Bibliometric Analysis of Industrial Internet of Things

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ABSTRACT

Industrial Internet of Things (IIoT) is getting growing attention because it enables researchers and industry professionals to develop innovative, efficient and smart systems aiming to enhance operational efficiency and productivity in the next generations of smart factories. This research study focuses on the quantitative analysis of research trends and developments occurring in the IIoT research domain, which is accomplished by conducting bibliometric analysis of published research in the Web of Science database. This paper outlines the research indicators such as journals, authors, institutions, organizations and countries contributing significantly to the IIoT research. The analysis results indicate that the number of publications and their citations are increasing consistently and even exponentially after 2008. The data also reveals that Gidlund M is the most influential and active author, and IEEE Transactions on Industrial Informatics is the most influential journal in IIoT research. Sweden and China are in the leading position in this field. Additionally, the analysis results reveal the links and relations among the co-authors and their partnering institutions working together in the research field of IIoT. We believe that the results of this study will not only spark further research in this domain but will also be very helpful for the researchers in various aspects.

Keywords: *Industrial Internet of Things (IIoT), Smart factory, Wireless Sensors, Bibliometric analysis*

1.   INTRODUCTION

In recent years, Industrial Internet of Things (IIoT) [1] is captivating growing attention both from academia and industry because of its potential to enable Industry 4.0, which is also referred as smart manufacturing. This fourth industrial revolution aims to yield and provide massive customization of products and services to meet the ever-increasing requirements of growing population in modern economies and societies in a sustainable manner. The IIoT comprises of a wide range of technologies from various domains such as sensing, computing, communication, networking, and storage. The premier technologies include sensor and robot networks [2, 3], cloud [4] and edge computing [5], Internet of Things (IoT) [6], and industrial big data [7]. In a smart factory, IIoT employs various sensors and objects to constantly collect data and forward it to cloud-based data centers or edge devices for storage and onward processing to reveal business insights. Despite considerable advancements in various aspects of IIoT such as architectures, protocols, and security, none of the existing study presented an overall picture of IIoT domain.

In recent years, bibliometric analysis [8] is a well-recognized method to quantitatively analyze an overall picture of a research domain. The prime focus of bibliometric analysis is to gauge the magnitude of published research articles and their impact through citations. Bibliometric indicators such as authors, journals, universities, institutions, and countries are crucial metrics to evaluate the impact and influence in a particular research domain. Moreover, bibliometric indicators can easily provide an overall picture of a research area. Bibliometric analysis has been widely adopted in various domains to determine and highlight the most prominent and influential contributors such as authors, publications, and countries. Examples of such studies include bibliometric analysis of scientific literature on internet, video games and cell phone addiction [9], green supply chain management [10], electronic healthcare [11], Internet advertising research [12], and global remote sensing research trends. However, to the best of our knowledge and literature review, this is the first bibliometric analysis of IIoT research and none of the existing study have investigated this topic.

This study aims to investigate state-of-the-art and recent advances in the domain of IIoT through quantitative bibliometric analysis of research articles published in the Web of Science1 (WOS) database. To highlight the major contributors in IIoT, this paper outlines key research indicators such as journals, authors, institutions, organization, and countries. Overall, results analysis clearly indicates that the number of publications and their citations are consistently increasing especially exponential growth is observed after 2008. The publication data reveals that Gidlund M is the most influential and active author, and IEEE Transactions on Industrial Informatics is the most prestigious journal in the IIoT domain. Moreover, countries such as Sweden and China are leading research in this field. Furthermore, we identified links

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[1] https://clarivate.com/products/web-of-science/

and relations among the co-authors, co-citation authors, and their partnering institutions involved in research collaboration.

The organization of this paper is as following: Section 2 illustrates the methodology adopted in this study. The bibliometric analysis and results are described in Section 3. Section 4 presents the graphical mapping for co-authorships among organizations and countries. Section 5 discusses the main conclusions of the paper.

2. METHODOLOGY

Selection of appropriate tools and techniques to analyze any given information is always critical in any research study. This is because data analytics provides useful information to decision makers which has significant impact to any society. This research study has collected available data from the WOS database, which is a scientific citation indexing service that provides a comprehensive citation search to researchers and scientific community. It incorporates several databases which covers research from most of the well-known scientific resources including more than fifteen thousand journals and fifty-five million articles. WOS was formerly owned by Thomson Reuters; however, Clarivate Analytics is the current owner of this service. Other databases such as Scopus and Google Scholar also provide similar services but are not included in this research study.

For data collection, the timespan is from the start of the IIoTs field (first article is reported in 1981 in the WOS) to 2017. The keywords used in the search process on current research study topic are industrial internet of things, IIoTs, Industrial IoT, smart factory and wireless sensors under the title of "topic". Although WOS contains fifteen different types of publications; however, this study focuses only publication types which includes articles, proceedings paper and review articles in English language and the total numbers of publications found are 3352 from 1981 to 2017.

