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Scenarios of machine operation and maintenance in the cyber-physical production systems in Industry 4.0

Scenariusze eksploatacji i obsługi maszyn w cyber-fizycznych systemach produkcji w Przemyśle 4.0

Abstract

The article presents scenarios of machine operation and maintenance in the cyber-physical production systems in Industry 4.0. The inspiration for the publication is the growing popularity of the concept of Industry 4.0. The integration of different technologies: electronics, computer technology, industrial robotics, artificial intelligence etc., have contributed to the change in the ways of machine operation and maintenance (we say about machine we think about robots). Cyber-physical production systems are built with different units, objects, and they are the fundamental pillars of Industry 4.0, completely change the robots service. Traditional technology required continuous supervision, maintenance and operation of machines. Employees were required both during the start-up of the machines and during their operation. Cyber-physical production systems, unlike homogeneous systems, are systems with different elements (components) and characteristics, and the participation of the operators (employees) in these systems is kept to a minimum or completely eliminated. Intangible components of the production system, e.g. computer programmes, data processing and transmission, controls the operation of devices. The goal of this publication is to initiate a discussion about scenarios of changes in the technical exploitation of machines in cyber-physical production systems in Industry 4.0.

Key words:
machine, maintenance, cyber-physical production systems, Industry 4.0

Streszczenie

Artykuł przedstawia scenariusze technicznej eksploatacji maszyn (obiektów technicznych) w perspektywie rozwoju cyber-fizycznych systemów produkcji w Przemyśle 4.0. Inspiracją do powstania pracy jest rosnąca popularność koncepcji Przemysłu 4.0. Integracja różnych technologii, m.in. elektroniki, techniki komputerowej, robotyki, sztucznej czy inteligencji, przyczyniła się do zmiany sposobów eksploatacji maszyn (robotów). Cyber-fizyczne systemy produkcji, będące podstawowym filarem Przemysłu 4.0, całkowicie zmieniają pracę służb utrzymania ruchu. Tradycyjna technologia wymagała ciągłego nadzoru, konserwacji i obsługi maszyn, a pracownicy potrzebni byli zarówno w trakcie uruchomienia maszyn, jak i podczas ich eksploatacji. Cyber-fizyczne systemy produkcji, w przeciwieństwie do układów jednorodnych, są układami o różnych charakterystykach i właściwościach, a uczestnictwo operatorów (pracowników) w tych systemach jest ograniczone do minimum lub całkowicie wyeliminowane. Niematerialne elementy systemu produkcyjnego, np. oprogramowanie, komputerowe przetwarzanie i przesyłanie danych, samodzielnie sterują pracą urządzeń. Celem niniejszej publikacji jest zainicjowanie dyskusji o scenariuszach zmian w technicznej obsłudze i eksploatacji maszyn (obiektów technicznych) w cyber-fizycznych systemach produkcji w Przemyśle 4.0.

Słowa kluczowe:
maszyny, eksploatacja, cyber-fizyczne systemy produkcji, Przemysł 4.0.

JEL: M11

Introduction

In order to ensure the safe operation of machines and continuous production, it is necessary to diagnose machines that provide information about their operation (productivity) and form the basis of the decision-making process. Parts and components of machines are naturally worn during machine operation. Both older and new machines are affected by failures and stops. Even the short (small) breakdown of the machine (micro stop) is causing losses for companies that find it increasingly difficult to rebuild due to strong competition in the market. In World Class Manufacturing (WCM), companies still reduce cost by TPM. Effective planning, coordination and control of machine increase the efficiency (productivity) and availability of machines for production. Even with a high level of automation and robotics, used machines must be subject to activities known as maintenance — i.e. activities aimed at ensuring the machine operation.

Industry 4.0 is called the smart manufacturing because production is realized by smart machines (industrial robots and manipulators etc.). In Industry 4. 0 smart machines in established areas are self-perfect by learning. Technology of learning machine in Industry 4.0 is called smart machine. Employees observe the machine operations by mobile equipment and computer system. Visual systems help them coordinate machine operations and their productivity. Modern companies invest in the new technology to stay competitive in the market, although buying industrial robots and manipulators is an costly investment, more and more companies decide to invest (the main customer for industrial robots: the automotive industry, the metal industry, the electronics industry, the food and beverage industry, the glass industry, the pharmaceutical and medical devices industries, and the photovoltaic industries) (more information: https://ifr.org/). An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications (ISO 8373:2012). Industrial robots are managed by the mechanism servo or other one (Spong and Vidyasagar, 1997; Honczarenko, 2004).

