A cyber-physical system based on collaborative distributed manufacturing system architecture for intelligent manufacturing

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Abstract

This paper systematically reviews the literature on cyber-physical systems (CPS) based on collaborative distributed manufacturing systems architecture for intelligent manufacturing. To this end, relevant journal articles were analyzed, examining literature about Internet of things, big data, distributed manufacturing systems, collaborative manufacturing, and intelligent manufacturing. Some important issues are identified, as well as gaps in the existing knowledge. Moreover, a CPS architecture in distributed manufacturing is proposed that acts as a platform for the collaborative environment to intelligently performing the tasks. The proposed architecture encapsulates different resources which can act as a guide for building a CPS framework for the equipment interconnection, to the data collection, processing, and the final knowledge procurement and learning. Furthermore, enabling technologies are discussed in the context of distributed manufacturing environments, or successful integration of different technologies to minimize the interoperability.

Keywords: Distributed manufacturing; Cyber-Physical Systems; Internet of Things; Interoperability

Introduction

During the previous decade, the rapid development of Information and Communication Technologies (ICT) has helped in the utilization of the Cyber-physical Systems (CPS) tools such as cutting edge sensors, information procurement framework, wireless communication devices, and appropriate processing arrangements (Monostori L., 2014). Coordination with such advancements leads to utilization of effective and efficient resources in the concerned facility. CPS is an arrangement of teaming up computational elements which are in escalated association with the encompassing physical world and its on-going procedures, giving and utilizing data-accessing and data-processing services available on the internet. CPS has gotten continually developed considerations of scientists from the scholarly world, industry, and government. In recent years, a precursor generation of CPS can be found in different application areas, such as aviation, automotive, civil framework, chemical processes, medicinal services, transportation, and manufacturing (Lee, et al., 2015).

In this research paper, the mentioned CPS in the context of manufacturing scenario has been taken into consideration for detailing the processing of complex manufacturing tasks. In particular, it is much more complex when one needs to process the jobs in a distributed manufacturing environment. The present industry is striving to move closer towards the fourth generation of industrial revolution (Industry 4.0), where manufacturing with the intelligent and collaborative platform is a must to keep up with the present competition and to produce a better quality of goods, at lower cost and in lesser time (Chaplin, et al., 2015). It is clear that information technology is known to be useful to reduce the risks in production and also to forecast the market conditions for a better and optimized production (Khodadadi, et al., 2016). On the other hand, collaborative manufacturing, when blended with interconnected network, yields smart production and also associates several industries situated in geographically distributed locations (Tchoffaa, et al., 2016).

Despite the fact that the solid approach of conventional assembling has its particular leeway, it is not adequate in today's dynamic assembling conditions. However, a few issues have been identified with the traditional manufacturing approach and expressed in (Saygin and Kilic, 1999). To overcome these issues, few scientists have understood that there is a need to integrate both the functionalities to accomplish better execution of the framework. Also, because of fast advancement of information and communication, product designers can rapidly circulate their resources at different spots. To accomplish the effective information and knowledge trade between various offices, there is a requirement for internet and communication technology through which it can be conceivable to connect every one of them.

This paper systematically reviews the literature on CPS based on collaborative distributed manufacturing systems architecture for intelligent manufacturing. Based on this systematic review, a CPS architecture for intelligent manufacturing is proposed.

The remaining sections of this paper are organized as follows. Section 2 presents the details about the systematic review methodology. Section 3 shows the architecture with respect to CPS architecture for intelligent manufacturing. Conclusions and future research directions are drawn is section 4.

Research Methodology

The aim of this paper is to make a systematic literature review (SLR) on CPS based on collaborative distributed manufacturing systems architecture for intelligent manufacturing. By the analysis and summarization of the research work done in this field, factors like how the information technology plays a major role in collaboration and decision support systems are also reviewed. In a preliminary analysis of the selected literature, a sort of essential ontology was created (see Fig. 1).

