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SMART MULTIFUNCTION PRODUCTION STAND

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Abstract: Innovation of SMART multifunction production stand solution consists of transferring the theoretical knowledge about the industrial IoT, openPOWERLINK and cloud computing into the practical application by creating the SMART multifunction production stand according to the latest trends that are gradually becoming a part of normal practice. The result of this project is not only the device (SMART multifunction production stand), but also the concept for creating an industrial application using Internet of Things (IIoT), Internet services (IS), cloud computing and using the open communication protocol POWERLINK.
Keywords: POWERLINK, Cloud, 3D printing, openSAFETY

1. INTRODUCTION

The theoretical part of the project focuses on communication protocols, "Open Source", the use of IoT and Internet services. The practical part of the project focuses on the design, development and realization of the new educational production stand using the industrial control system. The new educational system will be the smart multifunctional device, which will consist of two linear motors with handling areas 1x0,7 m. The device will be supplemented by a new control system (PLC) and the third axis with the effector. Over individual workplaces in the laboratory the complex information and control system will be created by connecting all devices in the laboratory with Internet services that allows solving many practical tasks which are comparable with the tasks from industrial practice.

Current status: The current innovative trends in the manufacturing industrial systems are in the early stages (Note: In many cases they are more hype than reality). Industry 4.0 is based on Internet of Things, or the IIoT. The systems communicate with each other (not always according to a hierarchy) and there is a need for data security, processing amounts of data (big data), diagnostic equipment and quality control of the products. These features require the use of the cloud. According to the curve drawn by Gartner Company [9] we can see the current innovation trends and their gradual implementation into the practice. This project assumes a complex solution utilizing the latest information technologies used in the industry.

2. PROJECT SOLUTION

The project solution was divided into the four phases, which were overlapped with each other and thus accelerated the device development.

1. In the first phase of the solution, we have created the software in the Automation Studio. At first we created the hardware configuration for two linear motors and subsequently we developed the control algorithm that has been being implemented into the programmable logical controller (PLC). We have implemented the control algorithms for positioning the axes (CNC functions) into the PLC using PLCopen Motion Control (MC) standard. This phase also included the creation of the local visualization, remote control by connection to the internet services, big data collection and safety functions implementation. Safety functions were provided by the Safelogic X20SL8100, which uses the openSafety protocol via POWERLINK. More information about safety requirements for critical processes control is mentioned in the papers [7] and [8].
2. During the second phase of the solution we have designed hardware components (mechanical parts), modeled the mechanical components and a controlled system. We ordered necessary material according to the design. Designed systems were physically created and connected to the control system. Over individual workplaces in the laboratory the complex information and control system was created by connecting all devices in the laboratory with Internet of Services which allows solving many practical tasks comparable with the tasks from industrial practice.
3. Implementation of the real time kernel into the Raspberry Pi 3 (RPI), connection the RPI with PLC using POWERLINK and GUI for RPI creation (GTK+) has been taking place within the third phase. Camera and the RFID reader have been connected to the Raspberry Pi. OpenCV [3] have been use for implementing image processing into the platform Raspberry Pi3, which includes camera input and has the necessary communication interfaces for implemented communication protocol openPOWERLINK [4]. Concept of the control system using the Industrial Internet of Things (IIoT) in the meaning of Industry 4.0 has been created (Fig. 2). The PLC uses Ethernet interface and the RPI uses WIFI wireless communication network for connection to the internet. Production system operating in real time will be local, i.e. outside the cloud. We have worked out the detailed manuals.
4. We have evaluated the quality parameters of the achieved results, tested and adjusted the equipment. The minimal ability for this SMART multifunction production stand is: 3D milling, laser cutting, 3D printing (using smart materials even 4D), writing- Marking Technology, testing of equipment at an acceleration and vibration and can be extended to other functionalities.

The individual phases have been being solved in parallel in order to increase efficiency. The longest delay was caused by waiting for the ordered material and we used this time to solve the other parts of project.

During five month we created the new modern educational system - SMART multifunction production stand as shows the project schedule. This device uses open POWERLINK communication network to control the system in real time. The multifunction device is capable of producing the products according to the customer requirements with the added value which is the IT information.

