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Industry 4.0, CPS, IoT, machine monitoring

Jarosław ZUBRZYCKI [0000-0002-7454-8090]*, *Antoni ŚWIĆ* [0000-0003-0405-4009]*, *Łukasz SOBASZEK* [0000-0003-1298-2438]*, *Juraj KOVAC*[0000-0002-7793-9564]***, *Ruzena KRALIKOVA*[0000-0002-9231-7886]**, *Robert JENCIK*****, *Natalia SMIDOVA*[0000-0002-6511-4397]**, *Polyxeni ARAPI*[0000-0003-0009-6041]*****, *Peter DULENCIN*******, *Jozef HOMZA*******

CYBER-PHYSICAL SYSTEMS TECHNOLOGIES AS A KEY FACTOR IN THE PROCESS OF INDUSTRY 4.0 AND SMART MANUFACTURING DEVELOPMENT

Abstract

The continuous development of production processes is currently observed in the fourth industrial revolution, where the key place is the digital transformation of production is known as Industry 4.0. The main technologies in the context of Industry 4.0 consist Cyber-Physical Systems (CPS) and Internet of Things (IoT), which create the capabilities needed for smart factories. Implementation of CPS solutions result in new possibilities creation – mainly in areas such as remote diagnosis, remote services, remote control, condition monitoring, etc. In this paper, authors indicated the importance of Cyber-Physical Systems in the process of the Industry 4.0 and the Smart Manufacturing development. Firstly, the basic information about Cyber-Physical Production Systems were outlined. Then, the alternative definitions and different authors view of the problem were discussed. Secondly, the conceptual model of Cybernetic Physical Production System was presented. Moreover, the case study of proposed solution implementation in the real manufacturing process was presented. The key stage of the verification concerned the obtained data analysis and results discussion.

* Lublin University of Technology, Lublin, Poland, j.zubrzycki@pollub.pl, a.swic@pollub.pl, l.sobaszek@pollub.pl
** Technical University of Kosice, Kosice, Slovakia, juraj.kovac@tuke.sk, ruzena.kralikova@tuke.sk, natalia.smidova@tuke.sk
*** Slovak Academy of Sciences, Bratislava, Slovakia
**** Manex s.r.o, Čaňa, Slovakia, robert.jencik@manex.sk
***** Technical University of Crete, Chania, Greece
****** Spojená škola Juraja Henischa, Bardejov, Slovakia, peter.dulencin@gmail.com, homzaj@gmail.com

1. INTRODUCTION

The key goal of Industry 4.0 (I4.0) is to be faster and increase production efficiency. Industry 4.0 combines a large number of new technologies to create value. The main technologies in the context of Industry 4.0 are Cyber-Physical Systems (CPS) and the Internet of Things (IoT). This approach is considered as a key enabling technology in the Fourth Industrial Revolution (i-SCOOP, 2021).

Cyber-Physical Systems use modern control systems, have embedded software systems and dispose of an Internet address to connect and be addressed via IoT. This way, products and means of production get networked and can "communicate", enabling new ways of production, value creation, and real-time optimization. Cyber-Physical Production Systems create the capabilities needed for Smart Factories (Harrison, Vera & Ahmad, 2016).

In the context of Industry 4.0 (mechanics, engineering, etc.) Cyber-Physical Systems are seen as the next step in the development of continuous production improvement through integration, interaction and communication (Onik, Kim & Yang, 2019). Looking at Industry 4.0 as the next new stage in the organization and control of the value chain during the product life cycle, mechanical systems began, mechatronics and adaptronics were introduced, and Cyber-Physical Systems are now beginning.

Cyber-Physical Systems essentially enable us to make industrial systems capable to communicate and network them, which then adds to existing manufacturing possibilities. They result to new possibilities in areas such as remote diagnosis, remote services, remote control, condition monitoring, systems health monitoring and so forth (Ratchev, 2017).

2. SOME VIEWS ON UNDERSTANDING CYBER-PHYSICAL SYSTEMS

1.1. Definitions of CPS

To understand Industry 4.0, it is necessary to introduce the following keyword "Cyber-Physical Systems" (CPS) which are the core of this topic. "Cyber Physical Systems" are intelligent embedded systems, a combination of electronics and software, which are connected to the real world through sensors and actuators, and are also connected to each other and to the Internet. Thus, the physical world merges with a virtual world to a cyberspace, which is, according to its definition, a combination of digitalized data, creating a universe of information and communication connected through the internet.

In the same way, there are Cyber-Physical Production System (CPPS) dedicated to the industrial field. They collect physical values like temperature, dimensions, displacement, pressure, force, etc. via different kind of sensors. Thanks to their computing capabilities, they can process this data with specific algorithms, for for example for predictive maintenance (Yasniy, Pyndus, Iasnii & Lapusta, 2017), and transfer them e.g. to a MES.

Cyber-physical systems before Industry 4.0: In the original definitions, going back over a decade, IP addresses where not specifically mentioned in Cyber-Physical Systems. In 2008, Professor Edward A. Lee from the University of California, Berkeley, defined Cyber-Physical Systems as follows: "Cyber-Physical Systems are integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa" (Ratchev, 2017).