This paper will highlight several notions and ideas for further research work in distributed manufacturing. Also, this will enhance research in computer sciences, artificial intelligence, and mathematics by (i) making a study for these in the industry 4.0 perspective; (ii) finding the less developed fields in the present research (iii) highlighting topics for further study. As an analysis, a flow chart was prepared, showing the basic framework of the project which is also useful in the summarisation and further analysis of the research works published so far (Wong, et al., 2012). A standard five-step methodology has been followed in this SLR, which is reflected as follows:

1. Question formulation;
2. Locating studies;
3. Study selection and evaluation;
4. Analysis and synthesis;
5. Reporting and using the results.

In place of the traditional approach, a SLR methodology has been followed. This is mainly focussed on (i) redefining the bases for the current work; (ii) integrating the SLR approach into the current body of knowledge; (iii) defining the basics; (iv) finding the appropriate research topics. Hence a SLR has been made on the role of information technology, artificial intelligence, computer sciences, distributed manufacturing and IoT in the development of the SMEs to revolutionize their processes to tend to industry 4.0.

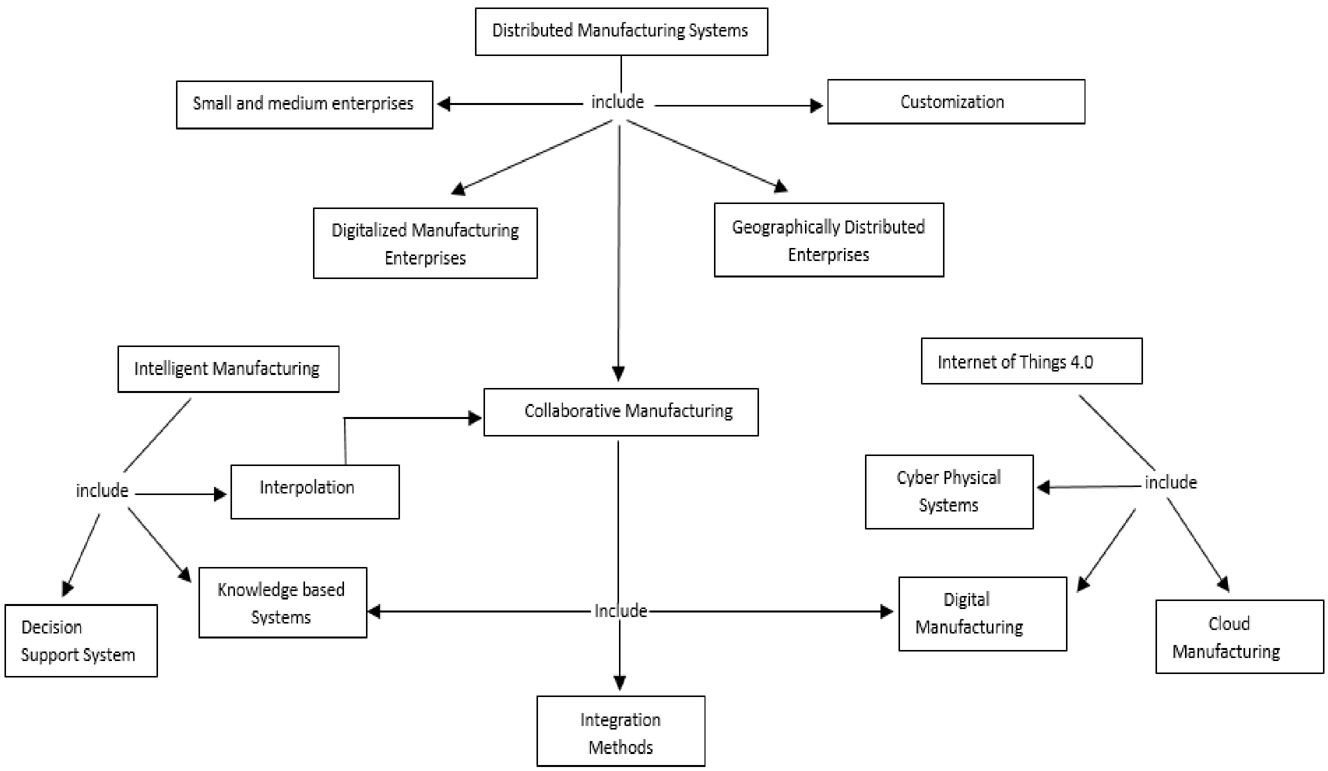

Figure 1. Main topics related with distributed manufacturing, intelligent manufacturing, collaborative manufacturing and internet of things (IoT).

