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Application of Cyber-Physical Systems (CPS) in manufacturing systems: A bibliometric study

IVAN CORRER
Methodist University of Piracicaba – UNIMEP
MAIARA AMANDA VIEIRA
Einstein Integrated Colleges of Limeira - FIEL
FERNANDO MERCURI NICOLA
Einstein Integrated Colleges of Limeira - FIEL
MILTON VIEIRA JUNIOR
Methodist University of Piracicaba – UNIMEP
ALEXANDRE TADEU SIMON
Methodist University of Piracicaba – UNIMEP

Abstract

The industrial production of the future will be characterized by a strong individualization of products under highly flexible production conditions. In this context, the concept of Industry 4.0 emerges, covering the most recent technological innovations in the fields of automation in conjunction with information technology. One of these innovations are cyber-physical systems (CPS) that enable integration with manufacturing systems, aiming at making intelligent decisions through real-time communication and cooperation with humans, sensors, machines and processes. In this context, this article aims to present a bibliometric study related to the application of cyber-physical systems (CPS) in manufacturing systems in the last 10 years (2008-2018), aiming to identify the main authors, research and countries that study and relate the theme. The research was carried out using the Scopus, Web of Science and Science Direct databases. With the results obtained, related to the number of publications by author, citations of articles, publications by institution, citations by countries and publications in scientific journals, it can be concluded that the topic addressed has grown annually and has become of great relevance for the emergence and development of new applications with the use of cyber-physical *systems in manufacturing systems, a concept related to that of intelligent manufacturing, scope of industry 4.0.*

Keywords: Cyber-Physical Systems; Manufacturing systems; Bibliometric study.

1. INTRODUCTION

In the context of future-oriented industrial production and its respective technologies in constant improvement, the concept of Industry 4.0 emerges. This industrial concept covers the most recent technological innovations in the fields of automation in conjunction with information technology, being subsequently applied in manufacturing processes (KAGERMANN et al., 2016).

In the era of Industry 4.0, manufacturing systems are able to monitor physical processes, create the so-called "digital twin", also known as the Cyber-Physcal System (CPS) and make intelligent decisions through communication and cooperation in real time with humans, machines, sensors and so on (RAJKUMAR et al., 2010; WANG et al., 2016).

Through the PHC many identify the opportunity for the fourth industrial revolution. The first industrial revolution contributed to the first mechanical loom, in 1764, the second to the assembly of Ford, in 1913 and the third to the first PLC in 1968. It is anticipated that the CPS may bring about a great leap similar to the previous innovative inventions mentioned (KAGERMANN et al., 2016).

With regard to manufacturing systems, the industrial production of the future will be characterized by the strong individualization of products under highly flexible production conditions (large series), the extensive integration of customers and business partners in business and value-added processes, and the link between production and high quality. Quality services that lead to so-called hybrid products (MEJJAULI et al., 2014; KAGERMANN et al., 2016).

In this context, this article aims to present a bibliometric study related to the application of Cyber-Physical Systems (CPS) in manufacturing systems in the last 10 years (2008-2018), aiming to identify the main authors, research and countries that relate this theme.

2. THEORETICAL FRAMEWORK

2.1. Industry 4.0

With the demand for quality standards in processes and products, added to the growing demand and technological innovations arising from what is already considered the fourth industrial revolution, there is a need for autonomous production controls, decreasing the chance of human error and accelerating the entire production chain process. (YU et al., 2011).

The industry is at the threshold of the fourth industrial revolution. Driven by the internet, the real and virtual worlds are getting closer and closer to form the Internet of Things (MONOSTORI, 2016).

Industry 4.0 combines integrated production system technologies with intelligent production processes, paving the way for a new technological era that will fundamentally transform industry value chains, production value chains and business models (ZHONG, 2017). Figure 1 presents the concept of integration of industry 4.0.