In Industry 4.0 the old technology is gradually being displaced by the new technology (according to PwC Report (2019): two technology trends will be on the robot market in the next years: the combination of collaborative robots and mobile platforms in big companies and the growth of market for robot leasing for small and medium-sized enterprises (SMEs)), and new decision-making problems appear. The scenarios of changes in the machine operating process during the period when old technology is changed by new one is the content of this publication.

Machine operation and maintenance in Industry 4.0

There is no universal definition of Industry 4.0. Industry 4.0 is a definition for new technical solutions and organization of production in cyber-physical systems. Industrial changes are made throughout the all value chain (Hermann et al., 2015). Industry 4.0 creates new opportunities for companies and customers in the market. Smart production is a combination of intelligent manufacturing technology with IT. Full automation in production, many industrial robots and manipulators, is the key trend in Industry 4.0. The Industry 4.0 creates several pillars. These pillars are: cyber-physical systems (CPS), Internet of Things (IoT), computer cloud, smart factory, Big Data, advanced analytics, cyber security, smart production, personalised products, smart supply chain (Rüßmann et al., 2015; Fatorachian and Kazemi, 2018; Jasperneite, 2012; Kagermann et al., 2013, Lasi et al., 2014). Smart conditions in industry create: smart solutions, smart innovations, smart supply chain, smart factory, smart products and smart services (Santos et al., 2017; Erboz, 2017).

In these conditions the machine operation and maintenance is different from machine operation and maintenance in old technology. The machine operation and maintenance in Industry 4.0 is a collection of all technical and organisational activities that are designed to enable the machine to perform the required functions (operations) and perform operations in smart conditions. Smart machines in Industry 4.0 are part of cyber-physical production systems (CPPS). CPPS is the integration of computers and physical processes (Lee, 2006).

Machines in cyber-physical production systems collect data, analyze process and control physical production. Industrial robots are more faster, more perfect and more smart than old machines (Rudtsch et al., 2014; Wang et al., 2015, Lee et al., 2015). Computers with access to network communication systems control particular machines. Device operating algorithms embedded in control devices are aimed at reducing equipment failure and increasing performance (Garg and Deshmukh, 2006, p. 205). Computers and Internet create new machine diagnostic scans. Machine tracking is continuous in Industry 4.0 (Gubbi et al., 2017). This is dynamic control of all machines in real-time and big datasets are created (during the process).

Monitoring machine performance is very detailed. Multifactor analysis provides information about different individual machine components and efficiency (productivity). Computers use data collected from both IoT and traditional systems and focus on detecting problems in machine operation before they become serious and cause downtime in the production (Almada-Lobo, 2016). Computers and networks transfer sensor data to local gateways to quickly analyse and filter them and service information to smart machines, that make decisions about their operations. Moreover they are uploaded over the Internet to cloud computing systems and service them for large number of users. The software can store data and perform the analyses needed to

Table 1
More important differences between traditional machine and smart machine

Traditional	Smart
Machine control by operators (process size control and adjustment)	Industrial robots and industrial manipulators work without operators
Analysis of machine parameters on the based on average statistics of their work (analysis of machine performance)	Programming and adjusting machine parameters to new situations in machine performance
Ignoring the effect of non-measurable volumes on machine operation	Taking into account the impact of non-measurable volumes on machine operation by playback and simulations
Alarming parameter limits (border control, emergency information, stopping machine in case of damage)	Monitoring, surveillance and visualization of machine operation, and coordination of machines in CPPS by computers and intelligence solutions (techniques). The ability to shape the properties and behavior of the system by learning function. Machines achieve such a degree of processing intelligence that they are responsible for all operations.
Transmission of machine data within the enterprise (company)	Transmission of machine data out of enterprises (companies) by Internet and cloud computing
Limited machine productivity capabilities in real conditions in conventional production systems	Many ways to increase machine productivity by machine learning and building different components of machines in the CPPS (machine
Homogeneous technical solutions: machines selected for the manufacturing process	cooperation by using of equipment with different operating functions and coming from different areas of technologies)
Operation of machine by employees (machine operators): maintenance both during machine start and during machine operation	Operation of machine by intelligence technologies (machine learning with a coacher or without of him)

Source: own study on the basis of Olszewski, 2006, p. 17.

detect trends and identify potential problems in the used machines (Piątek, 2019). Traditionally, algorithms, based on average statistics are replaced by artificial intelligence, which uses a variety of technologies, such as machine learning, deep learning, cognitive algorithms and complementary learning (Lee, Ardakani et al., 2015; Piątek, 2019).

