of process parameters, which values can be presented in the numeric indicator. A chose of parameter is up to the operator and may be made any time during the operation. It makes it possible to immediate preview the operation parameter of interest, without the necessity of looking it up in GUI tabs. A set of this parameters may be established by operator during configuration before the process is run.

The main area contains the panel of tabs which present: detailed parameters of drives, historic data (of freely chosen time period), CNC program management, remote pendant (manual control), alarms record, detailed system diagnostic (including cutter failure and spindle temperature).

An important element of the system is data logging and alarming of the selected (possible all) machining parameters. The NI LabVIEW Datalogging and Supervisory Control (DSC) toolbox provides the mechanism for configuration and maintenance of these functions of the system [11]. With LabVIEW DSC, one can interactively develop a distributed monitoring and control system with even few thousands tags. This module includes tools for communicating to conventional PLCs as well as programmable automation controllers such as NI CompactRIO targets, logging data to historical databases, managing alarms and events, and developing HMIs all within the single LabVIEW environment. Thus it suits perfectly for realization of the goals of the developed system.

The Citadel 5 databases for data logging and alarming parameters are stored in the workstation, which allows the operator to display them at any time both on the GUI of the workstation and on the remote operator panel realized by a tablet. Thus the operator has a continuous access to the process data and does not have to be present by the machine during operation.

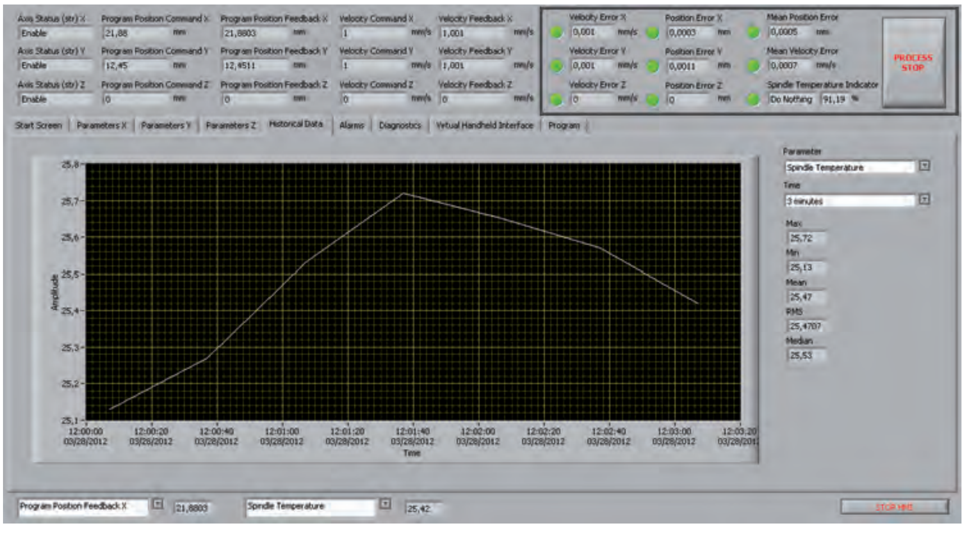


Fig. 3. Print screen of the workstation and tablet HMI implementation
Rys. 3. Zrzut ekranu z systemu wizualizacji stacji roboczej i tabletu

5. HMI interface on the smartphone

Due to the relatively small size of the smartphone's memory and relatively small display resolution, we were forced to significantly reduce the functionality of the interface screen for the device and only the most important process parameters are displayed here. There are diagnostic ones: position and velocity errors, mean square errors of position and velocity. A print screen of the main tab of the smartphone implementation is presented in fig. 4a.

a) b)

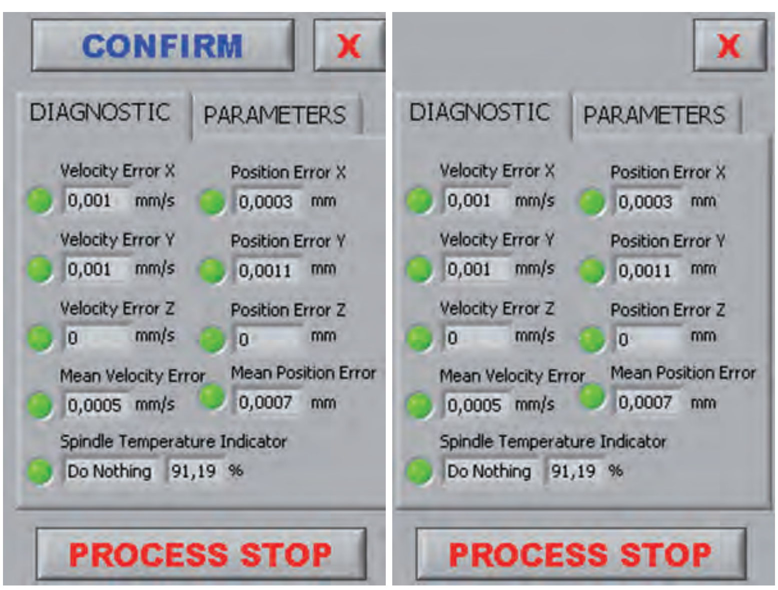


Fig. 4. Main tab of the smartphone HMI implementation
Rys. 4. Zrzut ekranu głównej zakładki systemu wizualizacji smartfonu