The term "Cyber-Physical System" was originally coined by Ellen Gill in 2006. CPS is a category of embedded system. It is often called a next-generation computing system that uses intelligent computing techniques associated with the physical world and computing units. CPS can interact with real systems through calculations, communication and controls. The interaction of computational and physical units leads to advanced implementations of the Internet of Things. IoT and CPS are designed to support real-time applications that can manage many sets of environmental data (Sabella, 2018). In other words, CPS is a combination of digital control and the physical environment. The basic scheme of CPS is shown in Fig.1.

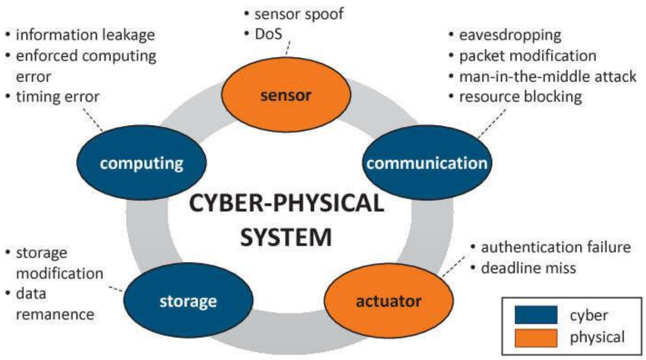

Fig. 1. Basic scheme of CPS

The Cyber-Physical System consists of cybernetic components and physical components, therefore we call it the cyber-physical system. CPS is based on a computer information processing system that is built into a product, such as an automobile, airplane, machine tool, or other device. This computer system interacts with the physical environment through sensors and actuators (Harrison, Vera & Ahmad, 2016).

These embedded systems are no longer separate, sharing their data through communication networks such as the Internet with cloud computing, where data from many embedded systems can be collected and processed (ADDI-DATA, 2015). This creates a system of systems. The collected data can be processed automatically or via the HMI – Human Machine Interface (Fig. 2).

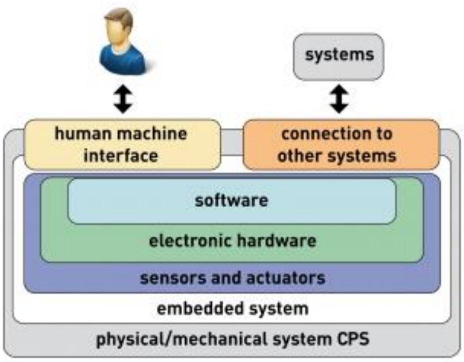

Fig. 2. CPS integrated subsystems (ADDI-DATA, 2015)

In (Schuh et al., 2014) CPS are defined by as cooperating systems, having a decentralized control, resulting from the fusion between the real world and the virtual world, having autonomous behaviors and dependent on the context in which they are, being able to constitute in systems of systems with other CPS and leading a deep collaboration with the human. For this, embedded software in CPS uses sensors and actuators, connect to each other and to human operators by communicating via interfaces, and have storage and data processing capabilities from the sensors or the network (Strang & Anderl, 2014).

The recent one, suggested by (Monostori, 2014), allows a clear synthesis of the various aspects of this large concept, coupling in addition the notion of services with CPS : "Cyber-Physical Systems are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet". To do so, embedded software in CPS uses sensors and actuators, connect with each other and with humans communicating via standard interfaces, and have abilities of storage and processing of data coming from sensors or from the network (Strang & Anderl, 2014). This interconnection of systems, as stated by (Gengarle et al., 2013), derives from the fact that a CPS encompasses together control, computation but also communication devices.

CPS is an intersection, not a union, of that which is considered virtual to that which is physical. It is no longer enough to separately understand, develop, manage and maintain cyber vs. physical components independently. It is necessary instead to understand their interaction.

1.2. CPS structure

Figure 3 shows the structure of a Cyber-Physical System (CPS) schematically. Within a manufacturing system, an embedded system in the sense of a CPS is integrated within physical systems, e. g. the machines. The embedded system includes sensors to gather physical data and electronic hardware as well as software to save, and analyze data. The results of the data processing are the foundation for an interplay with other physical or digital systems by means of actuators.

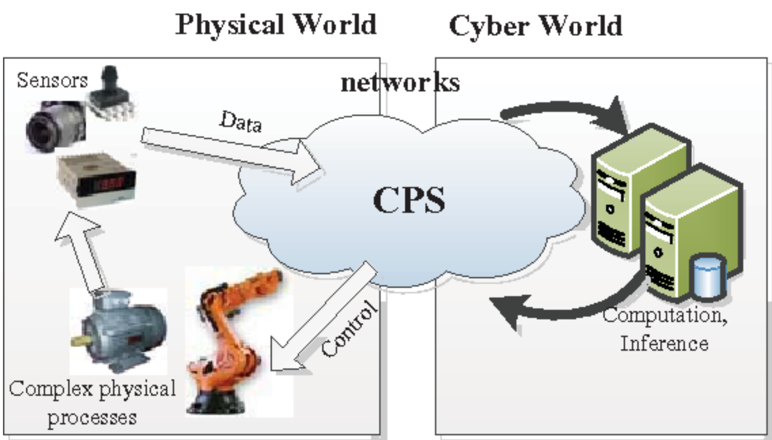

Fig. 3. A typical structure of the CPS

A CPS consists of one or more micro-controllers to control sensors and actuators which are necessary to collect data and interact from its environment. These systems also need communication interface to exchange data with other smart devices and a cloud. Data exchange is the most important feature of cyber physical systems. CPS connected over Internet are also known as Internet of Things.

