Comprehensive Bibliometric Analysis of Published Research in Cyber Physical System from 2009 to 2018

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This study was conducted to provide a comprehensive bibliometric analysis of published research on Cyber Physical System in order to understand the trends and compare the publications contributions among different regions, institutions, authors, subject areas and other domains. The publications on the CPS were retrieved from Scopus database from 2009 -2018. A total of 2,486 articles were identified after different search steps. The analysis was done using bibliometric procedure. The largest number of publications were recorded in 2018 (781). The results further revealed that, China contributed the highest proportion of 817(32.8%) publications, the USA was ranked second with total publications of 733 (29.5%). The most productive journals of publications were IFAC Papersonline and IEEE Access with 223 (9%) publications and total citation of 27,518. Similarly, the most productive authors were Shi, Liaoshan with 19 (H-index 11) and Yang, Guanghong Hong with 14 (H-index 7), these 2 top authors has cumulative citations of 3,421. The bibliometric analysis of subject area revealed that, Engineering has the highest number of publications with 765 (30.8%), followed by computer sciences with 605 (24.3%). However, among the top areas of research in CPS, business, management and accounting is the least with the with only 54 (2.2%) publications from 2009 to 2018. Moreover, keywords, affiliations and funding agencies statistics were reported. Finally, this study provide a sound ground and motivation for scholars from different fields to engage in interdisciplinary and multidisciplinary collaborations for successful research outcome.

Keywords: Cyber Physical Systems, industry 4.0, smart factory, smart manufacturing.

I. INTRODUCTION

Cyber-Physical Systems (CPS) is a system that merge the digital and physical activities of manufacturing, a mean for digital software to perceive and interact with a physical environment [1]. Another way to define it is as a technique that bridges the interaction between the physical and the virtual world [2]; [3]. An example of how a software entity can observe and comprehend physical phenomena is through sensors that gather information that can be processed as data [4]; [2]. The CPS application, the companies used it as a higher level of logistics services, more efficient processes with their partners, better cooperation between specific logistic functions and increased market and financial performance and competitiveness [5]. One often refers to "cyber-physical system" in production, which is described as a system constructed by interconnected and collaborating autonomous entities across all development levels, from individual machine elements to logistic networks. Such a system could deal with an immense number of different operations and make decisions in real-time to achieve optimal and robust outcomes. Some of the anticipated CPS benefits are also other advantages such as enhanced security, self-maintenance, predictability and accountability. The prospective advantages of digitalization are high, with the implementation of digital alternatives in information-intensive procedures, cost reduction of up to 90% and dramatic improvement of turnaround times. In addition to manually performing operations, CPS application process can drive efficiency, cost driver, and risk analysis that can also be enhanced by automatically-collected information using online request alternatives, which enables PDS's executives to respond immediately and real-time base assessments [6]. Atomicity and security can be increased by adding digital solutions to supply products. In era of Industry 4.0, the organizations are hyper connected with their smart devices and smart networks. This presents a very lucrative target for the cyber criminals who find many easier and insecure entry points into networks and devices [7]. Cybersecurity should no longer be viewed as a function of information technology or information security alone [8]. It needs to form an integral part of culture and strategy of the organization. It should be reflected in each facet of the organization, right from the strategy to the behaviour of an individual employee. Such an integrated cybersecurity vision aligns business functions of the organizations with needs of the stakeholders and becomes a more acceptable strategy [9]. Embedded computers and networks monitor and regulate physical procedures, generally with feedback loops that influence physical procedures and vice versa. The principal is that information is not stored on a single unit. Instead it is a vast network of units sharing their processing and storage capacity [9], this results in wireless control [10], information accessibility [3], and excessive storage capacity [9].

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Which is an essential for our last driver. Big data is a technique that is based around analyzing large quantities of data [2]. The previously mentioned drivers have enabled this technology by making it possible to generate vast amount of data through CPS, communicate it efficiently in real time by IoT and storing and distribution the data via cloud computing [3].