Figure 1 - Industry 4.0 integration concept

Source: Bauernhansl (2013)

According to Shen (1999), industry 4.0 consists of intelligent level manufacturing, thus being able to take advantage of advanced technological information and manufacturing technology, thus obtaining an intelligent, configurable and flexible manufacturing process, serving a global market.

Kagermann et al. (2013) states that the fourth revolution mainly affects the manufacturing industry, providing new products, optimized decision making and the ability to serve individual customers.

To accompany this industrial development, manufacturing systems have to be reconfigured so that they are able to absorb information and apply it to manufacturing processes, making them flexible, adaptable and intelligent in order to meet the new dynamic and global format of consumer market. This strategy was planned to offer a new potential to the manufacturing industry, such as meeting the individual requirements of customers, optimizing decision making and adding new capabilities to products (CONTRERAS et al. 2017).

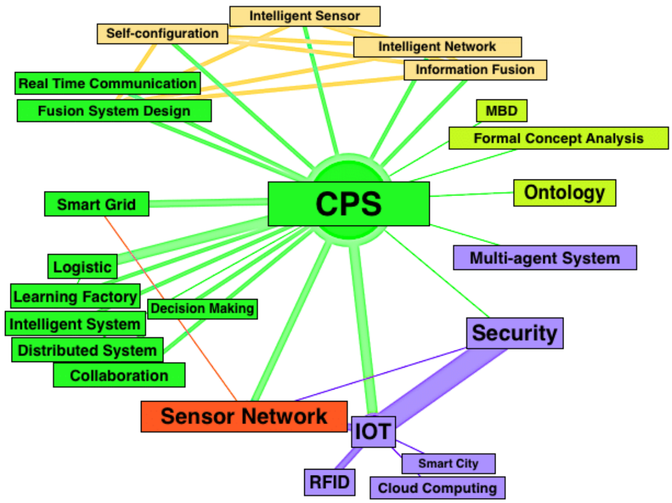
2.2. CPS (Cyber-Physical Systems)

Many researchers point to the origins of CPS for embedded systems, which are defined as a computer system within some mechanical or electrical system, designed to perform specific dedicated functions with real-time computing restrictions. According to this conception, in the CPS, several embedded devices are connected in a network to detect, monitor and act physical elements in the real world. (PARK et al., 2012).

The CPS can generally be characterized as physical engineering systems whose operations are monitored, controlled, coordinated and integrated by a computing and communication nucleus. (RAJUKMAR et al., 2011).

Lee (2015) states that the CPS is the intersection, not the union, of the physical with cyberspace. It is not possible to understand them separately, but rather their interaction. The potential of CPS to change all aspects of life is enormous. Concepts such as autonomous cars, robotic surgery, smart buildings, smart grid, smart manufacturing and implanted medical devices are just a few practical examples that have already emerged (NIST, 2013). Figure 2 shows the intersection of physical and cyber space.

Figure 2 - Intersection of physical and cyber space



Source: Monostori et al. (2016)

Within global supply networks, machines, storage systems and production facilities will incorporate the form of CPS. These systems will exchange information autonomously, triggering actions and independently controlling themselves within an intelligent factory. (ZÜHLKE, 2010).

In production systems, the concept of cyber-physical production systems - CPPS (Cyber-Physical Production Systems) is presented, which consist of autonomous and cooperative elements and subsystems that are connected based on the context within and at all levels of production , from processes, through machines, to production and logistics networks. (MONOSTORI et al., 2016).

Three main characteristics of cyber-physical productive systems should be highlighted here: Intelligence, that is, the elements are able to acquire information from their surroundings and act autonomously; Connectivity, that is, the ability to configure and use connections with the other elements of the system - including human beings - for cooperation and collaboration, for the knowledge and services available on the Internet; Ability to respond to internal and external changes. (MONOSTORI et al., 2016).

The layer of cyber physical devices, when properly implemented and with the necessary redundancy, is capable of providing status control through sensors and providing adjustments to any stage of manufacturing operations through actuators. (BABICEANU et al., 2016).

