Development of cyber physical system based manufacturing system design for process optimization

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Abstract. Cyber physical systems (CPS) are known as one of the significant advancement in computer science and IT. Cyber physical manufacturing system is the emerging research area in the field of computer science as well as manufacturing science and technology which is promoting the 4th industrial revolution which is known as Industrie 4.0. CPS generally focuses on the integration of physical world with cyberspace. It is the integration of communication, computation, control and physical elements. At present time, CPS is the point of interest for academia, government and industries. However, a systematic literature review of cyber physical system for manufacturing system is not available. This paper aims to present the findings on cyber physical systems on manufacturing systems and development of cyber physical system for intelligent manufacturing. The CPS is explained with the concept of CPS and five level architecture system for manufacturing systems. Further, key enabling technologies for cyber physical manufacturing systems is also discussed. In this paper both WoS and Scopus databases (2000-2020) is taken in consideration for literature review. Top journals, top cited papers, top authors and top research categories have been found out.

1. Introduction

In the present global manufacturing scenario integration of cyber components with the physical components in the industrial processes have become popular as it improves the reliability, efficiency and productivity of organization [1]. These days, industrial internet platforms are using to manage the interaction between the cyber and physical components which are also known as the core in operating manufacturing systems. During the last decades, rapid advancement in ICTs has forced the industries to develop the advanced wireless communication devices, sensors and data acquisition systems [2]. These technologies are integrated to a new advanced system known as CPS. The term CPS was coined in United States in 2006 due to the realisation of increasing the importance of integration of physical world with computer systems. In present time industries are more competition oriented to adapt more customer by adopting new practices and technologies [3]. Some authors suggested that industries need some resources which are difficult to imitate to achieve the competitive market advantage [4-5]. This can be achieve by investing the industries in cyber physical systems on shop floor as the strategic resource [6]. However, these new technologies may be inapplicable to some manufacturing contexts and limits the performance gains as contingency theory has showed which states that lack of fit
between the a new practice or technology with industry can cause in the performance issues to that industry as the environment and structure of that industry may not be suited to particular practice or technology [7]. At present time industries are more responsive to the customer demands and market changes which forced them to adopt cyber physical manufacturing systems over the traditional manufacturing systems. The need of cyber physical manufacturing systems over traditional manufacturing systems is discussed in the next sections of the paper. Further, CPS concept map is also discussed for the better understanding of the CPS with some research areas. Please note that the first paragraph of a section or subsection is not indented. The first paragraphs that follows a table, figure, equation etc. does not have an indent, either.

2. Literature Review
From the past few years researchers are working on the CPS to bridge the gap between computer system and physical world [8-9]. Multiple definition have been proposed in past on the CPS from the 2008 [10]. A concept map of cyber physical system is shown in Figure 1. CPS has emerging research area since the 1970’s. In 1970s first microprocessor stated to emerge. In 2006 Helen Gill coined the term CPS in United States which describes the systems that connects the physical world components with the digital world. CPS is defined as “physical and engineered systems whose operations are coordinated, integrated and monitored by a communication and computing core” [11]. In the last few years researchers are now focusing on the cyber manufacturing systems rather than other manufacturing systems [12-13]. (Liu and Jiang, 2016) proposed a CPS architecture for shop floor system to achieve the goal of intelligent manufacturing in an industry which provides the general guidelines to construct the CPS in industry from the hardware connection to the data processing and visualization level. Further, the architecture is verified in the small scale flexible automated production line [14]. (Ivanov et al., 2017) developed a control approach for the job shop scheduling in manufacturing (Customized manufacturing) process and presented a contribution to distributed scheduling in the production systems in the area of cyber physical manufacturing systems [15].

![Figure 1. Concept map of Cyber physical system](image-url)
(Mourtzis and Vlachou, 2018) developed a cyber physical system which is based on the condition-based maintenance and adaptive scheduling. It is concluded that captured data can be used to calculate important key performance index and identification of machine tool status [16].

(Silva and Lopez, 2019) studied the relevance of CPS in the different manufacturing contexts and concluded that stress shops are the most relevant environment for the implementation of CPSs. It is also found that cost of implementation is very high to overcome for smooth shops [17]. In the next section of paper need of the cyber physical systems over the traditional manufacturing system is discussed with a 5 level architecture for CPS.