Previous empirical studies as well as review investigated the application of industry 4.0 emphasizing on the cyber physical system (CPS) from different perspectives such as in the field of engineering, science and technology as well as some areas in public health and environmental sciences.[11] and [12], found that, Industry 4.0 can have a significant effect on the organisational operation, improving company's environmental operations as a major cooperates responsibility of every company. Similarly, empirical studies have established that, integrating technological application into organizations' corporate operations improved business environment and economic performances [13], [14],

Overall researches examine the application of CPS in almost all field of sciences, engineering, life sciences, management and environmental sciences where the efficacy of CPS was highlighted in improving all areas of human endeavors. However, the detail review of studies on the application of CSP and current status in all areas of human endeavor which are very important to understand its wide application feasibility and future research application area are still unclear. This study therefore, aimed at providing a comprehensive review of the published CPS related researches in all field from 2009 to 2018, to understand the trends and area that need improvement. A bibliometric procedure is employed to analyse the related studies. Bibliometric is the widely used method to map knowledge domain in all areas.

A. Objective of the Study

The main purpose of the present study is to conduct a bibliometric analysis of published researches on CPS research and specifically to meet the following objectives;

i. Investigate the growth pattern and distribution of Cyber physical systems research literature from 2009 to 2018

ii. Identify the features of core authors and journals that contain substantial proportion of Cyber physical systems research and

iii. Identify the key research domain including country, area of application, funding agencies, affiliation, language and keywords of Cyber physical systems research domain

II. METHODOLOGY

This study employed the Bibliometric analysis procedure to address the objective of this study. The Bibliometric study is a popular quantitative technique for the analysis of published documents articles or studies[15], therefore, bibliometric is the suitable methods to apply in order to quantify and visualize the research contribution in the area of industry 4.0 Cyber physical systems research. In utilizing the method, the researchers employed statistical techniques to analysed the Cyber physical systems research literature in terms of authors performances, the journals, research institutes and countries in order to discover the trends and future direction [16].

The analysis also takes into considerations, the citations, keywords and mapping of knowledge domain. In line with the objectives of this study and the preceding explanations, the study was carried out in the following steps; (i) Documents search and retrieval from Scopus database (ii) Bibliometric quantitative analyses of the 2,486 retrieved articles. The bibliometric quantitative analyses were conducted to investigate the trends of the publications within the selected 10 years (2009-2018), the subject areas of applications, authors productivity, journal productivity as well as citations with the Citescore and impact factor, keywords occurrences was also investigated with affiliation and funding. The detail study framework is presented in Figure 1.

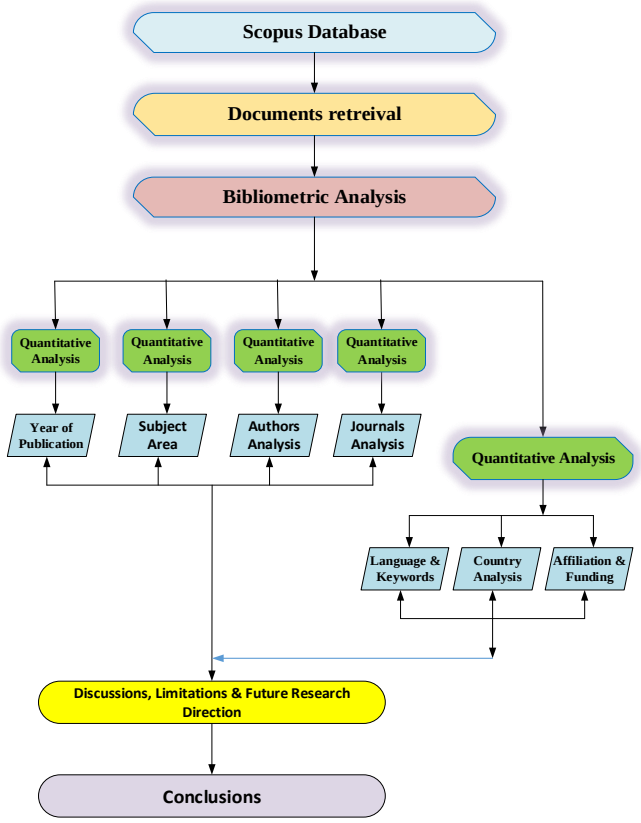

Figure 1: Research framework of the current study

A. Data source and search strategy

The data search and retrieval was conducted using Scopus database. The Scopus is a prestigious and influential scientific database; because it covers published researches with citations in all the field. Thus it is the one of the valuable tool for bibliometric studies [17] The Scopus was used because it provides more than 20% of the coverage of all scientific publications more than any other database including web of science [18]. Based on the above narrations, this study utilizes the Scopus database to retrieve all the literature used in this study.