2.3 Manufacturing systems

With regard to manufacturing systems, the application of CPS aims at the search for intelligent manufacturing with the objective of optimizing production and product transactions, making full use of advanced information and manufacturing technologies (HOFFMEISTER, 2017).

Researchers present a tendency towards Cyber-Physical Manufacturing Systems - M.CPS (Manufacturing Cyber-Physical Systems) that aim to deal with real operations in the physical world and, at the same time, monitor them in the cyber world with the help of advanced models processing, data simulation of manufacturing processes and operational levels of the system (BABICEANU et al., 2015).

The manufacturing domain is driven by events and, often, these events are collected through sensors and / or executed by actuators. Any action, activity or change in the monitored parameter, which influences the operational status of a manufacturing process or system, is seen as an event (BABICEANU et al., 2016).

In recent years, with advances in sensor and communication technologies, there has been an increase in the volume of research in the areas of Internet of Things (IoT) and cyber-physical systems aimed at manufacturing systems (HOFFMEISTER, 2017).

3. RESEARCH DEVELOPMENT METHODOLOGY

For the development of the research, a bibliometric study was used that was introduced as an analysis technique by Pritchard in 1969, which allows a quantitative diagnosis of the literature (SUN, WANG, HO, 2012).

According to Small (2003) and Gumpenberger and Gorraiz (2012), the bibliometric study aims to measure and monitor scientific production in several areas, in order to increase the performance of research and evaluate its trends, researching characteristics such as:

authorship, sources research, themes, geographical origins, citations and co-citations.

The methodology adopted for the realization of this article was composed of three stages: search for articles, analysis of articles and synthesis of results, in order to identify the researches that relate the application of cyber-physical systems in manufacturing systems.

For the search and selection of articles, a research protocol was developed and applied in order to define the inclusion and exclusion criteria of the texts to be used in the bibliometric study. The search for the articles was completed on 01/04/2018. Table 1 shows the research protocol used.

Table 1 - Research protocol

Criteria	Description
Database	*Scopus, Web Of Sciece, Science Direct*
Keywords	*"cyber-physical systems" AND "manufacturing systems" OR "cyber-physcal production systems" AND "manufacturing systems"*
Contains keywords	Title, Summary, Keywords
Period	2008-2018
Area	Engineering
Publication	Article
Search	Journals
Language	English

4. RESULTS AND DISCUSSIONS

From the search for articles using the inclusion and exclusion criteria defined in the research protocol, the following number of articles was obtained from the databases searched (Chart 2).

Table 2 - Number of articles found in the databases

Database	Description
Scopus	63
Web Of Science	20
Science Direct	10
Total	**93**

Among the 93 articles researched and selected, 18 articles were duplicated. After reading the title, summary and keywords of the articles, performed by 2 researchers involved, it was defined that 25 were aligned with the theme and were considered relevant to the study. The selection process is shown in Figure 3.

Figure 3 - Article selection process

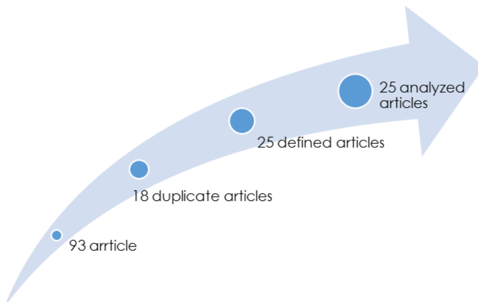
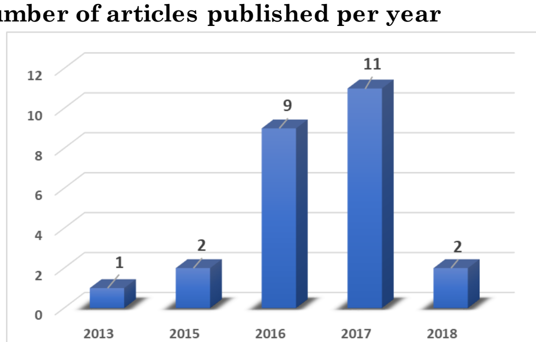


Figure 4 shows the evolution of research on the theme from 2008 to 2018 (considering the 25 selected articles). It is observed that the majority of studies are recent, being published in the last 5 years (2013 to 2018).