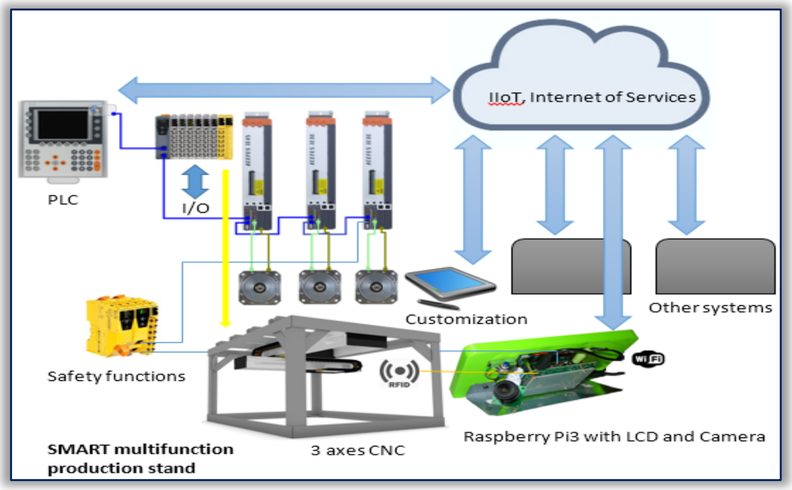

Figure 1. The main principle of machine operation

The movements in the axes X and Y perform two linear motors from HIWIN. The linear motors for movements in the X, Y direction have the maximum speed 4 ms^{-1}, acceleration 50 ms^{-2} equipped with the optical system of the metering with the accuracy of 0,001 mm from Renishaw.

During waiting for the components for third axis we created the paddle with haptic feedback. This system allows us developing of the control algorithms like PID and MPC (Model Predictive control) [6] and [2]. The haptic paddle uses the DC motor to generate the force to the human arm for the reason of controlling the motor, touch the virtual objects or fill the remote motor forces. This system was programmed using object-oriented programming in c++ language.

All mechanical part of the Smart multifunction production stand was modeled in the software Autodesk Inventor. The movement in the Z-axis ensures the servomotor from B&R, whose rotational movement is transformed to slide through the trapezoidal bar. The servomotor equipped by incremental encoder has the maximum speed 1ms^{-1} and acceleration 10ms^{-2}. The third axis in the direction Z have the effector that includes milling machines, two heads for 3D printing (4D with using the smart material), laser engraving tool, drawing tool and the gripping device (will be extended for automated storage/retrieval machine and machine for package, laser cutting system, saws sharper machine, DPS printing machine, etc.). The device has two extruders to provide material feed and print nozzle heating for the use as a 3D printer. The indispensable part is the heated pad. The design of this device makes it easy to replace the tool (Figure 2 a).

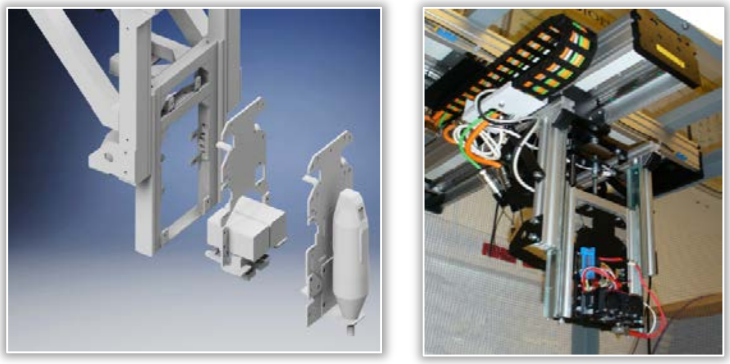

Figure 2. a) Tolls replacing principle, b) real photo with two heads for 3D printing