Machine learning focuses on real machines problems by processing of big data and learning from them. Deep learning uses neural networks to process unimaginable amounts of data. Cognitive computing is a subset of artificial intelligence algorithms. Computers learn, remember, and conclude based on associative memory (like people's thinking). Different forms of learning machines create complementary learning. Different types of AI specialize in solving different types of problems. The simultaneous use of many of them allows machines to gain additional knowledge about their operations. In Industry 4.0, it aims to improve different algorithms so that machines are able to learn themselves. Machine learning can be with teacher (machine coacher) or without of him. In the first situation algorithms are taught specifically by the operators to detect errors. They are given a subset of data with emergency situations to remember and prevent devices from remembering such situations. In the second, machines work on datasets without the help of operators. The result is a set of automatically found patterns, based on collected data that can be applied to existing situations. When the situations change, the machines again learn. In the traditional maintenance are two levels: autonomous and professional maintenance (Elliot and Hill, 1999; Legutko, 2009, Gajdzik, 2014), and in CPPS is added the level of predictive maintenance (Wang, 2016, Patel, 2018, Elliot, 1999; Durmus, 2019). Based on machine data, device failure can be predicted.

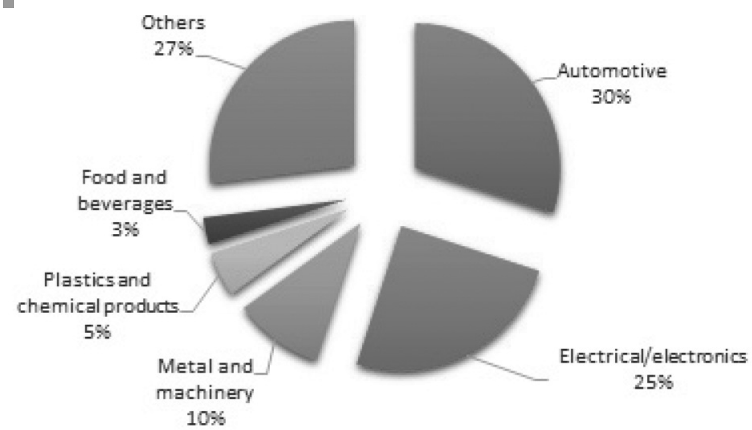
The goal of maintenance is "zero accident" in real conditions of machine work by using different data (Wang and Wang, 2012). This goal is more realistic in cyber physical production systems because the synergy between different technologies (mechanics, electronic control, computers, software, artificial intelligence) improves machine productivity (Patel, 2018). In table 1 the difference between used technologies is presented.

The industrial robots market — information from report IFS

The new technology in Industry 4.0 gradually displaces old technology. There are many companies with different technologies (older or newer) in the market. Industrial robots and manipulators have long been used in companies (from 60. 20-th century), but in smart systems their role is new. They together with software and computer processing and transfer of big data can work without human workers (operators). Smart robotics technologies enable companies to react to changing infrastructural conditions, varying capacity requirements, requirements for greater product variety and consumer trends in an agile and effective manner. According to report IFR (2019, p. 13) there are more and more industrial robots in particular sectors of industry (figure 1).

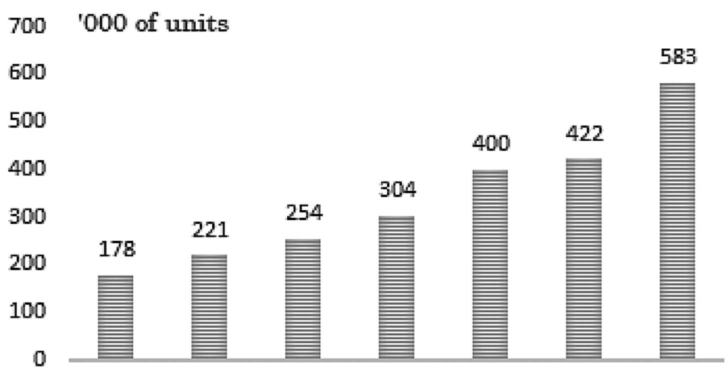
According to report IFR — International Federation of Robots (2019, p.13–16): "Since 2010, demand for industrial robots has risen considerably due to the ongoing trend toward automation and continued technical innovations in industrial robots. From 2013 to 2018, annual installations increased by 19% on average per year (CAGR). Between 2005 and 2008, the average annual number of robots sold was about 115,000 units, before the global economic and financial crisis caused robot installations to fall to just 60.000 units in 2009 with lots of investments being postponed. In 2010, investments made leeway and drove robot installations to 120.000 units. Until 2015, annual installations had more than doubled to almost 254.000 units. In 2016, the mark of 300.000 installations per year was crossed and in 2017, installations surged to almost 400.000 units. In 2018, global robot installations increased by 6% to 422.271 units, worth USD 16,5 billion (without software and peripherals). The operational stock of robots was computed at 2.439.543 units (+15%). (...) World forecast: until 2022:583.520 units, + 12% per year on average from 2020 to 2022". The end of 2018, 2,4 million units of industrial robots have been in operation worldwide. From 2020 to 2022, almost 2 million units of new industrial robots are expected to be installed in factories around the world. Total global annual sales will reach over 583.000 units in 2022 (figure 2).