Data retrieval was done from August 30th to 5th September 2019 from the Scopus database. The researchers conducted searches with central theme or code to retrieve the articles relevant to the research objectives.

The term used was any articles containing "cyber physical system* in the article's abstract, title or key. Based on the objective of this study, the oldest publications are considered to be published in 2009 and the more recent is 2018. The first query string used was (TITLE-ABS-KEY ("cyber physical system*") and this produced 12,270 document results. After inspecting these articles, it was discovered that, some articles were published in 2019 and some for 2020, in order to limit the articles to the 2009 to 2018 this query was used to limit the articles to the years under investigation thus; (TITLE-ABS-KEY ("cyber physical system*") AND (EXCLUDE (PUBYEAR, 2020) OR EXCLUDE (PUBYEAR, 2019)). This second query resulted in retrieval of 2,647 documents.

Lastly to make sure that, no review article was included in the analysis, another query was used to excludes all the review articles after reading their details, all their EIDs were retrieved and added in the search query so that all the review should not appear in the results, the query further reads (TITLE-ABS ("cyber physical system*")) AND NOT EID (insert EID of review articles here**)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (EXCLUDE (PUBYEAR , 2020) OR EXCLUDE (PUBYEAR, 2019)), (*see Appendix A for EIDs of review articles*). This last query produced 2,486 researched based articles.

B. Data Analysis

In order to achieve the objectives of this study, the analysis of data generated from Scopus database in form of CSV format was used. Microsoft Excel 2016 was used to sort the data for the generation of tables, graphs and other statistical procedures. The top authors, journals, country, funding agencies etc. were ranked according to the publication rates and citations. The data visualization was conducted using the VOSviewer software to create networks based on countries, keywords and other information (van Eck & Waltman, 2011). The VOSviewer has one unique advantage over other tools in mapping knowledge domain displays and is suitable for analyzing complex networks and large data with citations and keywords (van Eck & Waltman, 2011).

III. RESULTS

The data analysis was conducted as stated in the preceding section of data analysis. The results obtained from the analysis of the retrieved documents on cyber physical system researches published from 2009 to 2018 are presented in line with objectives of the study. The findings have been presented and described under nine (9) headings as spelt out in the study purposes and frameworks thus: publications growth by year, subject area analysis, author productivity analysis, journal productivity analysis, language of writing analysis, keywords, country, affiliation, funding agencies analyses respectively.

A. Publications Growth by Year of Publications

The applied technique yielded 2,486 publications from 2009 to 2018. The first article in this category was published in 2009 with 2 publications, the annual publications were stable from 2009 up to 2011. A dramatic increase was noticed from 2012 to 2018. The number documents during these years (2012-2018) shows exponential growth in the trend. The annual documents and accumulated documents are shown in figure 2. The highest annual publications were seen in 2018 totaling 781. This representation provides a clear picture of the publication trend in CPS from 2009 to 2018