CPS includes transdisciplinary approaches, combining the theory of cybernetics, mechatronics, design and process science. Process control is often called embedded systems.

Embedded systems are able to monitor and control physical processes by sensors and actuators. CPS are Embedded Systems, but are networked with each other to utilize globally or locally in another CPS available information sources and services. Accordingly, CPSs combine the vision of intelligent, adaptive control systems with seamless vertical, horizontal and dynamic information exchange between heterogeneous platforms (Gengarle et al., 2013).

Thus, CPS are a combination of interacting embedded computers and physical components. Both computation and physical processes work in parallel to bring about the desired output. Computers usually monitor the physical processes via sensors in real-time and provide feedback to actuators.

3. CYBER-PHYSICAL PRODUCTION SYSTEM

Production systems that already have computer technology are extended by network connection (Świć & Gola, 2013). They allow communication with other devices and output information about them. This is the next step in production automation. Networking of all systems leads to “Cyber-Physical Production Systems – CPPS”, and thus to intelligent factories, in which production systems, components and people communicate through a network and production is almost autonomous. The system consisting of data, artificial intelligence, machines and communication is not only automated but also intelligent (Szabelski, Krawczuk & Domińczuk, 2014). The machine is able to collect data, analyze it and make decisions based on this analysis.

The definition of CPPS is from (Cardin, 2019): “Cyber-Physical Production Systems are systems of systems of autonomous and cooperative elements connecting with each other in situation dependent ways, on and across all levels of production, from processes through machines up to production and logistics networks, enhancing decision-making processes in real-time, response to unforeseen conditions and evolution along time”.

The main differentiating requirements within a CPPS are: adaptability, convertibility, and integrality (Fig. 4). At the core of I4.0 lies the idea of constantly adapting systems. Adaptation can happen in structure, function, or both. As such, adaptation can only be implemented if the system components can be integrated with each other (integrality). It additionally requires a relative modular physical structure (convertibility) to support a wide scope of adaptive solutions beyond simple functional adaptation (Vogel-Heuser, Lee & Leitão, 2015).

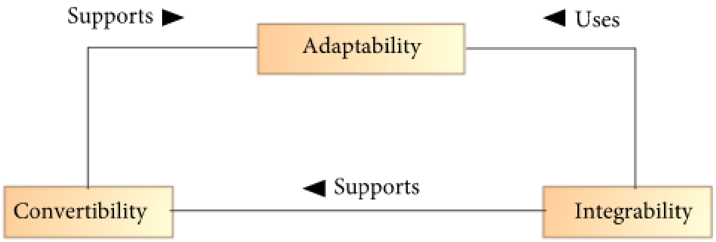

Fig. 4. Associations between the core requirements in CPPS

The extent to which different adaptability, convertibility, and integrality functions are implemented is a direct measurement of the degree of how cyber-physical, at the light of I4.0, a production system really is (Al-Alia, Guptab & Nabulsic, 2018).

The adaptability requirements focus mainly on the expectations on system behavior. It has been accepted for many years now that the ability to adapt to changing conditions is of paramount importance for production systems. The notion of CPPS seems to encompass also the possibility of structural adaptation whereby mobile equipment can even change, in a more or less autonomous way, the factory layout.

The convertibility requirements adaptation is reflected on how the system behaves. Convertibility is about the physical characteristics of the system that ultimately allow it to make use of its adaptive behavior. Modularity is greatly recognized as the prevailing characteristic, and a CPPS should ensure that its components can be combined in different ways to adapt and generate new functions when required. It therefore requires from its CPPM (Cyber-Physical Production Modules) a minimal level of mechanical interfacing and compatibility (Klimeš, 2014).

4. CONCEPTUAL MODEL OF CYBERNETIC PHYSICAL PRODUCTION SYSTEM

The conceptual model of the Cyber-Physical Production System consists of five layers: physical, network, data, analytical and application. The structure of the proposed model was presented in Fig. 5.

Physical layer: This layer consists of sensors, actuators, monitoring devices and computational elements. The real-time data collected from the product sensors can be processed locally by the operator and/or transferred to the cloud for further processing. Based on the system nested processing algorithm, the generated command to command the controls can be executed locally or remotely (Huebner, Facchi, Meyer & Janicke, 2013).

Network layer: CPS and CPPS can access cyberspace using various network protocols such as WiFi, WiMAX, GPRS and 3G/4G/LTE technology. Other IoT-oriented data protocols, such as MQTT, CoAP, AMQP, Websocket, and Node, are used to transfer data from peripheral devices to the cloud for further storage and processing. Each protocol has its advantages over others depending on speed, latency, bandwidth, reliability, security, and scalability.

Storage layer: CPPS systems collect a lot of data from objects that are in the physical layer. This data can be stored on a local server or in the cloud.