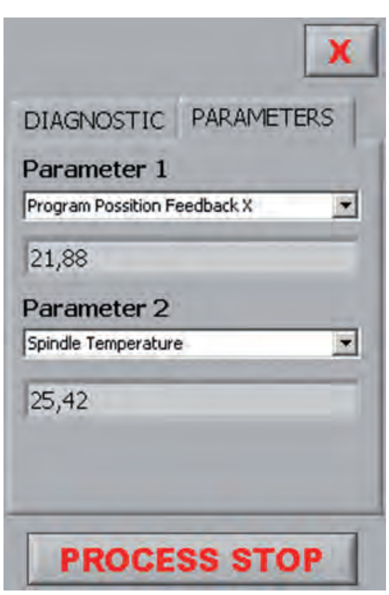


Fig. 5. „Parameters" tab of the smartphone HMI
Rys. 5. Zakładka "Parametry" systemu wizualizacji smartfonu

Specificity of the mobile devices means that part of the HMI function must be changed. The ability to place the phone in your pocket poses a threat of accidental activation of certain functions, such as pressing the stop button. Therefore, preventive measures are necessary. That is why to avoid accidentally stop the process one has to confirm the action in one second (fig. 4b). The "Confirm" button is visible and available to press only one second after the "Process stop" has been touched.

Apart of the above drawbacks mobile devices offer a set of very useful futures such as SMS, sound and vibration notices which may and are used to inform the operator about the most important process events.

The application is complemented by „Parameters" tab (fig. 5) where two combo box lists and numeric indicators are placed. They have the same functionality as the ones from footer of the workstation implementation. Thus, in spite of the confined display resolution, it allows the operator to check each available process parameter.

6. Fuzzy description of the process state

One of the most innovative features of the presented HMI system are diagnostics functions of device status and running process. The parameters subject to constant monitoring are the position and velocity errors of movement of the tool and spindle temperature. Used in diagnostic algorithms will be illustrated on the example of the analysis of temperature changes of the spindle.

Occurring during machining spindle warm-up phenomenon may lead to a deeper or shallower recess of the cutter in the machined material what is crucial for the machining accuracy comparable to the constant expansion of steel (spindle). Therefore the operator must be able to track the actual temperature of the spindle and get information that should enhance or limit cooling (by increasing the flow of cooling water).

In order to solve this problem we created a fuzzy inference system, which based on current temperature and the temperature derivative, displays the operator some auxiliary instruction. The numerical sharp output varying in the range from –1 to 1, means complete closure and cessation of the cooling process for (–1) or a total opening coolant valve and cessation of treatment (+1).

To design the "controller" the Fuzzy System Designer tool supplied with the NI PID and Fuzzy Logic Toolkit has been used.

Configuration of fuzzy inference system configuration as well as other interface elements is carried out before turning the display system. It allows one to set and view two sets of input membership functions and one set for output. Temperature membership functions are set based on the current ambient temperature (measured from the temperature sensor), and the desired accuracy. The spindle used is made mainly of stainless steel, which of the linear coefficient of thermal expansion is $12 \cdot 10^{-6}/°C$, i.e. that increases by 12 µm with a change of 1 °C. The boundaries of membership function are calculated as for which accuracy is maintained on the basis of the above value and the desired accuracy (in µm).

In the case of a set of functions for the temperature derivative the maximum and minimum value of the derivative is assumed. The interface of the system manual configuration is shown in fig. 6.

The following membership functions of input sets (for temperature and its derivatives) has been assumed: for temperature three fuzzy sets *TooLow*, *Optimum*, *TooHigh*, similarly three ones *TempDec*, *TempCon*, *TempInc* for is derivative. The membership functions to these input fuzzy sets are depicted in fig. 7.