The following steps were followed:

Step 1: What is the role of information technology, IoT, collaborative manufacturing and distributed manufacturing in the development of the SMEs towards Industry 4.0?

What topics and issues related to information technology, collaborative manufacturing, and distributed manufacturing are considered when SMEs apply the concept of industry 4.0?

Step 2: Two bibliographic databases were used (Scopus and Web of Science) for this review and different combinations of keyword strings were used to obtain a different number of results (Table 1). The majority of the published papers and highly relevant peer-reviewed journals in the field of study were available in the above mentioned bibliographic databases (Kamal and Iran, 2012).

Table 1. Search strings and number of results.

search strings	search field	date of search	number of results
Web of Science			
("distributed manufacturing" alternatively, "collaborative manufacturing" alternatively, "intelligent manufacturing") moreover, ("industry 4.0")	Topic	28.02.16	19
("distributed manufacturing" alternatively, "collaborativemanufacturing." alternatively, "intelligent manufacturing") moreover, ("decision support system")	Topic	28.02.16	15
("distributed manufacturing" alternatively, "collaborativemanufacturing." alternatively, "intelligent manufacturing") moreover, ("small and medium sized enterprises")	Topic	28.02.16	5
("distributed manufacturing" alternatively, "collaborativemanufacturing." alternatively, "intelligent manufacturing") moreover, ("IOT or "internet of things")	Topic	28.02.16	29
Scopus			
("distributed manufacturing" alternatively, "collaborative manufacturing" alternatively, "intelligent manufacturing") moreover, ("industry 4.0")	article title, abstract, keywords	28.02.17	29
("distributed manufacturing" alternatively, "collaborativemanufacturing." alternatively, "intelligent manufacturing") moreover, ("decision support system")	article title, abstract, keywords	28.02.17	76
("distributed manufacturing" alternatively, "collaborativemanufacturing." alternatively, "intelligent manufacturing") moreover, ("small and medium sized enterprises")	article title, abstract, keywords	28.02.17	10
("distributed manufacturing" alternatively, "collaborativemanufacturing."	article title,	28.02.17	47

alternatively, "intelligent manufacturing") moreover, ("IOT" or "internet of things")	abstract, keywords		

The initial combinations of keywords yielded 178 articles, i.e. 20 for Web of Science and 158 for Scopus. Mendeley software was used to remove duplicate papers on the relevant similar topics as obtained on the two databases.

Step 3: In this step, some filtration criteria were defined to get the most relevant studies to be included in the work. Only time horizon of ten years was selected (2007-2017) because industry 4.0 is a new concept that came into existence during this period (Colicchia and Strozzi, 2012). Following are the most relevant subject areas that were considered while selecting the peer-reviewed journals.

- Web of Science:

a. Engineering Manufacturing;
b. Computer Science Interdisciplinary Applications;
c. Engineering multidisciplinary;
d. Computer Science artificial intelligence.

- Scopus:

a. Engineering;
b. Computer Science;
c. Mathematics;
d. Material Science.

Table 2. Summary of the systematic review articles selection and evaluation.

Databases and criteria	Search 1	Search 2	Search 3	Search 4	Total
Web Of Science	*19*	*15*	*5*	29	68
INCLUSION/EXCLUSION CRITERIA					
data range (2007-2017)	19	12	3	29	63
document type (article)	5	6	1	10	22
subject area (engineering manufacturing, computer science interdisciplinary applications, engineering multidisciplinary, computer science artificial intelligence)	2	6	1	7	16
language (English)	2	6	1	7	16
SCOPUS	29	76	10	47	162
INCLUSION/EXCLUSION CRITERIA					
data range (2007-2017)	29	40 (till 2016)	7	47	123
document type (article, review, conference papers)	24	29	5	42	100
subject area (engineering, computer science, mathematics, material science)	22	29	5	38	94
Language	20	29	4	31	84

This filtration reduced the number of articles to be reviewed to 147 in Scopus and 14 in Web of Science. Mendeley was used to remove duplicate papers, and remaining papers were for our reference and analyses. This process was performed by reviewers to check for concordance and agreement. Following is the criteria for eligibility of papers: (i) relevance to industry 4.0; (ii) focus on the area of manufacturing studies; (iii) qualitative and quantitative nature of papers; (iv) focus on the keywords: information technology, distributive and collaborative manufacturing in the context of industry 4.0 with importance on decision-support system and IoT. Table 2 shows the summary of the criteria applied for this SLR.