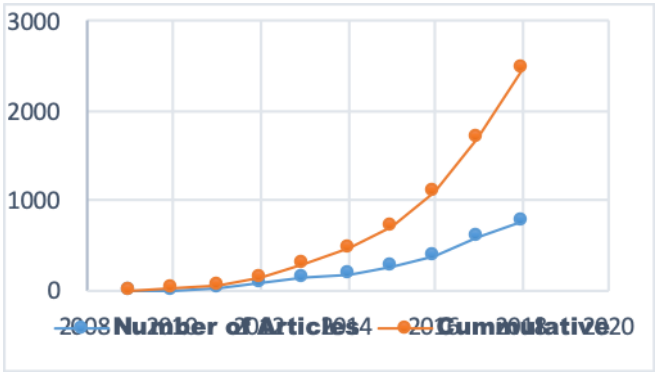

Figure 2: Publication growth by year

B. Subject Area Analysis

The bibliometric analysis of subject area where the research in CPS was presented on figure 3. Top 10 must productive fields of application were analysed. In line with the guidelines set for this review the total retrieved documents was 2,486 and among the retrieved articles 2,392 (96.2%) were published in 10 top subject area selected for this analysis. The results presented on figure 3 shows that, out of the 2, 392 articles produced, Engineering has the highest number of publications with 765 (30.8%), followed by computer sciences filed with a total of 605 (24.3%). The third most popular filed was Mathematics with a total publication of 298 (12.0%), material sciences were the fourth populous filed with total publications of 152 (6.1).

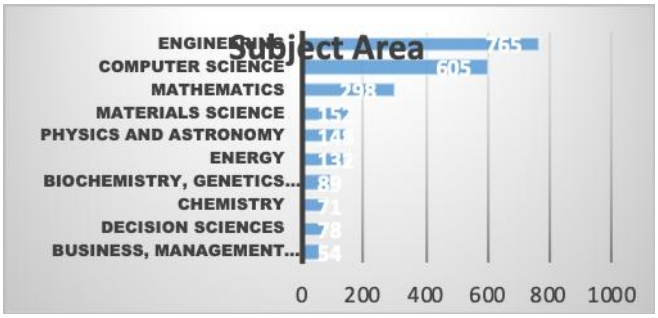

Figure 3: Distribution of documents by subject area

Furthermore, looking into the pattern of publications in CPS as presented in figure 3 showed that business, management and accounting field is the least area with the application of CPS in the research with only 54 publications accounting to 2.2% of the total publications produced from 2009 to 2018.

C. Author Productivity Analysis

The retrieved results show that, a total of 8,924 authors contributed to the publications of all the 2486 articles included in this study.

Among the top 10 authors presented here Chen has the highest publication of 19 while Koutsoukos, is the list with 9 publications only. The details of most prolific authors as presented in Table 1 shows that, the top 10 authors selected for this study were cited for a total of 3,421. An-Min Wang, Hong was the most influential with a citation number of 1011 with h-index of 11, followed by Chen with citations of 718 with h-index of seven (7), details of citation and h-index can analyses were presented in Table 1.

D. Journal Productivity Analysis

The 2,486 articles that meet the selection criteria and retrieved for this research were all published in 162 different relevant journals. The top 10 selected journals are the active journals in terms of IR 4.0 Cyber Physical system components, the journals were presented in Table 2. The total number of articles published in this field by the top 10 authors is 589 representing 25% of the total retrieved items. The journal most prolific in the field of CPS was IFAC Papersonline with 119 publications, followed by IEEE Access with 104 publications, and Sensors Switzerland with 76 publications. The citation analysis of the top 10 journal included in this section has a total citation of 88,212. Further analysis shows that, Sensors Switzerland has the highest citations of 25,391 (28.8%) followed by IEEE Access with the citations of 19,331 (21.9%) and IEEE Transactions on Smart Grid with citations of 10,830 (12.3%). However, the least cited journal is International Journal of Distributed Sensor Networks with a citation of 2,337 (2.6%).

E. Language of Writing Analysis

The bibliometric analysis of retrieved articles in CPS in terms languages of publications in which the article was written showed that, the 2,486 retrieved articles were written in nine (9) different languages. Though the majority of the articles were written non-English speaking countries but 2257 (90%) of the articles were written in English Language, followed by Chinese with 187 (7.5%) Germany was the third with 31 articles written in German language. Russian follow with 4 articles Spanish and Japanese has 2 article each while French, Korea and Portuguese has only 1 publication with their languages (Figure 4). This showed that, the primary Language used in writing these reviewed articles is English.