Processing and analytical layer: The processing and analytical layer is used to process data using simulation models (Gola & Świć, 2013). With the help of SQL queries, reports, graphs and visualizations, it is possible to generate data for monitoring purposes in almost real time. Data mining techniques such as data aggregation, classification, and regression can be used for predictive maintenance and planning. In this layer, monitoring and control actions can also be transferred back to the physical layer so that some devices and machines can be activated.

Application layer: This layer is the user interface for consumers, operators, manufacturers, third party suppliers and other service providers. It has a user-friendly access to an interface in which the above stakeholders can interact with the CPS layers based on privileged access and priority.

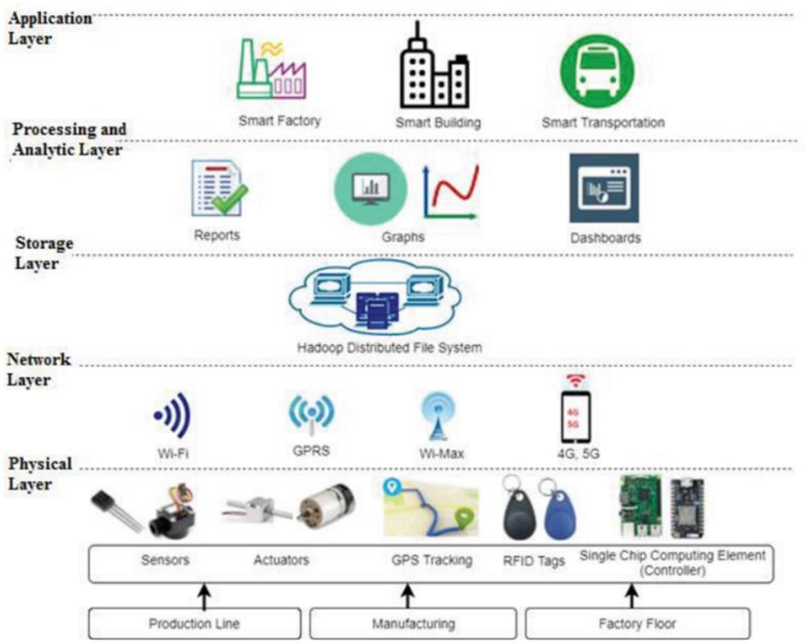

Fig. 5. Cyber Physical production System Conceptual Model

To verify the concept of the proposed model, it was implemented in a real production environment. A detailed description of the proposed solutions as well as the work carried out is presented in Chapter 5.

5. PRELIMINARY STUDIES – CASE STUDY

5.1. Characteristics of the enterprise

Based on the assumptions of the presented concept of a cyber-physical production system, solutions were implemented in a selected manufacturing enterprise dealing with the production of broadly understood fastening systems for the audio-video industry (Fig. 6). Manufacturing processes in a given enterprise are mainly carried out on CNC machines, and the majority of the processes involve machining.

The implementation of the system was aimed at acquiring significant parameters of key technological machines. The collected data allow to obtain a lot of important information that will be used in the process of the machines utilization optimizing and increasing the profitability of production (Gola, 2014).

Fig. 6. An example of the produced assortment

5.2. Implemented monitoring system

The implemented monitoring system was built using components of the solution called COMODIS, which is a wireless monitoring system (ASTOR, 2021). Additionally, the system uses selected industrial automation devices and a computer with appropriate software.

The proposed solution was built in keeping with the structure presented in Chapter 4. Due to the components used, the developed system combined the following layers:

- **Physical Layer** and **Network Layer** – mainly through the use of wireless analyzers communicating with the controller and made data available to the PLC controller (by means of appropriate network protocols),
- **Storage Layer** and **Processing and Analytical Layer –** through the use of a PLC controller that collected data from the controller and then made it available in the form of files easily interpreted by the computer software.

The diagram showing the connections of individual layers and the information flow in the system was presented in Fig. 7.

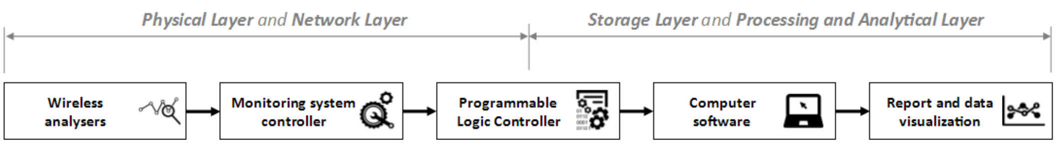

Fig. 7. Diagram of the implemented system

The idea of building the system was to use it in terms of obtaining information on the of the technological machines utilization that include:

– machine working times – determining the degree of machines utilization in total and on individual shifts,
– electricity consumption – constituting the basis for estimating the cost of machines utilization.

In the presented system 5 analyzers (measuring sensors) have been utilized. They have been installed in the control cabinets of the following technological machines:

1. Bending Center.
2. Punching Machine.
3. Press Brake Machine 1.
4. Press Brake Machine 2.
5. Laser.

Mentioned machines are crucial in the production – almost all production processes in the selected enterprise begin from these stations. The scheme of implementation and communication of the system components is presented in Fig. 8.