In **Step 4**, the content was analyzed and summarized to a chronological development of the study fields and to identify the key issues and the possible topics for further research. The common ideas and the possibility of errors in the overall papers were found to obtain a better quality data. The data was hence systematized and tabulated. This paper illustrates the formal presentation of the results to the academic community (**Step 5**). The remaining content of the paper reports the findings of the present study in a thematic way.

Cyber-physical system based distributed manufacturing environment

Distributed manufacturing is a type of decentralized manufacturing honed by ventures utilizing a system of geologically scattered assembling offices that are coordinated using information technology. A distributed manufacturing system (DMS) is characterized as an arrangement of self-governing specialists, which are commonly reliant on each other. Nowadays, the extent of DMS has evolved to enterprises who purposely supplement each other on innovation and work force (Erwin Rauch et al., 2015). Fig. 2 shows the architecture for distributed manufacturing environment resulting from the analyzed articles. The detailed description of each layer of the architecture is displayed in Fig. 3, Fig. 4, and Fig. 5.

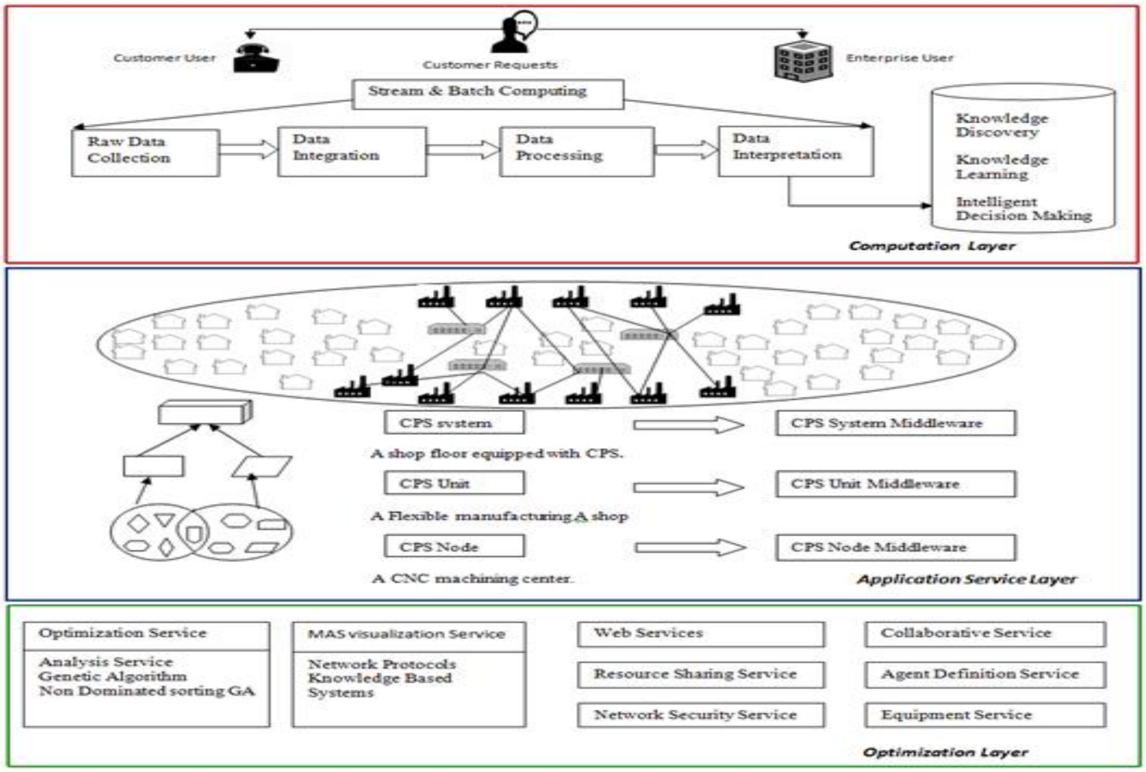

Figure 2. CPS architecture for intelligent manufacturing.