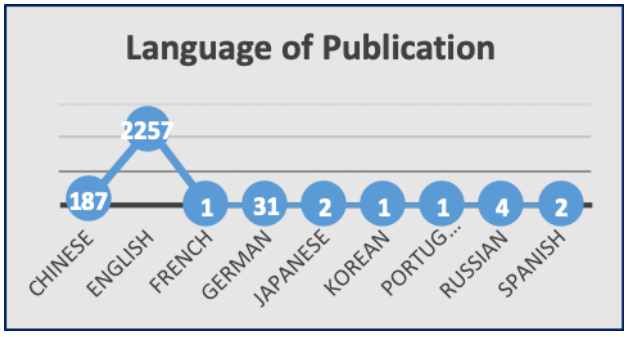

Figure 4: Language of Publications

F. Keywords Analysis

The keywords analysis resulted in identification of 6484 total author keywords larger percentage of the keywords were used once. After re-labeling synonymic single words and congeneric phrases, 248 met the threshold of minimum five occurrences for the mapping in VOSviewer. After reviewing and removing the duplicates, 238 keywords were used for the analysis and mapping in VOSviewer. The results revealed that, cyber physical system was the most frequently encountered keyword with 568 occurrences, this is followed by the industry 4.0 with 133 occurrences and the third most frequently occurred keyword was internet of thing with 128 occurrences. As presented in Figure 5 the larger circle size and font indicates higher occurrence.

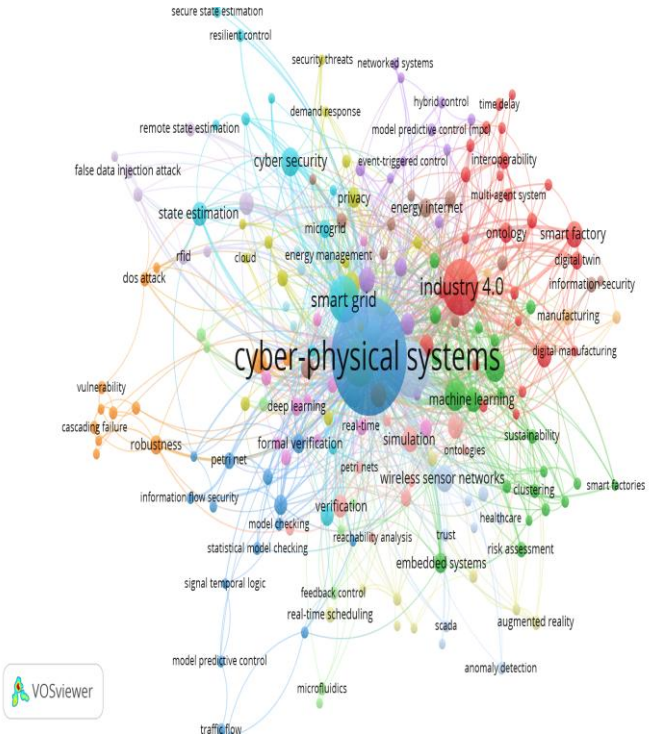

Figure 5: Keywords frequently encountered

G. Country Analysis: Productivity and collaborations

The distribution of the publications geographically involved 86 countries over six continents (Figure 6). Among the 86 countries there were 17 countries that published only one article during this period (2009-2018), the countries for the 6 published articles was unidentified. The analysis further shows that, 50 countries published at least 5 articles. The top 10 selected most productive countries as depicted in Fig. 6 showed that, China was ranked first with (817 publications) followed by US with (733 publications), Germany (211 publications), Italy (122 publications), United Kingdom (119 publications), South Korea (117 publications), Spain (101 publications), Canada (99 publications), India (86 publications) and Australia (78 publications). These top 10 countries particularly have rapidly developed economies than their counter-part and their domestic research capacity and impact on globally appears to have increased accordingly (Nafade et al., 2018)