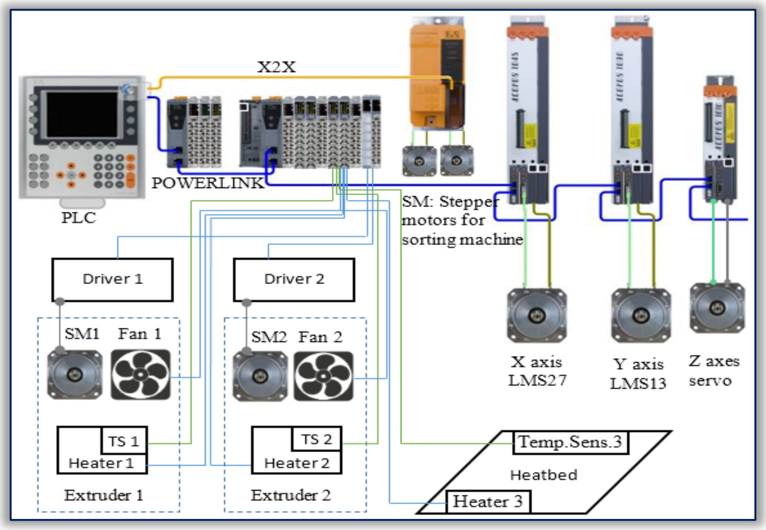

Figure 3. The scheme of the part of the system with 3D printing effector

The PLC PowerPanel 4PP451-0571-75 is used as the control system. The ACOPOS 1010, 1045 and 1090 servo inverters are connected to the PLC via the POWERLINK to control two linear motors and one rotary servomotor [5]. Our solution requires two virtual axes more, to control two stepper motor for the 3D printer effector. The drivers for the stepper motors are connected to the module which generates two PWM signals according to the virtual axes outputs.

Each logical part is programmed as a stand-alone module in the form of a state machine which is operating by the appropriate data structures. The central control program of the device controls each unit separately.

3. VISUALIZATION

The device displays status information by visualizing on the PLC screen. This visualization is also for the operator commands. Second visualization is created in the form of web pages that are located on the integrated PLC web server with possibility to control all the processes and showing the logs. Third visualization is on the raspberry Pi 7" display, displaying the basic information with the basic controls. The last one visualization is made by the light beacon mounted on the device construction and is used as an additional signaling device.

You can control the device by three following ways:

— By buttons located on the PLC Power Panel 400,
— controls in web visualization,
— GUI on Raspberry Pi display.

Internal visualization consists of several pages. It allows turning on/off the motors, select and start the CNC program, set extruder nozzle temperatures, manually control the movement of individual axes, confirm possible error states and show all important information. Visualization was created in Automation Studio as bilingual, supporting the English and the Slovak languages.

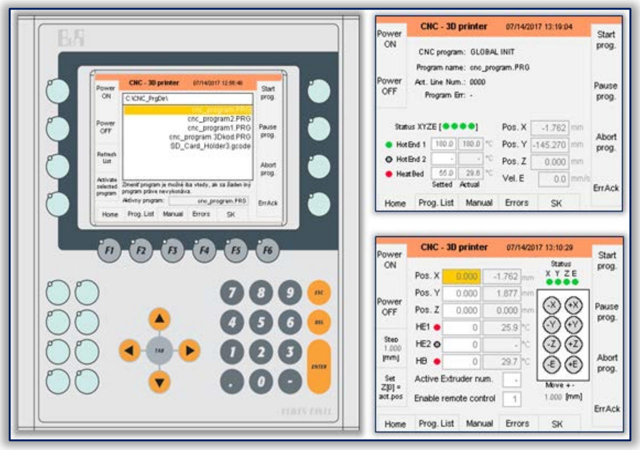

Figure 4. PLC PowerPanel 400 and local visualization pages

Web visualization is created in the form of web pages (Figure 4) that are located on the web server integrated in the local PLC. In addition to displaying information, visualization also allows direct control of the device as well as internal visualization. This remote control can be enabled or disabled by setting in the manual control page in the internal visualization. Web visualization is also available from the Internet because the PLC is networked and has a fixed public IP address. This allows you to control and monitor the CNC device from various end devices (laptop, tablet, mobile phone, ...). To enter the visualization you must first login by entering your login name and password. CNC programs are uploaded via FTP.

Bootstrap framework was used to create visualization. Individual pages are fully responsive and can therefore also be used on mobile devices and tablets as well. Functionality and responses to control are mediated by Javascript and AJAX using the jQuery framework.

The control system performs data collection using the database and data processing during CNC execution (Big data). Industrial manufacturing processes can have data stored in their own datacenter - we are talking about a private cloud. The second option for smaller businesses and the general public is to share the capacities of the datacenter with others – it means the public cloud computing. For data storage, we chose the first option - a private cloud on a powerful computer with a number of connected slave devices. The "advantage" of our solution is the detailed knowledge of the technical details of the cloud. At the same time, each execution of the program is recorded as an act of creating (in case of 3D printing) or machining an object (if used as a CNC cutter or milling machine). Each object records the following information, presented in Figure 5.