Figure 4 shows the evolution of research on the theme from 2008 to 2018 (considering the 25 selected articles). It is observed that the majority of studies are recent, being published in the last 5 years (2013 to 2018).

It should be noted that the number of articles in the period of 2018 is related only to the research published until April 1, 2018 (period of the search for articles), so this decrease in publications must be disregarded for analysis.

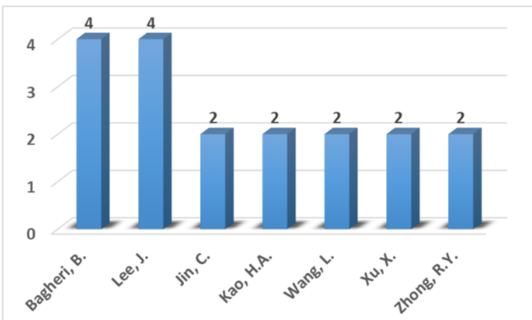
Figure 4 - Number of articles published per year



As can also be seen, it is possible to identify an increase in research on the theme year by year, which demonstrates an increasing interest from authors and researchers on the subject. The increase in the number of publications has been influenced mainly by the greater interest in research related to the concepts of Industry 4.0.

Figure 5 shows the authors who publish the most on the subject, and, as can be seen, researchers Behrad Bagheri and Jay Lee are the ones who have the largest number of article publications (four) and five authors have two articles published. It should be noted that seventy-one other authors published an article on the topic.

Figure 5 - Number of publications by authors



This dissolved result of authorship of the articles related to the theme, is mainly due to the growth and interest in the last years of the authors on the researched subject. As the subject is still new, there is still no reference base of authors on the subject, which may happen in the near future with advances in research related to cyber-physical systems in manufacturing environments.

Table 3 presents the list of the 10 articles with the highest number of citations. As can be seen, the article "A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems" published in 2015, appears in first place with 384 citations. The second most cited article was "Recent advances and trends in predictive manufacturing systems in big data environment" published in 2013, with 151 citations. The number of citations for each article was obtained from the databases searched until 04/01/2018.

Table 3 - Number of citations of articles

Authors	Title of Articles	Year of Publication	Number of citations
Lee J., Bagheri B., Kao H.-A.	*A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems*	2015	384
Lee J., Lapira E., Bagheri B., Kao H.-A.	*Recent advances and trends in predictive manufacturing systems in big data environment*	2013	151
Monostori L., Kadar B., Bauernhansl T., Kondoh S., Kumara S.,	*Cyber-physical systems in manufacturing*	2016	81
Babiceanu R.F., Seker R.	*Big Data and virtualization for manufacturing cyber-physical systems: A survey of the current status and future outlook*	2016	24
Lee J., Bagheri B., Jin C.	*Introduction to cyber manufacturing*	2016	19
Harrison R. Vera D., Ahmad B.	*Engineering Methods and Tools for Cyber-Physical Automation Systems*	2016	16
Thramboulidis K., Christoulakis F.	*UML4IoT—A UML-based approach to exploit IoT in cyber-physical manufacturing systems*	2016	12
Iarovyi S., Mohammed W.M., Lobov A., Ferrer B.R., Lastra J.L.M.	*Cyber-Physical Systems for Open-Knowledge-Driven Manufacturing Execution Systems*	2016	10
Yao X., Lin Y.	*Emerging manufacturing paradigm shifts for the incoming industrial revolution*	2016	9
Garetti M., Fumagalli L., Negri E.	*Role of ontologies for cps implementation in manufacturing*	2015	9

As can be seen, of the ten articles with the highest number of citations, authors Behard Bagheri and Jay Lee stand out, that of the four published articles, three of these are among the most cited. This situation shows a clear tendency of these authors as a reference of the studied theme.