Table 1: Top 10 Leading Authors in CPS Research

SN	Author Name	Scopus ID	Year of 1st Publication	TP	h-index	TC	Current Affiliation	Country
1	Shi, Liaoshan	56206356800	2014[a]	19	11	543	Academia Sinica, Institute Of Physics, Taipei, Taiwan	Taiwan
2	Yang, Guang, Hong	7405751358	2007[a]	14	7	113	State Key Laboratory of Synthetical Automation for Process Industries, Shenyang, China	China
3	Yu, Wen	55993706000	2014[b]	12	9	655	Centro de Investigacion y de Estudios Avanzados, Mexico City	Mexico
4	Sun, Dong	56220414100	2012[a]	11	6	63	City University of Hong Kong, Kowloon, Hong Kong	Hong Kong
5	An-Min Wang, Hong	55839137900	2013[a]	11	10	1011	Nanjing Agricultural University, Nanjing, China	China
6	Zegzhda, D.P.	13103571000	2016[a]	11	4	35	Peter the Great St. Petersburg Polytechnic University	Russian
7	Chen, J.	7501878473	2011[b]	10	6	718	Shanghai University, Shanghai, China	China
8	Song Haibin	7404036564	2014[a]	10	6	153	Nankai University, Tianjin, China	China
9	Zhao, M.	56461804500	2015[b]	10	5	47	Chongqing University, Chongqing, China	China
10	Koutsoukos, Xenofon D.	6603632868	2012[a]	9	4	83	Vanderbilt University, Nashville, United States	U.S.A

Table 2: Top ten Leading Journals in CPS Research

	Source	Number of Publications	Number of Citations	Cite-Score 2018	The Most Cited article	Times cited	Publisher
1	IFAC Papersonline	119	8,187	0.99	Future Modeling and Simulation of CPS-based Factories: an Example from the Automotive Industry [22]	25	IFAC Secretariat
2	IEEE Access	104	19,331	4.96	Toward social internet of vehicles: Concept, architecture, and applications [23]	134	IEEE
3	Sensors Switzerland	76	25,391	3.72	Network location-aware service recommendation with random walk in cyber-physical systems[24]	30	Multidisplaniary Digital publishing institute
4	IEEE Transactions on Industrial Informatics	65	6,414	8.82	A Manufacturing Big Data Solution for Active Preventive Maintenance[25]	84	IEEE
5	International Journal of Distributed Sensor Networks	46	2,337	1.63	Integrated collaborative filtering recommendation in social cyber-physical systems[26]	18	SAGE
6	IEEE Transactions on Smart Grid	45	10,830	11.91	Cyber-physical security testbeds: Architecture, application, and evaluation for smart grid[27]	152	IEEE
7	IEEE Transactions on Automatic Control	44	10, 051	6..76	Attack detection and identification in cyber-physical systems[28]	598	IEEE
8	IEEE Internet of Things Journal	33	4,568	11.33	Research directions for the internet of things[29]	733	IEEE
9	Future Generation Computer Systems	32	4,447	6.3	Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: A fog computing approach[30]	159	Elsevier
10	Zhongguo Dianji Gongcheng Xuebao Proceedings of the Chinese Society of Electrical Engineering	25	6,707	2.79	Key technologies and trends of cyber physical system for power grid Key technologies and trends of cyber physical system for power grid[31]	98	Zhongguo Dianji Gongcheng Xuebao