Physical connection layer

Sensors are the basic devices to measure physical environment in the vicinity. Appropriate sensors can be used to detect temperature, vibration, pressure, mass flow rate, etc. (Banica and Florinel-Gabriel, 2012). So, the foremost step of CPS implementation in distributed manufacturing environment is to embed components like sensors, radio-frequency identification devices (RFID) and measurement devices on the manufacturing resources and to distribute them in the production environment (Kai Ding and Pingyu Jiang, 2016). All the machines need to be connected to a local network such as local area networks (LANs) and metropolitan area networks (MANs). Convention, processing, area, separation, and capacity should be considered when the installed segment is picked. For instance, the uniform and vigorous associations between heterogeneous physical elements (e.g., fabricating assets, sensors, actuators, and estimation gadgets) ought to be characterized; appropriate sensors (sort and particular) should be chosen and sent to legitimate areas with minimal effort and high productivity on the premise of authentic machining assignments. To execute the information learning framework given in Fig.3, numerous critical thinking systems in manmade brainpower, for example, Case-based Reasoning (CBR) and Machine Learning (ML), can be utilized. Taking care of an issue by CBR includes acquiring an issue depiction, recovering comparative cases by contrasting estimation or post-handled information with cases for the situation base, reusing the data in the recovered cases, overhauling the proposed arrangement as indicated by particular conditions in target space, and holding another experience to the case base (De Mantaras, et al., 2005).