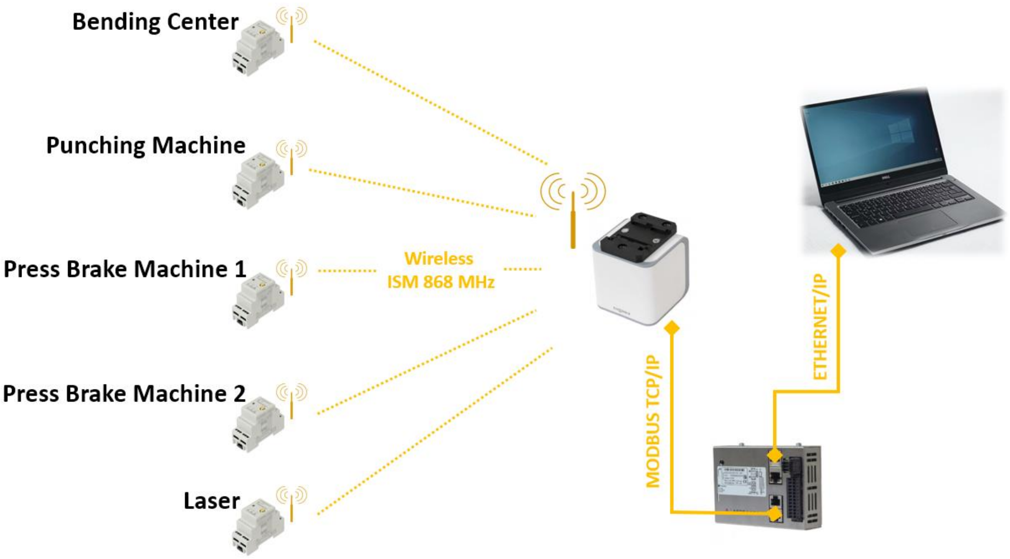

Fig. 8. The system and its components

The main components were the end elements of the system in the form of wireless energy analyzers, which (through the use of transformers) enable the monitoring of the parameters of a three-phase network with a neutral wire. The analyzers communicate with the controller by radio in the 868 MHz band, enabling the monitoring of 30 parameters. Selected parameters of the analyzers are presented in Table 1 (ASTOR, 2020b).

Tab. 1. Basic parameters of the analyzers (ASTOR, 2020b)

Energy analyzer	
Parameter	**Value**
Nominal supply voltage	230 V AC
Power supply frequency	50 Hz
Accuracy of measurement	0.5%
Transmission	Radio – ISM 868 MHz
Transmission method	Bidirectional – 9600 bps, 200 kbps
Working temperature range	0 to + 35 ° C
Mounting method	TH35 (DIN)
Transformer – primary current	100 A
Transformer – secondary current	33.3 mA
Antenna – cable length	3 m
Antenna – connector	SMA

In the presented system, the controller collects information about electricity parameters, but it is possible to expand it with additional sensors that allow you to control, for example, the temperature or the level of lighting. The selected parameters of the analyzers are presented in Table 2 (ASTOR, 2020a).

Tab. 2. Basic parameters of the controller (ASTOR, 2020a)

Controller	
Parameter	**Value**
Nominal supply voltage	5 V DC / 2 A Standard Micro-USB
Power consumption	1.1 W
Operating range	Up to 350 m outdoors
Connectors	RJ45 Ethernet Port, USB micro B 2.0, USB A 2.0
Maximum number of devices (end elements)	~ 255
Temperature range of operation	-10 to + 55 ° C
Mounting method	TH35 (DIN) or free standing
Communication	Radio – ISM 868 MHz (bidirectional – 9600 bps, 200 kbps), Modbus TCP
Analysis of additional parameters	temperature, light intensity

The advantage of the solution is a built-in web application that allows to manage end devices and observe the recorded values of the parameters (Fig. 9).

The controller provides communication via the Modbus TCP protocol with external devices. This possibility was used to integrate subsequent layers of the proposed system. In order to collect the registered data, the Astraada ECC2100 Slim PLC was used. The mentioned PLC is equipped with 4 digital inputs and 4 outputs, 4 analog inputs and communication modules: RS232/RS485 port, 2 configurable Ethernet cards. Additionally, it is equipped with a WebServer, USB port and Micro SD slot (ASTRAADA, 2015).