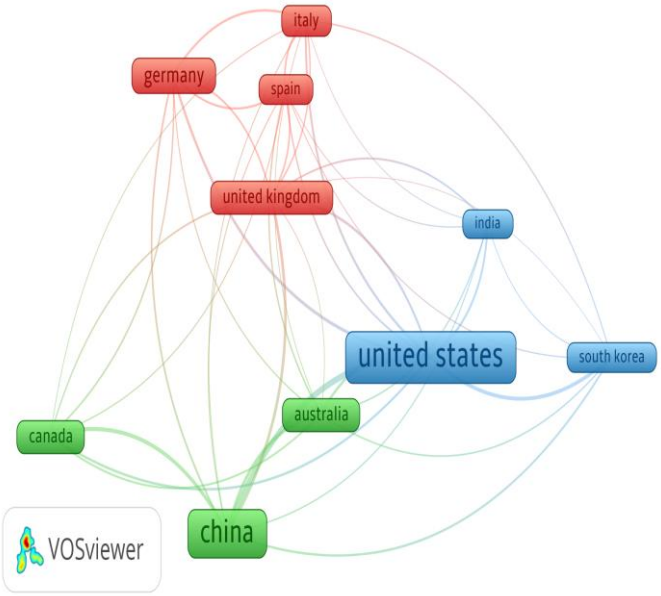

Figure 6: Top 10 Countries

Further information presented on Table 3 disclosed the total citations per country, link strength and cumulative citations by continents. As shown (Table 3), US lead with 15,565 citations followed by China with 9980 citations. The least most cited country was India with 333 citations. Similarly, the distributions based on the strength of the country's collaboration link, shows that, China lead with 231.00 link closely followed US with 224.00 link. However, India was the least country in terms of strength link among top 10 productive countries reported in this study.

The top most productive countries were from four continents among the 7 in the world, information (Table 3) revealed that, Asia top the list with 1021, followed by North America with 834 while Australia was the least with only 78 publications. Concerning cumulative citations by continents North America was the highest with cumulative citations of 18,059 closely followed by Asia with 11,222, Europe was third with 7,992 cumulative citations and Australia was the last with 2,449 cumulative citations (Table 3)

H. Affiliation Related Analysis

The bibliometric analysis based on authors' affiliation shows that, there were total of 160 affiliations spread among the 86 countries. Among the 160 affiliations there were 150 authors' affiliations that published 7 – 29 article during this period (2009-2018). The analysis further shows that, the top 10 selected most productive authors' affiliations presented in Table 4 showed that, Ministry of Education China was ranked first with (71 publications) followed by Zhejiang University with (47 publications), Tsinghua University (47 publications), Chinese Academy of Sciences (45 publications), Shanghai Jiao Tong University (45 publications), Northeastern University, China (37 publications), Carnegie Mellon University (35 publications), South China University of Technology (34 publications) University of California, Berkeley (31 publications) and Chongqing University (30 publications). The results of the analysis show that, Ministry of Education China has the highest number publications from 2009 to 2018.

Table 4: Top 10 Affiliation

SN	Affiliation	Country	Documents	%
1	Ministry of Education China	China	71	2.8
2	Zhejiang University	China	47	1.9
3	Tsinghua University	China	47	1.9
4	Chinese Academy of Sciences	China	45	1.8
5	Shanghai Jiao Tong University	USA	45	1.8
6	Northeastern University, China	China	37	1.5
7	Carnegie Mellon University	Germany	35	1.4
8	South China University of Technology	China	34	1.4
9	University of California, Berkeley	USA	31	1.3
10	Chongqing University	China	30	1.2
	Total		422	17

I. Funding Agencies Analysis

The results on the funding agency analysis revealed that, out of the ten top funding agencies, National Natural Science Foundation of China was the highest funding agency with a total of 361 funded publications; this was followed by National Science Foundation with 162 publications funded from 2009 to 2018.

Table 3: Top Country by Continents and Citations

SN	Continent	Country	TP	Citations	Link Strength	Cumulative Citations
1	Asia	China	817	9980	231.00	11,222.00
2		India	86	333	20.00	
3		South Korea	117	909	38.00	
4	Australia	Australia	78	2449	58.00	2,449.00
5	Europe	Germany	211	3521	50.00	7,992.00
6		Italy	122	1484	37.00	
7		Spain	101	1391	34.00	
8		United Kingdom	119	1596	64.00	
9	North America	Canada	100	2494	55.00	18,059.00
10		United States	733	15565	224.00	

The distribution further showed that, Fundamental Research Funds for the Central Universities was the third funding agency with funded 72 publications to their credit, followed closely by National Basic Research Program of China with 40, National Research Foundation of Korea with 34 publications, Office of Naval Research with 26 publications, European Commission with a total of 25 funded publications, Ministry of Education with 22, National Aerospace Science Foundation of China with 21 publications and lastly Air Force Office of Scientific Research is the least among the top ten with 20 publications as clearly presented in Figure 7.