Figure 1
The share of particular industries in total robots in the world



Source: Report IFR, 2019, p. 13.

Figure 2
Annual installations of industrial robots in 2013–2022



Source: World robotics, IFR, 2019.

Scenarios of machine operation and maintenance in cyber-physical production systems

In Industry 4.0, two forms of industrial robots are in the market:
1) traditional industrial robots
2) collaborative industrial robots (figure 3).

Moreover two forms of robots adoption are developed in Industry 4.0: traditional (today) and smart (tomorrow) (IFR, 2019). More information about two forms in table 2.

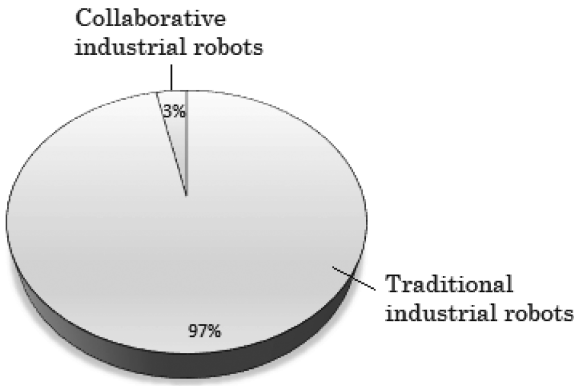
Scenario 1: The cyber-physical system is exploiting until the loss of its reliability. After loss of work ability, the system is subject to radical changes: new machines and better industrial robots are put into the system. The technical facilities of new machines are higher than old ones. In new situation, the new forms of cooperation between new machines are created. In traditional technology, such a scenario was implemented in relation to simple irreparable objects (traditional technology) (Kazimierczak, 2000, p. 21). In the cyber technology, this scenario concerns a situation where the system has lost its ability to adapt to the new situation and new environment. The new situation has outgrown the capabilities of the system, and a new technology has appeared on the market, which replaced the existing one.

Table 2
Today and tomorrow robot adoption

Today	Tomorrow
■ more intelligent components in production systems	Machine learning" enables industrial robots ■ to learn by trial-and-error or by video demonstration ■ to self-optimise ■ to communicate with other machines to improve entire processes
■ greater connectivity of technology by interfaces and cloud computing	New business models, e.g. Robots as a Service (RaaS)
■ easier using of machines (robots) by demonstration programming and visualization	

Source: Report, IFR, 2019.

Figure 3
Collaborative and traditional robots in 2018 in the world



Source: IFR (Press Conference 18th September 2019 Shanghai).

The differentiation of technical solutions (technological development) in cyber-physical production systems allows me to present four scenarios for changes in the machine operation and maintenance. The scenarios are images of the analyzed situations in different variations of their changes.

Scenario 2: Particular elements (components, objects, machines, units) are gradually replaced by new ones in the cyber-physical systems. The investments are carried out over fixed intervals of time. The individual operating parameters of the machines are analyzed but the condition of machines is estimated in the aspect of their useful functions for development of cyber-physical systems (on the base of: Kazimierczak, 2000, p. 21). By autonomous and professional maintenance, the machines are adapted to the new situations. Workers (managers) decide when the particular elements of machines in CPPS will be replaced new ones.

Scenario 3. The cyber-physical system is equipped with an increasing number of intelligent objects (machines) that adapt to new situations themselves. Systems collect information and flexibly adapt to each situation and environment. When it comes to technical operation, the process of learning machines allows them to simultaneously renew fitness through preventive maintenance with limited human participation. The process of learning changes by machines is an imitation of human thinking.

Scenario 4: The cyber-physical system is constantly adapting to new situation and environment. Smart machines collect information and flexibly adapt to each situation, and are able to anticipate further one, thanks to the predictive decision-making systems that are based on historical data. As regards technical exploitation, this scenario covers actions defined by predictive maintenance. However, smart predictive maintenance is possible after some time after the start of the system, it must take some time for the devices to learn and overtake reality (Durmus, 2019). New form of service will be developed, that will be called: Robots as a Service (RaaS).

Summary

In recent years, the popularity of the concept of Industry 4.0 has been growing. The new concept is based on the synergy of different technologies (electrical, electronic, computer, communication, mechanical, etc.) and mobile platforms. In this industry, smart machines are part of CPPS. In new reality smart machines (collaborative robots) relieve employees. Smart machines can adopt to new situation and environment. The problem of machine operation and maintenance in CPS was the content of the publication. Presented scenarios of machine operation and maintenance may be the subject of further scientific discussion. This discussion can help to reduce the gap in knowledge on the presented subject.

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