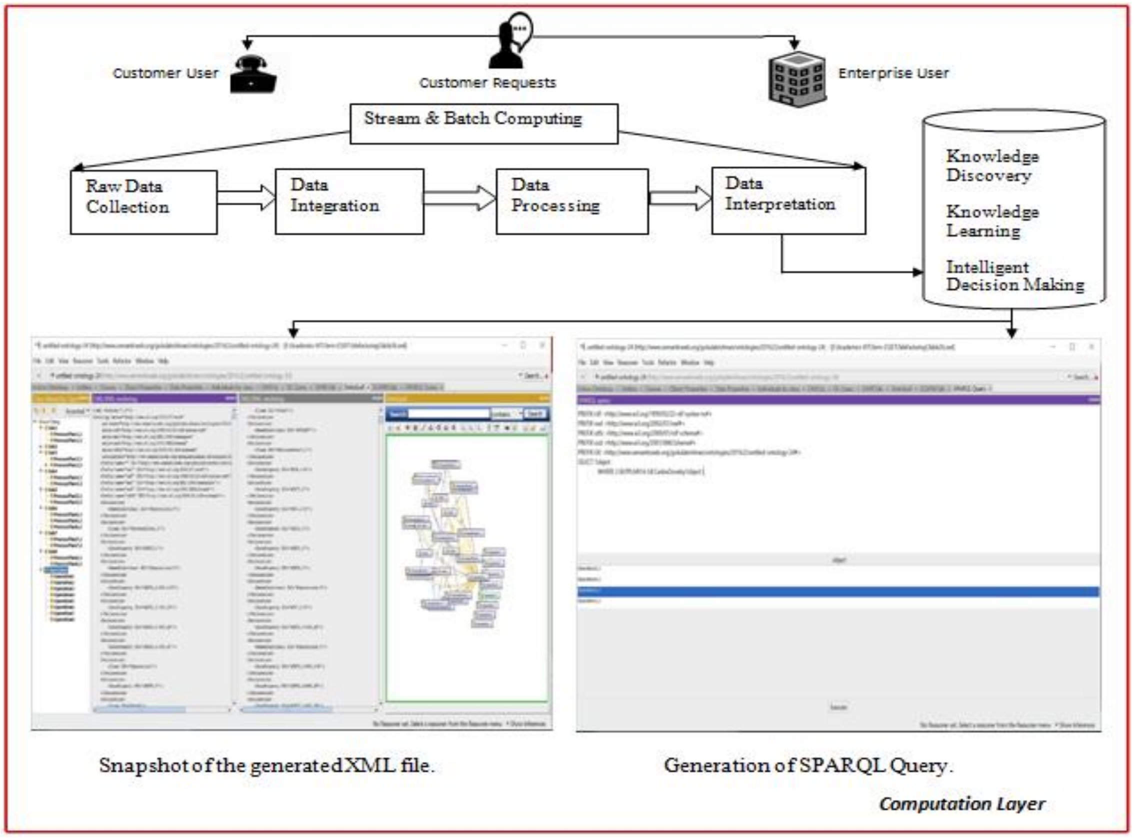

Figure 3. A framework for knowledge acquisition and learning.

Middleware layer

In this research, a general middleware for implementing the CPS is developed as shown in Fig. 4. Middleware frequently empowers interoperability between applications that keep running on various working frameworks, by providing administrations so the application can trade information in gauges based manner. Middleware is like the canter layer of a three-level single framework engineering, except that it is extended over different frameworks or applications (Chao Liu and Pingyu Jiang, 2016). Cases incorporate EAI programming, telecommunications software, transaction monitors, and informing and queuing programming. Subsequently, CPS middleware goes about as a bond among physical connection layer, computation layer, and external applications. As per the above depictions, the middleware must bolster the accompanying capacities:

Device administration. Diverse outside applications are probably going to utilize distinctive sensors/RFID gadgets/estimation gadgets which have distinctive brands and sorts (Didem Gürdür, et al., 2016). Besides this, these gadgets have their correspondence, protocols, and benchmarks. Accordingly, an open gadget administration module is expected to drive these various gadgets to cooperate, and eventually accomplish the objective of attachment and play.

Interface definition. The information interface gives a channel to CPS hub correspondences and required information/data to the calculation layer and outer applications, concealing every one of the points of interest of differing qualities.

Information administration. The information gathered from sensors/RFID gadgets/estimation gadgets can be creation state (e.g., temperature, humidity, and clamour), machine working condition (e.g., power, speed, and vibration), work piece state and quality information (e.g., area, size, harshness, and resilience), and so forth. The possibly vast assortment of information sorts and arrangements requires a uniform information configuration and information trade standard to oversee information in setting with process-related data in the shop floor (Dunbing Tang, et al., 2016).

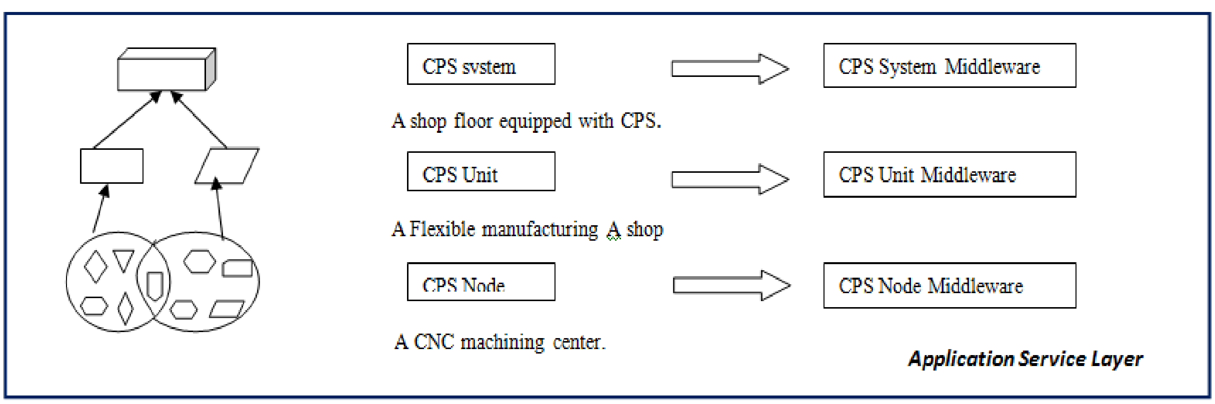

Figure 4. Development of a general middleware.