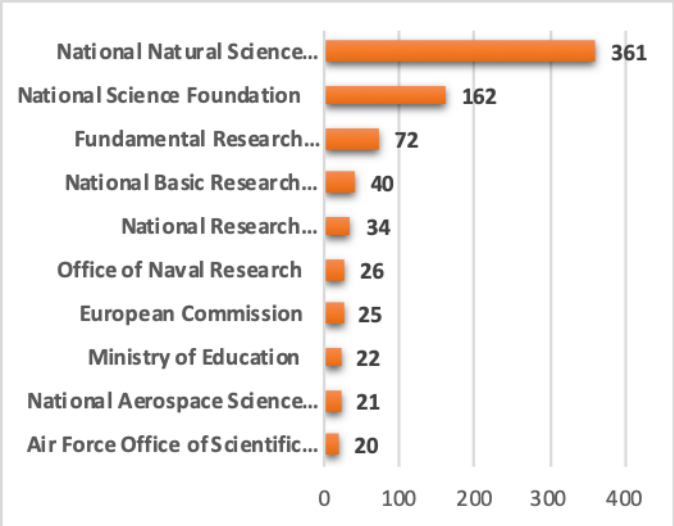

Figure 7: Top 10 funding Agencies

IV. CONTRIBUTIONS OF THE STUDY

Through the bibliometric analysis the finding of this study provide a comprehensive representation of the application of CPS (Industry 4.0 component) in a multidisciplinary research area. The findings complement the industry 4.0 highly publicized impact in all areas of endeavours within the research community and lay a solid foundation for future research in multi-disciplinary areas. Specifically, the discovery and identification of CPS based research in interdisciplinary areas provide a sound ground and motivation for scholars from different fields to engage in interdisciplinary and multidisciplinary collaborations for successful research outcome. The quantitative analysis of top sources journals is a guide to scholars in selecting target journals for examination of literature and submission of relevant manuscripts for possible publication. The identification of top 10 articles can facilitate research as a follow up a familiarity with CSP researches. Moreover, the analyses were based on systematic procedure and revealed potential gaps and direction for future research especially with regards to area of application where more researches are needed to complement the other aspect of CPS applications.

V. LIMITATIONS

This study attempted to give a comprehensive bibliometric analyses of the published researches related to CPS in all areas of scientific researches, although significant effort has been put to ensure a robust bibliometric analysis was conducted, some few short comings that should be a concern for the researchers in future studies emerged. First, the published articles used in this study were collected from Scopus database alone which may not cover many other related research vital to the successful attainment of the objective of this study and that, the organization related information of the papers used may not be consistent since organizations names do not have consistent format. Thus, this study did not analyse the collaborative networks among different authors and institutions. Secondly, the study identified literature on the CPS using "Cyber physical System" through the subject classification system of Scopus few articles may have been missed. Thirdly, cyber physical systems involve other sub-constructs or sub-systems (cyber-security and embedded system) and due to insufficient integration of authors, their academic levels and in-depth analysis of different sub-systems and knowledge points was not performed.

VI. FUTURE RESEARCH DIRECTIONS

Due to the time and resources constraints on the part of the researchers' other areas that should have been considered were unavoidably ignored, further studies should consider using two different database or more to obtained a relatively larger documents that will allow comparison and conducting more comprehensive bibliometric analysis of the sourced data. In the same being and due to the dearth of CPS researches in the area of business management and accounting, researchers especially in this area should endeavor to adopt CPS in their research activities to investigate the efficacy of CPS in improving the business management and accounting field. Similarly, future bibliometric research should focus on detail analysis of CPS research by exploring all other sub-systems using more detailed manual reviews to summarize the existing researches in the area of CPS.

VII. CONCLUSION

This review comprehensively analysed 2,486 research based articles on cyber physical system of industry 4.0 in the past 10 years using bibliometric analysis procedure. Specifically, the source journals were quantitatively analyzed, and the most productive journals authors, countries and subject areas were revealed through co-authorship analysis, as well as their network distribution. The citation networks and 10 key articles were identified via citation analysis. More importantly, based on countries productivity, keyword co-occurrence and major subject/discipline areas of CPS application in research, a critical analysis of current challenges, gaps, and future directions was ultimately discussed. Overall, this study revealed some interesting findings and can also help scientists to locate research hot spots and gaps by offering comprehensive analyses and structured information on this topic.

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