3. Need of Cyber physical systems in manufacturing

The impact of CPS and IoT on the manufacturing companies will be significant. At present most of the industries use the CPS and IoT concepts but applications in the manufacturing sectors are limited [18]. The studies are limited in other sectors with the use of embedded sensors in manufacturing equipped or products with RFID tags. Data analysis is less for the data extracted from these devices [19]. These systems can be implemented to analyse the IoT data which further used in the decision making [20]. There are specific ways in which the cyber physical manufacturing systems are better than the traditional manufacturing systems which is shown in the Figure 2. Five specific ways i.e. Production line monitoring, smart supply chains, asset monitoring, predictive analysis and personalized products are discussed along with their description which shows that the cyber manufacturing systems are better than the traditional manufacturing systems.

| How Cyber physical manufacturing systems are better than Traditional manufacturing systems? |
|-------------------------------------------------|
| Production Line monitoring                       | As the industry floor expands, it is difficult to monitor the multiple assembly lines. With the smart factory, the ability to remotely monitor multiple production lines that are located at different manufacturing plants and at different geographical locations becomes easier and more defined. |
| Smart Supply Chains                              | The processes linked with the entire supply chain are not only complicated but are also hard to keep track of. Watching over each and every step of the supply chain management is a tedious and time-consuming process. Industry 4.0 is designed to provide an intelligent supply chain that is embedded with radio frequency identification (RFID) tags and sensors to allow process automation, inventory tracking, and real-time monitoring. |
| Asset Monitoring                                 | Assigning and monitoring assets can be a challenging task when done manually. Keeping a record of each manufacturing asset and identifying who is using any particular asset at a given point of time is not possible with manual processes. With the help of the IoT, factory managers effortlessly can monitor every asset that is connected with the system, measure its efficiency, know about its availability and active time, and decide or identify who is using or will need the asset at a particular time. |
| Predictive Analysis                              | Manufacturers that still rely on the legacy systems often stockpile replacement parts that are at higher risk of failure results in occupying a lot of factory space. Predictive analytics can bring an end to stockpiling by allowing companies to monitor their equipment and their performance. The data visualization generated as an outcome of PA also specifies how many machines are functional at the moment, the efficiency of each active machine, as well as generates alerts for all the machines that are not functioning as expected and needs maintenance. |
| Personalized Products                            | There was a time when a product would be mass-produced with same design and features, maybe in a few different colors. Now, as the communication between a manufacturer and consumers get easier, there’s more room for personalization and co-creation of the exact product that is preferred. As automation enters the production line, meeting the demand of customizing a product according to customer needs is quite possible. The combination of IoT and JET manufacturing allows companies to consider customer preferences and meet the demands accordingly. |

Figure 2: Advantages of cyber manufacturing systems over traditional manufacturing systems

Five level architecture for the CPS in manufacturing systems is shown in the Figure 3 which shows the data passing to the higher levels gets reduced in size as the value of information rises.
Figure 3. Five level architecture in CPS in manufacturing.

4. Framework of cyber physical system on manufacturing system
Cyber physical system (CPS) architecture for IMS (intelligent manufacturing system) is shown in Figure 4 which includes three layers are: physical connection layer, middle layer and computational layer. In this section explanation of each layer is also represented.

4.1. Physical connection layer
Generally, sensors are known as the gateway for machines to sense the surroundings physical environment. Various signals in manufacturing environment such as vibrations, temperature and pressure can be extracted by using the appropriate sensors in industries. In the implementation of cyber physical systems shop floor of industry is embed to the components such as RFID devices, sensors and various types of measurement devices on manufacturing resources. These different components are distributed to the production environment of industry. Industrial intranet or fieldbus technology is used to connect the group of machines together. The issues about distance, location processing, storage and protocols are needed to consider in this layer during the selection of embedded component. For example, there should be proper robust and uniform connection between actuators, manufacturing resources, measurement devices and sensors which should be defined properly and deployed on their location with high efficiency and lower costs.