Computation layer

Much information, continuous on the web or historical offline, is assembled by different sensors/RFID gadgets/estimation gadgets, or acquired from Enterprise Information Systems (EIS) for example, ERP, MES, and SCM as shown in Fig.5. Particular models, calculations, and apparatuses must be utilized to separate basic examples that give better understanding over working machine conditions, work piece quality, producing forms, and so on (David Romero and François Vernadat, 2016). Considering the job shop planning, for instance, the dispatching principles are fused with the information received from online estimation, information handling, or information combination, which bodes well particularly when machines work as mind-boggling generation condition and experience an alternate crumbling rate (Seitza and Nyhuisa, 2016). In this layer, two types of enormous information registering that should be tended to be batch computing and stream figuring. Batch computing is utilized to process expansive volumes of recorded information, and stream figuring is utilized to handle the information stream got from sensors. After group registering or stream figuring, the outcomes are transmitted back to the machine site for operation/prepare control and upkeep. So this layer goes about as supervisory control to make machines or to assemble process self-versatile and self-ware (Zhang and Tao, 2017). Then again, generous learning about machine operation conduct and generation prepare has been removed by information mining while executing CPS in the shop floor. This layer assumes liability for coordinating the produced learning with people's understanding, consequently making a brought together perspective of information, data and learning to strengthen the basic leadership.

By applying an information securing and learning procedure to create handle administration, CPS will develop in much clever way, as all the more assembling undertakings are executed.

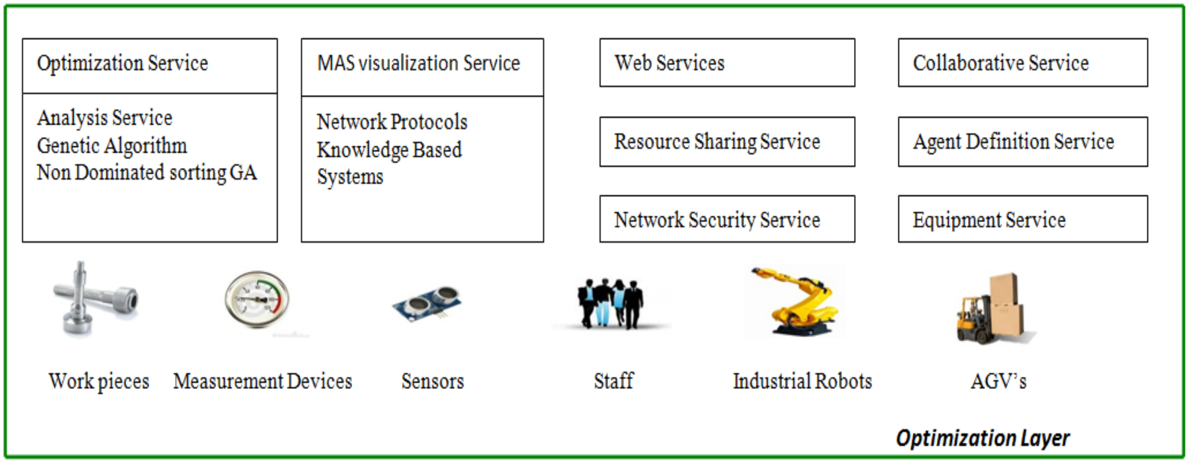

Figure 5. Services and instruments required to implement CPS to shop floor.

Conclusion and future research direction

In this paper, based on the findings from the previous studies, we analyze, synthesize and generate a comprehensive SLR on the role of CPS based on collaborative manufacturing with distributed manufacturing environment. The SLR methodology turned out to be a valuable tool for a detailed analysis of the literature with the improvement including the synthesis of main findings of the literature, and to establish a foundation for future research. Moreover, a CPS based on collaborative manufacturing architecture for intelligent manufacturing is proposed. The architecture consists of three key layers: the computational layer, application service layer, and optimization layer for the setup and operation of the CPS. In the computational layer, *interconnection and interoperability among different devices* like sensors, RFID and measurement devices are established. Whereas in the application service layer the relationship among physical connection layer, computation layer, and their external applications was established. In the optimization layer, the supervisory control to make machines or to assemble process, self-versatile and self-aware can be performed.

In future work, one can use the proposed architecture to reduce their interoperability issues in the real time environment and will be helpful for future digitalization.

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