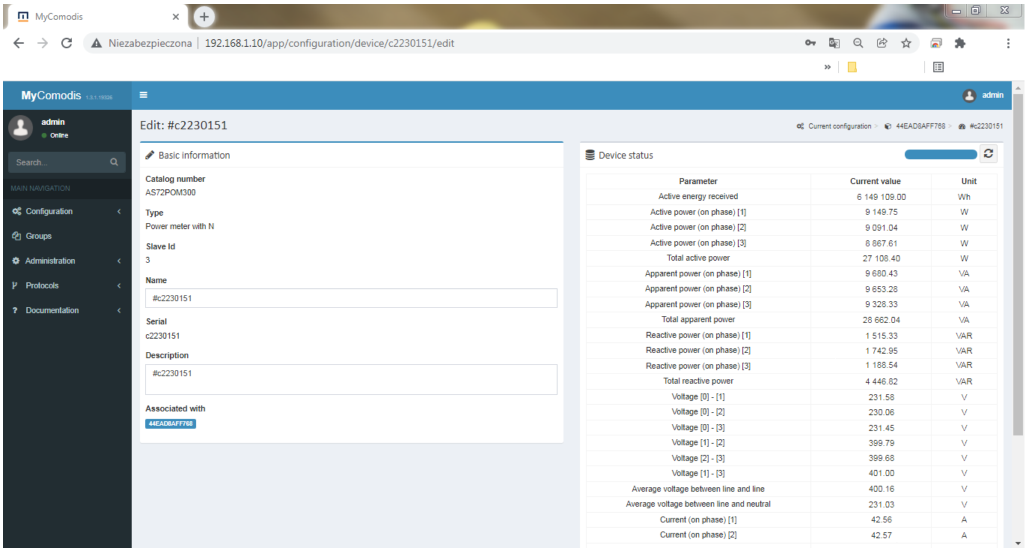

Fig. 9. Access to the main controller from the webservice level

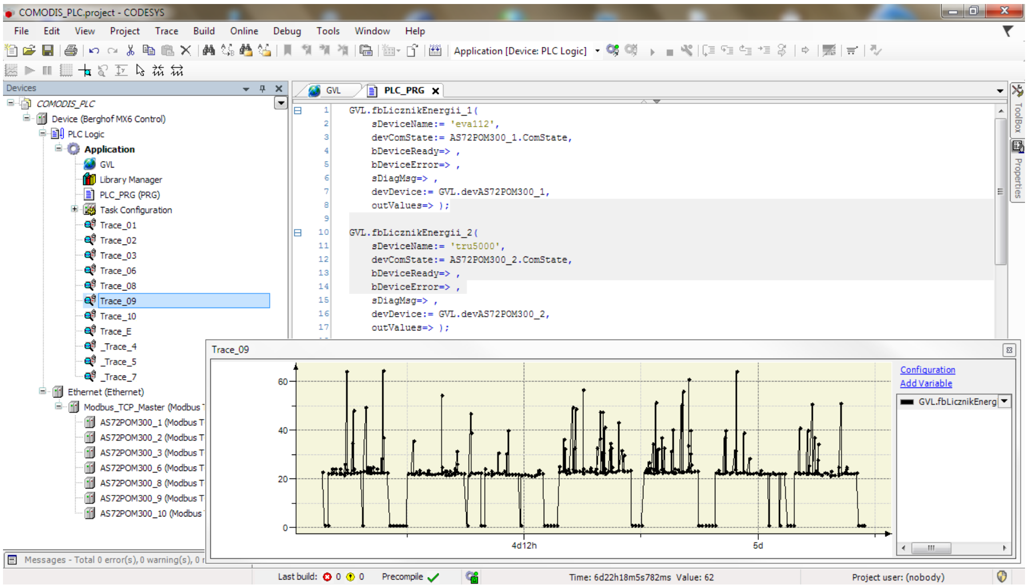

Fig. 10. Data collection using PLC and CODESYS environment

The CODESYS V3.5 (SP15 Patch 2) environment was used to program the controller, which was also used to implement the libraries enabling communication with PLC. As a result, it was possible to save the data recorded by the end elements of the system. Data was recorded at a frequency of 0.1 Hz. The data collection process by means of *Trace* component of the CODESYS environment is shown in Fig. 10.

The data collected with the PLC was exported to a *.CSV files. The use of this format enables convenient data exchange between various computer applications. In the proposed solution, the data was imported to a spreadsheet in which (through the use of appropriate formatting and formulas) the data is presented to the user in a more accessible form (Fig. 11). It is important that through the use of the CSV format, the data can also be used in other specialized applications – for example, the Matlab or the RStudio environment.

RAW DATA	PROCESSED DATA			CHART		
Current [A]	Shift	Hour	Current [A]	Hour	Current [A]	Status
22.375	3	00:00:00	22,38	00:05:00	22,20	1
22.375	3	00:00:10	22,38	00:10:00	22,31	1
22.375	3	00:00:20	22,38	00:15:00	22,17	1
22.25	3	00:00:30	22,25	00:20:00	22,17	1
22.25	3	00:00:40	22,25	00:25:00	22,44	1
22.25	3	00:00:50	22,25	00:30:00	0,84	1
22.25	3	00:01:00	22,25	00:35:00	0,84	1
22.25	3	00:01:10	22,25	00:40:00	2,29	1
22.375	3	00:01:20	22,38	00:45:00	26,53	1
22.375	3	00:01:30	22,38	00:50:00	22,68	1
22.375	3	00:01:40	22,38	00:55:00	24,53	1
22.375	3	00:01:50	22,38	01:00:00	23,64	1
22.375	3	00:02:00	22,38	01:05:00	22,48	1
22	3	00:02:10	22,00	01:10:00	22,46	1
22	3	00:02:20	22,00	01:15:00	22,57	1
22	3	00:02:30	22,00	01:20:00	22,36	1
22	3	00:02:40	22,00	01:25:00	22,72	1
22	3	00:02:50	22,00	01:30:00	22,70	1
22.125	3	00:03:00	22,13	01:35:00	22,42	1
22.125	3	00:03:10	22,13	01:40:00	22,79	1
22.125	3	00:03:20	22,13	01:45:00	22,54	1
22.125	3	00:03:30	22,13	01:50:00	22,31	1
22.125	3	00:03:40	22,13	01:55:00	22,31	1
22.25	3	00:03:50	22,25	02:00:00	22,44	1
22.25	3	00:04:00	22,25	02:05:00	13,87	1
22.25	3	00:04:10	22,25	02:10:00	0,82	1
22.25	3	00:04:20	22,25	02:15:00	0,82	1
22.125	3	00:04:30	22,13	02:20:00	0,82	1
22.125	3	00:04:40	22,13	02:25:00	0,81	1
22.125	3	00:04:50	22,13	02:30:00	0,81	1
22.125	3	00:05:00	22,13	02:35:00	0,83	1