4.2. Middle Layer
The middle layer of cyber physical system aimed at the data transfer extracted from the embedded components to the central server for the further analysis. External applications (quality control, dynamic job scheduling and condition monitoring) and production commands of computation layers are acts as the controller for control. In cyber physical system middle layer acts as the bonding layer between the external applications, computation layer and physical connection layer. In the implementation of cyber physical system middle layer must support the following function which are discussed below:
**Device Management:** Different types of external applications for devices having different brands, standards and protocols are used in cyber physical systems. All these devices having their own standards and communication protocols. In CPS a public device module is needed to drive these multiple devices together to achieve the plug and play goal in an industry.

**Interface definition:** Data interface in the CPS helps to provide a channel for cyber physical system node communication. It requires the data and information to the external applications and computational layer to hide the details of diversity.

**Data management:** In an industry data extracted from the different sensors and RFIDs can be quality data (tolerance, location, roughness and size), machine working conditions (vibrations, speed and power), and production environment state at a particular time (noise, humidity and temperature). This requires a uniform data format as there is large data types and formats which is used to manage and share the data with the shop floor environment.

4.3. **Computation Layer**

Large amount of data with different formats and standards is calculated by RFIDs and sensors from the EIS (Enterprise information systems) such as SCM, ERP and MES. There is requirement of specific algorithms and models are used to extract the data which can provide the better insights about the manufacturing processes, machine working conditions and quality. For the better understanding let us take an example of job shop scheduling, in which the rules for dispatching of a product are incorporated with the data collected from the data processing and online measurement systems which makes sense when the machines are working in the complex production environment. Stream computing and batch computing needs to be addressed in computation layer. Stream computing is used for processing the data streams extracted from the sensors and batch computing is generally focused on the processing of large data volumes based on the historical data’s. After the stream data and batch data the results obtained are transmitted to the machine sites for the maintenance and operation control purposes. This layer acts as the supervisory control to make the machining environment self-ware and self-adaptive. Data mining techniques while implementing the shop floor environment to know the behaviour of production process and machine operations. This layer helps in
the decision making by integrating the generated knowledge based on the human’s experience. In the next section of paper key enabling technologies for the cyber physical systems are discussed.

5. Key Enabling Technologies for Cyber physical systems
For the implementation of CPS in the manufacturing systems three main key technologies should be taken into consideration which are discussed below with the help of Figure 5.

The three key technologies with intelligent decision making on the basis of knowledge acquisition, Industrial big data analysis for manufacturing processes and interconnection with interoperability among different devices is shown in figure below:

![Figure 5. Key enabling technologies for CPS.](image)

6. Research analysis and direction
This paper focuses on the structured literature review. In this study articles related to cyber physical system in manufacturing systems searched on the databases like WoS and Scopus by using the keywords “Cyber physical systems” AND “manufacturing systems”. Total 1873 articles were found on the Scopus database and 478 articles were found on WoS from 2000-2020. It can be seen that no. of publications in Scopus are more as compared to WoS. Researchers are focusing more on Scopus indexed journals than the WoS indexed journals. Figure 6 represents the no. of articles published with respect to year (2010-2020).

![Figure 6. Research publications in WoS and Scopus databases from 2000 to 2020 on CPS with manufacturing systems.](image)

Figure 7 shows the different research areas of cyber physical system w.r.t. manufacturing systems. It is found that engineering manufacturing having most of publications with 20.4% weightage which is
followed by engineering industrials with 13.5%. Engineering mechanical having lesser number of publications among all the research areas having 3.9% of total contributions.

![Figure 7. Research areas on CPS with manufacturing systems.](image)

Different publication types have been shown in Figure 8. It can be seen that most of the publication types are articles. In WoS 430 articles and in Scopus 669 articles have been published which is followed by review type publications. It is found that researchers are focusing less on book reviews only 1 book review on WoS and 9 on Scopus database is found after analysis. While it is also found that researchers are more focusing on the proceedings paper as most of the publications have been found in conference proceedings paper on Scopus database with the count of 986.

![Figure 8. Different publications types on both WoS and Scopus databases on CPS with manufacturing systems.](image)

Top 10 authors working in the area of cyber physical systems w.r.t. to manufacturing systems is find out on both the databases. It is found that Xu, X. having most of publications on both the databases WoS (16) and Scopus (29). Tao, F. having 19 publications and having second rank on
Wang, LH having second rank on WoS with 13 publications. Top 10 authors on both of the databases is shown in the Table 1.