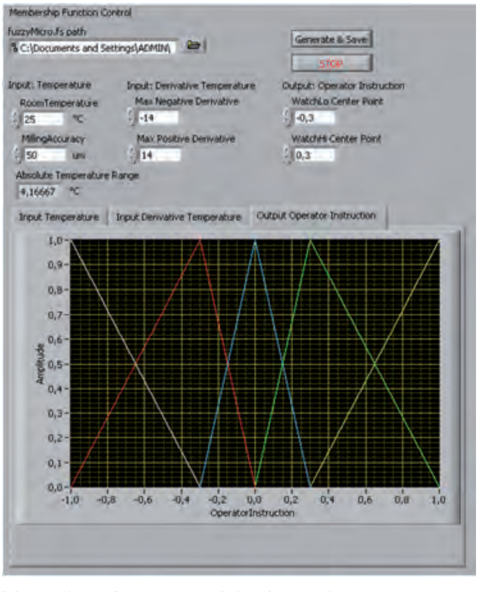
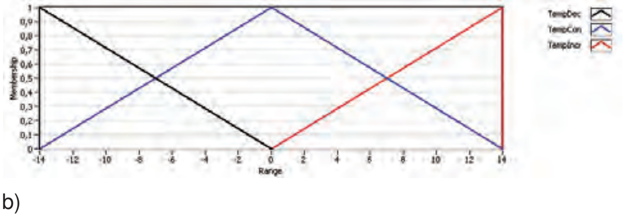


Fig. 6. Manual configuration of the fuzzy diagnosis system

Rys. 6. Ręczna konfiguracja parametrów rozmytego systemu diagnostycznego

a)



b)

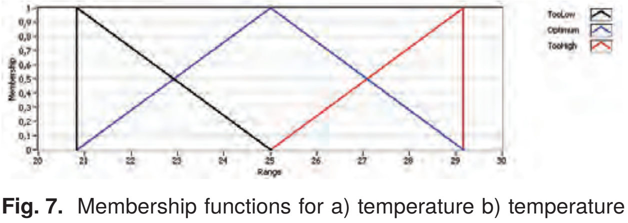


Fig. 7. Membership functions for a) temperature b) temperature derivatives

Rys. 7. Funkcje przynależności a) aktualnej temperatury, b) pochodnej temperatury

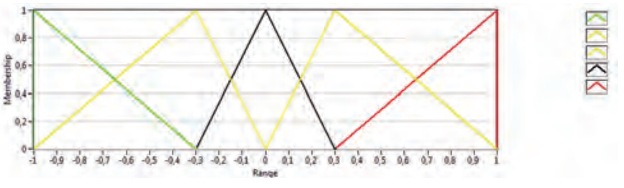


Fig. 8. Output membership functions of the fuzzy temperature diagnosis system

Rys. 8. Funkcje przynależności wyjścia rozmytego systemu diagnostycznego

Fuzzy evaluation of the temperature of the spindle and the development of instruction to the operator is described using five fuzzy sets: Warm, WachW, Do nothing, WatchC, Cool, which membership functions are presented in fig. 8. The infering rules for such prepared system may be presented in a form of the infering tab. 1. Thus the result of temperature evaluation is a hint for the operator. The sharp output calculeted with the use of the output membership functions presented in fig. 8 may in future be used to an automatic temperature control. For the time beeing it is only used to inform the operator about the system possible inaccuratnesses or possible failures.

For ease of operation a graphic indicator of the spindle temperature has been prepared. For this purpose a multi-state LED indicator has been designed. It takes four states depicted by color and text messages: Blue, Yellow, Green and Red colors for Warm, Watch, Do nothing and Cool instructions for operator, respectively. It is supplemented by a percentage description of the diagnosis reliability. The possible appearance of the multi-state LED indicator is presented in fig. 9.

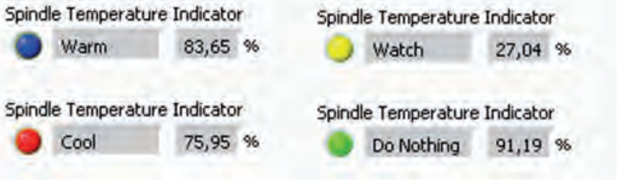


Fig. 9. Multi-state LED indicator – instructions for operator

Rys. 9. Multi-state LED Indicator – instrukcje dla operatora

Such prepared, the system allows the machine operator to rapid diagnosis of the spindle. In order to save memory of the portable devices diagnostic system calculations are performed on a workstation and transmitted through the SVE to other devices of the HMI (tablet and smartphone).

7. Conclusions

The presented in the paper HMI system has been developed in order to implement and test some new futures of the modern visualization system of the numerical micro machine tool. A quick implementation and easy maintenance of the system was satisfied due to the chosen NI LabVIEW platform. It provides functionality which allows one to extend easily the system by the functionality of e.g. mobile devices, highly advanced control algorithms etc.

The presented functionality: remote communication with operator and the use of fuzzy logic to determine trend of temperature of the spindle shows trends in the development of the new HMI systems, especially those including the diagnostic goals, which as it was shown are relatively easy to implement and its result simple to present to the operator.