PARAMETERS	
Operating current [A]	10

MACHINE UTILIZATION:	
Idle time [h]:	22,5
Busy time [h]:	19,04
As a percentage [%]:	84,6%

UTILIZATION ON SHIFTS:	
SHIFT 1	
Idle time [h]:	7,5
Busy time [h]:	6,60
As a percentage [%]:	88,0%
SHIFT 2	
Idle time [h]:	7,5
Busy time [h]:	6,48
As a percentage [%]:	86,3%
SHIFT 3	
Idle time [h]:	7,5
Busy time [h]:	5,95
As a percentage [%]:	79,4%

PARAMETERS:	
Avg. voltage [V]	414,84
Avg. power factor [-]	0,79
ELECTRIC POWER CONSUMPTION:	
Daily [Wh]	140003,55
Daily [kWh]	140,00
Per hour [kWh]:	7,35

POWER CONSUMPTION:			
Hour	Current [A]	Power [W]	Inst. Cons. [Wh]
00:05:00	22,20	7275,46	606,29
00:10:00	22,31	7312,33	609,36
00:15:00	22,17	7264,54	605,38
00:20:00	22,17	7264,54	605,38
00:25:00	22,44	7353,30	612,77
00:30:00	0,84	0,00	0,00
00:35:00	0,84	0,00	0,00
00:40:00	2,29	0,00	0,00
00:45:00	26,53	8694,23	724,52
00:50:00	22,68	7433,86	619,49
00:55:00	24,53	8040,15	670,01
01:00:00	23,64	7747,93	645,66
01:05:00	22,48	7368,32	614,03
01:10:00	22,46	7360,13	613,34
01:15:00	22,57	7396,99	616,42
01:20:00	22,36	7327,35	610,61
01:25:00	22,72	7446,15	620,51
01:30:00	22,70	7439,33	619,94
01:35:00	22,42	7346,47	612,21
01:40:00	22,79	7469,37	622,45
01:45:00	22,54	7387,44	615,62
01:50:00	22,31	7312,33	609,36
01:55:00	22,31	7312,33	609,36
02:00:00	22,44	7353,30	612,77
02:05:00	13,87	4545,37	378,78
02:10:00	0,82	0,00	0,00
02:15:00	0,82	0,00	0,00
02:20:00	0,82	0,00	0,00
02:25:00	0,81	0,00	0,00
02:30:00	0,81	0,00	0,00
02:35:00	0,83	0,00	0,00

Fig. 11. Analysis of the collection of data with the use of a spreadsheet

The use of physical layer devices, the implementation of communication at the network level, as well as data collection and processing made it possible to verify the assumptions of the last layer of the system, i.e. the Analytical Layer. At this stage, reports were generated using the collected data. As a consequence, the conclusions were made and the areas of use of the obtained information were defined.

5.3. Use of data – results and conclusions

The data that was systematized and processed with the use of a spreadsheet was used to prepare reports concerning the analyzed machine operating parameters (time and energy consumption). A detailed report was prepared for each machine (Fig. 12), as well as a comprehensive data statement for all machines included in the system (Tab. 3). The results of analyzes prepared with the use of information obtained with the system for a period of one month are presented below.

Generating reports for each of the machines made it possible to determine the load level of each of them. Reports provide key information that is necessary for the effective implementation of production and optimization of the use of machines. For example – based on the report presented in Figure 12 – it can be concluded that with the use of Press Brake Machine 2 on shift 3 it was possible to implement additional work – the machine was occupied only for one half of the available time. This information can be used, for example, in the production planning department during the task scheduling process.