### Table 1. Top 10 authors on WoS and Scopus (CPS w.r.t. manufacturing systems).

| S.No. | Author (WoS) | Publications (WoS) | Author (Scopus) | Publications (Scopus) |
|-------|--------------|--------------------|-----------------|----------------------|
| 1     | Xu, X.       | 16                 | Xu, X.          | 29                   |
| 2     | Wang, LH     | 13                 | Tao, F.         | 19                   |
| 3     | Tao, F.      | 12                 | Anderl, R.      | 18                   |
| 4     | Li, D.       | 12                 | Wang, L.        | 18                   |
| 5     | Jiang, PY.   | 11                 | Jiang, P.       | 15                   |
| 6     | Ding, K.     | 9                  | Yao, X.         | 15                   |
| 7     | Liu, C.      | 8                  | Barbosa, J.     | 14                   |
| 8     | Wang, SY.    | 8                  | Cecil, J.       | 13                   |
| 9     | Sanin, C.    | 7                  | Romero, D.      | 13                   |
| 10    | Szczerbicki, E. | 7        | Taisch, M.      | 13                   |

Top ten sources also find out on both the databases and it is found that IEEE access having most of the publications on WoS is 35 which is followed by Journal of manufacturing system with 29 publications. International journal of production research is at third rank with 28 publications. On other hand Procedia CIRP having most of publication with 126 counts which is followed by IFIP.
advances in information and communication technology with 69 publications. Procedia manufacturing having 60 publications and at third rank on Scopus database. It is found that publications on WoS is lesser as compared to Scopus database. Table 2 shows the top 10 sources on both WoS and Scopus.

Top five papers on both databases is find out. Paper title “Implementing smart factory of industrie 4.0: An outlook” is most cited paper on WoS database with 446 citations while on Scopus database “A cyber-physical system architecture for industry 4.0 based manufacturing systems” is most cited paper with 1243 citations. Table 3 shows the top cited papers on both the databases.

Table 3. Top cited papers on WoS and Scopus (CPS w.r.t. manufacturing systems).

| S.No. | Paper Title (WoS)                                      | Citation (WoS) | Paper Title (Scopus)                                | Citation (Scopus) |
|-------|--------------------------------------------------------|----------------|----------------------------------------------------|-------------------|
| 1     | “Implementing Smart Factory of Industrie 4.0: An Outlook” | 446            | “A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems” | 1243              |
| 2     | “Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination” | 269            | “Service innovation and smart analytics for Industry 4.0 and big data environment” | 596               |
| 3     | “Cyber-physical systems in manufacturing”              | 268            | “Cyber-physical production systems: Roots, expectations and R&D challenges” | 446               |
| 4     | “Current status and advancement of cyber-physical systems in manufacturing” | 197            | “Cyber-physical systems in manufacturing”          | 382               |
| 5     | “Intelligent Manufacturing in the Context of Industry 4.0: A Review” | 188            | “Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination” | 380               |

7. Conclusion

In this paper developments in CPS with the manufacturing systems is discussed. A concept map is presented for the better understanding of CPS with the different research areas. A five level architecture is also discussed for the manufacturing industries. Need of cyber physical manufacturing system over traditional manufacturing systems is also discusses. Further, framework for intelligent manufacturing system is developed and discussed. Bibliometric analysis of work done on CPS in manufacturing system is discussed with the help of data collected from both WoS and Scopus databases from 2000-2020. It is found that CPS is an emerging research area in the engineering field in which now researchers are focusing. Most of the publications are from conference proceedings and on Scopus database. Key enabling technologies for manufacturing systems is also discussed. It can be concluded that CPS in manufacturing system can be considered as important step in the development of future manufacturing systems. Whether the Industry 4.0 or CPS combined with the manufacturing industries which aims to promote intelligent manufacturing and providing the technical support for both upgradation and transformation of manufacturing industry. It can be summed up in three aspects: Internet based manufacturing, process intelligence and product intelligence. It is found that future manufacturing will be personalized manufacturing based on cyber physical systems, smart manufacturing, digital manufacturing and network based manufacturing. CPS will continue to
transform the manufacturing trends among the industries and create more surprising value the future global manufacturing scenario.

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