The fuzzy logic algorithm used make it possible to detect and inform the operator about the danger of destruction of the device (milling cutter), possibility of exceeding the acceptable tool position errors and incorrect temperatures of the spindle and others. The evaluated results of the fuzzy algorithm (after confirming the correctness of the configuration) may also be easily used in an fully automatic control system.

Acknowledgements

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Bibliography

1. Chae J., Park S.S., Freiheit T., *Investigation of micro-cutting operations*, “International Journal of Machine Tools and Manufacture”, vol. 46, no. 3–4, 2011, 313–332.
2. Frank P.M., *Fault diagnosis for linear systems*, Control Systems, Robotics, and Automation, 16, 2011.
3. Kang1 I.S., Jeong S.K., Yong W.S., *Cutting force model considering tool edge geometry for micro end milling process*, “Journal of Mechanical Science and Technology”, vol. 22, 2008, 293–299.
4. Korbicz J., Kościelny J.M., *Modeling, Diagnostics and Process Control: Implementation in the DiaSter System*, Berlin, Springer, 2010.
5. Korbicz J. et al. *Fault Diagnosis: Models, Artificial Intelligence, Applications*, Berlin, Springer, 2004.
6. Malekian M., Park S.S., Jun Martin B.G., *Tool wear monitoring of micro-milling operations*, “Journal of Materials Processing Technology”, vol. 209, 2009, 4903–4914.
7. Rutkowski L., *Metody i techniki sztucznej inteligencji*, PWN, 2005.
8. Wang J., Gong Y., Abba G., Antoine J.F., Shi J., *Chip formation analysis in micromilling operation*, “International Journal of Advanced Manufacturing Technology”, vol. 45, no. 5–6, 2009, 430–447.
9. [www.acer.com].
10. [www.apple.com].
11. [www.ni.com].

Mobilny system wizualizacji mikroobrabiarki

Streszczenie: W artykule przedstawiono mobilny system wizualizacji mikroobrabiarki numerycznej wykorzystujący urządzenia mobilne: tablet i smartfon. System jest wdrażany i testowany w katedrze Automatyki Przemysłowej i Robotyki na Wydziale Elektrycznym Zachodniopomorskiego Uniwersytetu Technologicznego w Szczecinie na prototypie mikroobrabiarki powstającej w ramach grantu N R03 0050 06. Oprócz podstawowych zadań interfejsu HMI (ang. *Human Machine Interface*), do których należą do nich między innymi monitorowanie głównych parametrów obróbki, projektowany system realizuje bardzo zaawansowane funkcje w tym: zdalna kontrola ruchów urządzenia w ręcznym trybie pracy (zdalna wędka), informacje dźwiękowe, tekstowe (SMS, e-mail), wibracje urządzenia, zestaw funkcji diagnostycznych. Ponadto przewidziano w systemie możliwość informowania operatora o zniszczeniu narzędzia (freza), możliwości przekroczenia akceptowalnych wartości błędów obróbki oraz niepoprawnej temperaturze wrzeciona. Wszystkie te nieprawidłowości wykrywane są przy użyciu algorytmów wykorzystujących logikę rozmytą. Akwizycja wartości zmiennych procesowych oraz wszystkie niezbędne obliczenia przeprowadzane są z wykorzystaniem oprogramowania NI LabVIEW oraz sterowników CompacRIO, kontrolerów Aerotech i ich bibliotek. W artykule skupiliśmy się na dwóch wybranych elementach systemu: zdalnym informowaniu operatora urządzenia oraz wykorzystaniu logiki rozmytej do określenia trendu temperatury wrzeciona.

Słowa kluczowe: mobilne HMI, CNC, diagnostyka, logika rozmyta

Bogdan Broel-Plater, PhD

He received the MSc and PhD degrees in control engineering in 1975 and 1986, respectively. Currently assistant professor in the Department of Control Engineering and Robotics, Faculty of Electrical Engineering, West Pomeranian University of Technology in Szczecin. Main scientific interests: programmable logic controllers, industrial application of fuzzy-logic control, mechatronics.

e-mail: bbp@zut.edu.pl

Paweł Dworak, PhD

He received the MSc and PhD degrees in control engineering in 1999 and 2005, respectively. Currently assistant professor in the Department of Control Engineering and Robotic, West Pomeranian University of Technology, Szczecin. Main scientific interests: multivariable control systems, adaptive control, process data acquisition and visualization, industrial applications of modern control algorithms.

e-mail: pawel.dworak@zut.edu.pl

Marcin Mikołajczak, BSc

The first graduate degree (BSc) in Automatic Control and Robotics at the faculty of Electrical Engineering at West Pomeranian University of Technology in Szczecin, currently a student of second degree (MSc) in Automatic Control and Robotics at the faculty of Electrical Engineering at West Pomeranian University of Technology in Szczecin. Interest in new technologies and building automation.

e-mail: marcin.mikołajczak@gmail.com