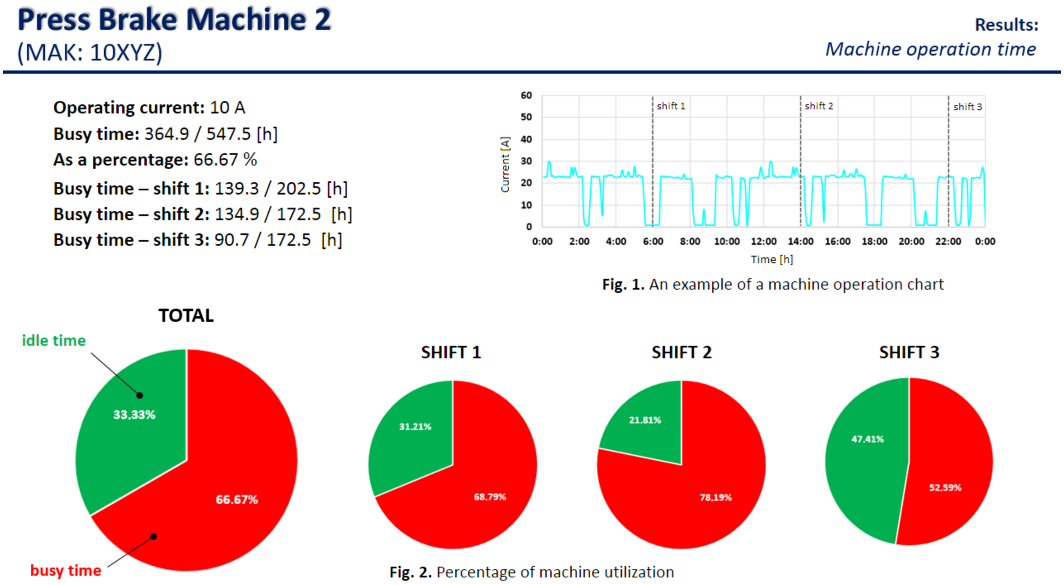

Fig. 12. Report generated based on collected data.

Tab. 3. Operation times for individual machines

ID	NAME	Busy time / available time [h]				Busy time / idle time [%]			
		Shift 1	Shift 2	Shift 3	TOTAL	Shift 1	Shift 2	Shift 3	TOTAL
01	Bending Center	29.0 202.5	73.0 172.5	23.6 172.5	**125.6** **547.5**	14.33 85.67	42.29 57.71	13.70 86.30	**22.97** **77.03**
02	Punching Machine	6.8 202.5	0.0 172.5	14.3 172.5	**21.1** **547.5**	3.35 99.65	0 100	8.31 91.69	**3.87** **96.13**
03	Press Brake Machine 1	129.9 202.5	112.8 172.5	135.2 172.5	**377.9** **547.5**	64.14 35.86	65.36 34.64	78.37 21.63	**69.21** **30.79**
06	Press Brake Machine 2	139.3 202.5	134.9 172.5	90.7 172.5	**364.9** **547.5**	68.79 31.21	78.19 21.81	52.59 47.41	**66.67** **33.33**
09	Laser	146.4 202.5	132.4 172.5	69.1 172.5	**348.0** **547.5**	72.28 27.72	76.76 23.24	40.14 59.86	**63.60** **36.4**

An overview of the operating times of all machines also provides a lot of information. These data can be used in the technology planning department. The variant technology allows some operations to be carried out with the use of other machines in order to relieve the machines with a high degree of load. An example is the use of the Punching Machine, which in the analyzed period was occupied only by 3.87% of the available time, while the Laser was used for 63.60% of the available time.

The implemented system also allowed for the analysis of electricity consumption by individual machines. The obtained results of the analyzes are presented in Table 4. The presented data are the basis for estimating the production costs on a given machine, and are also helpful in the process of orders valuation. Therefore, they provide a lot of information, valuable from the point of profitability of the production.

Tab. 4. Electricity consumption by individual machines

ID	NAME	ELECTRICITY CONSUMPTION [kWh] (for one month)	
		An average per hour	**TOTAL**
01	Bending Center	11.82	1486.34
02	Punching Machine	1.85	39.91
03	Press Brake Machine 1	1.13	428.55
06	Press Brake Machine 2	7.41	2705.68
09	Laser	10.72	3732.60

In order to fully implement the concept of a cyber-physical system, it is necessary to implement the system control in a closed circuit. Although it was not implemented in the area of the presented works, it is fully possible. Then, with the use of appropriate software and an expert system, it would be possible to automate processes and control production – for example by assigning orders based on the current load level, energy consumption or prediction based on obtained historical data. The conducted research proves that the models and concepts presented in this work are reasonable, and their use is the future of production systems.

6. CONCLUSION

It may still seem complicated, but cyber physical systems are complex. Therefore, if we want to understand Industry 4.0 or smart production, it is necessary to understand the essence of the basic technological pillars and the concept of new production, including CPS resp. CPPS, IoT, Big Data, artificial intelligence technologies and more. A significant CPS challenge involves defining and supporting new cooperative engineering paradigms to enable this synthesis of mechanical and software design and development. Physical systems are realized in matter, in contrast to logical systems conceptualized in software. In intersecting the two realms, cyber-physical systems are inherently harder to design, harder to model, harder to analyze, harder to simulate, harder to test, and therefore substantially more difficult to successfully innovate and realize. The implementation example of a monitoring system for selected parameters of technological machines operation presented in the paper confirms the advisability of the use of proposed solutions in practice. They provide a lot of information about the ongoing processes. The efficient data transfer and effective use of information is the basis of the technologies used in CPPS solutions. In the future, CPPS will be present in all industries and, under the Industry 4.0 paradigm, will open new production methodologies that will become tomorrow's industry standard.

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