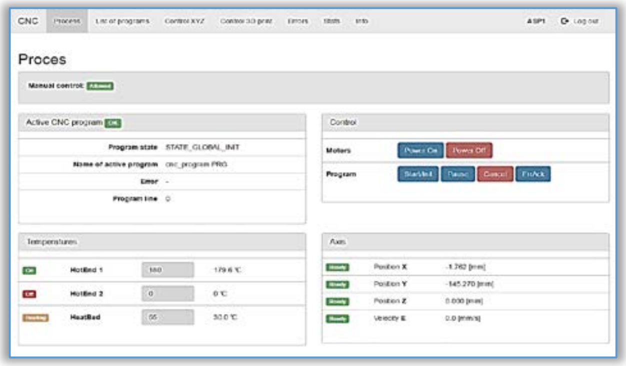

Figure 5. Web visualization using Web Server

— CNC program execution time; the date and time of the program start; date and time of program end; the name of the program; Completion status - Records whether the program has been successfully completed or stopped (manually, caused by an error, ...);
— the CNC program line number that was last executed; the maximum torque reached (*Mmax*) for the X, Y, and Z axes; the CNC program line number at which the *Mmax* was reached; Largest Lag Error (*LagEmax*) for X, Y, and Z axes;
— the CNC program line number at which *LagEmax* was reached; RFID tag code (if assigned); photo (if required); checkout information.

These data are sent from the PLC via HTTP to an external cloud server that processes and stores the data in the database. Each object has assigned the unique identifier to an external server. The storage success information and the current unique identifier are returned in response to a request from the PLC. The list of objects in the visualization web is loaded directly from an external server using AJAX technology (in the tab Stats). If the control system is not temporarily connected to the Internet or to the local network where the server is located, it saves the process data into the internal memory and after the subsequent connection to the network the data is transferred and stored.

Raspberry Pi can be used in the industrial applications as a smart sensor or camera system with image processing equipped by POWERLINK as the slave device (CN) using CiA401 profile (Figure 6 b).

Figure 6. a) SMART multifunction production stand, b) Raspberry Pi 3 Model B

4. TECHNICAL DETAILS

Real-time communication protocol: openPOWERLINK; Raspberry pi linux kernel version: rpi-4.9.30-rt21; communication cycle for CNC: 400us; communication cycle to communicate with Raspberry Pi 3 Model B: 2ms; CNC operating area 1000x700x400 mm; Movement step 0,001 mm; private cloud installed on PC: AMD Opteron 6238, 2 processors, 12-Cores, 3.2 GHz, RAM 64Gb, HDD 2TB; cloud computing software: Apache Spark and Apache server WAMP; PLC programming tool: Automation Studio version: 4.2.

5. PROJECT OUTPUTS

The SMART multifunction production stand is able to make the products according to the customer requirements with the added value –product IT Information. The functionality was tested on 3D printing, 3D milling and drawing machine.

In addition, we wrote the book about the motor control using PLCopen MC standard for students (Jozef Hrbček at all.: Motor control using B&R systems, EDIS 2017, 166 pages, ISBN 978-80-554-1327-3, in Slovak). A second publication entitled "Control system for the haptic paddle, ISSN 1729-8814" was published in an indexed scientific journal [1]. Third publication is the diploma work focused on using of the linear motors (Martin Kucharčík: Application with two linear motors, 2017). During the solution we also solved the problems of secure data transfer over the Internet.

6. CONCLUSION

This work has been an invaluable contribution to our professional growth. All our goals have been met. We also see the benefits in using the acquired knowledge into the teaching subjects „Control systems", „Programming of control systems", „Processes visualization", „Control theory" and „Advanced control theory". New ideas were emerged during the solution of this project, which was transformed into the submission of bachelor's and master's theses for 2018/2019. With our new experience we are able extend the existing device and implement the teaching of POWERLINK and the concept of Industry 4.0 to the curses „Information Communication Networks" and „Communications Security". Innovation of this solution consist in transferring theoretical knowledge about the IoT, openPOWERLINK and cloud in the practical application by creating the SMART multifunction production stand according to the latest trends that are gradually becoming a part of normal practice. Thanks to this project, the possibility of connection between practice and teaching process will be created; even more the students will receive practical insight and knowledge which are recoverable in the industry.

Acknowledgement

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