Regarding the number of authors from the countries that published the most (Figure 6) and the ranking of institutions with the largest number of publications (Figure 7), the United States stands out with 10 authors who published on the topic, and in relation to institutions the Universty of Cincinnati stands out with 4 publications, and with 2 publications each, The Royal Institute Of Technology and Universty Of Auckland. It should be noted that seven other countries have an author on the subject and that forty-two other institutions have published an article on the subject.

Figure 6 - Number of publications by authors by countries

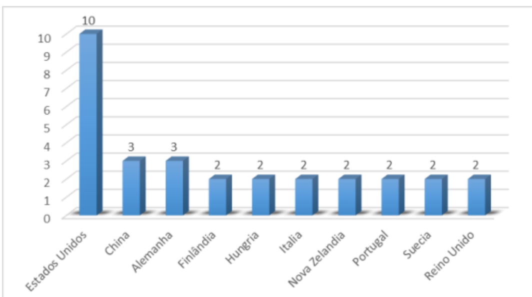
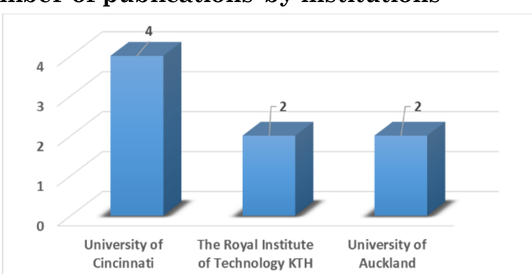


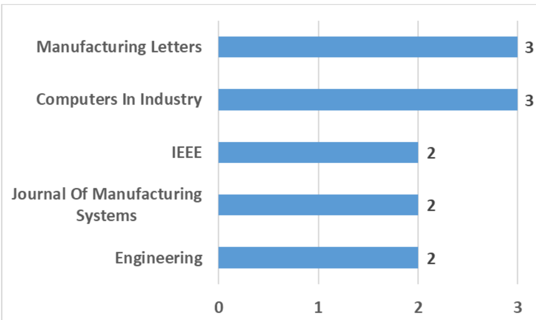
Figure 7 - Number of publications by institutions



As can be seen, the largest number of articles and authors involved in research on the topic are in educational institutions in the United States, presenting an increase in research and development on the topic, which can make them reference institutions about the subject.

With regard to the scientific journals that most publish articles on the subject of cyber-physical systems focused on manufacturing systems (Figure 8), the journals Manufacturing Latters and Computer in Industry stand out with three publications each on the topic, and IEEE journals Internet of Things Journals, Journal of Manufacturing Systems and Engineering with two publications each. Another thirteen journals published an article on the topic.

Figure 8 - Number of publications in scientific journals



5. CONCLUSIONS

This article aimed to present the relationships and interactions of the CPS (Cyber-Physical System), through a bibliometic study. For the elaboration of the results, data were extracted as: quantity of publication by author, quantity of citations of articles, quantity of publications by institutions, quantity of citations by countries and quantity of publications in scientific journals.

The results obtained in the research show that the authors Jay Lee and Bahrad Bagheri are the authors who have published the most articles on the subject so far. In the citations theme, the most cited articles were "A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems" with 384 citations and "Recent advances and trends in predictive manufacturing systems in big data environment" with 151 citations. It is noted that the country that has the most influence in research is the United States, with a total of 10 publications on the topic. The University of Cincinnati institution with 4 articles published on the topic was the one that stood out the most. Finally, the scientific journals that published the most on the subject were Manufacturing Letters and Computers in Industry with 3 publications each.

Through the analysis of the results, it is concluded that the topic addressed has grown annually and has become of great relevance for the emergence and development of new applications with the use of cyber-physical systems for manufacturing systems, a concept related to the intelligent manufacturing, Industry 4.0 scope.

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