For the graphical visualization purposes; VOS Viewer2 software is used which depicts graphical representation of organizations and countries that contributes as co-authors in their research studies.

3. DATA ANALYSIS AND DISCUSSIONS

Data sets from WOS core collection are retrieved in February 2018 and a bibliometric analysis has been conducted and presented in the following sections.

3.1 Publication Trend Analysis

As stated earlier, Industrial IoTs is getting more and more attention from the research community especially in the last decade, which is evident from Figure 1, which clearly demonstrates that the number of publications are rapidly increasing every year. The first 20 years are almost a flat mainly because of absence of wireless sensing technologies. However, advancements in various technologies such as wireless sensor
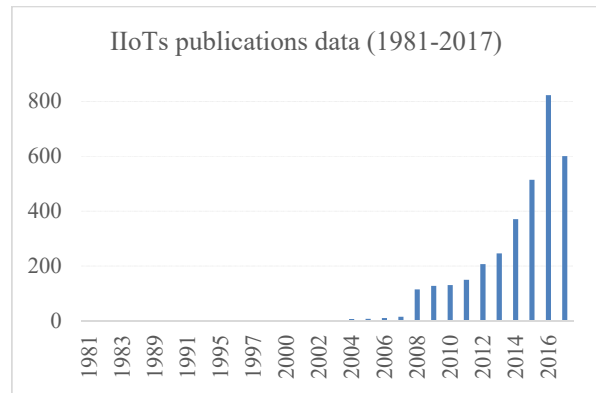

Figure 1: Number of annual publications in IIoT research since 1981

and networking enable research in IIoT. This resulted in exponential growth of publications from 2008 to onward. Overall publications growth model for the entire period from 1981 to 2017 follows $y = 0.1923e^{0.2577x}$ with $R^2 = 85.55\%$. Indeed, there are more number of researchers engaged in IIoT domain and WOS has expanded its database to include many new emerging journals in the last few years.

According to WOS records as illustrated in Table 1; there is not much research activity noticed in almost first two decades with the exception of the 3rd and last decade. All the counted articles are single digit until 2005. However, after this period, in next two years, the publication count risen to double digit (11 and 15) in 2006 and 2007 respectively. However, after 2008; there is an exponential increase of publications with more than 100 articles published every year for a period of four years in the IIoT field. Furthermore, the number of published articles reached more than 500 articles in 2015 with the exception of
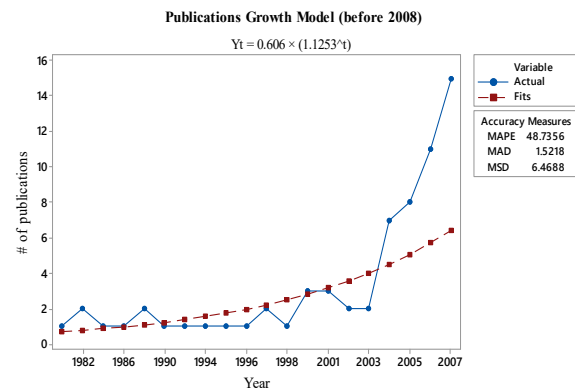

Figure 2: Publication growth model

Table 1. Total published articles per year for a period of 30 years

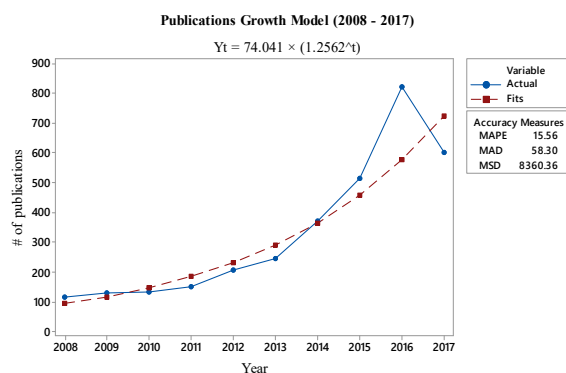|	Total number of publications (1981-2007)					Total number of publications (2008– 2017)		
S.no.	Year	Publications	S.no.	Year	Publications	S. no.	Year	Publications
1	1981	1	11	1997	2	31	2008	115
2	1982	2	12	1998	1	32	2009	128
3	1983	1	13	2000	3	33	2010	131
4	1986	1	14	2001	3	34	2011	150
5	1989	2	15	2002	2	35	2012	207
6	1990	1	16	2003	2	36	2013	246
7	1991	1	17	2004	7	37	2014	371
8	1994	1	18	2005	8	38	2015	514
9	1995	1	19	2006	11	39	2016	823
10	1996	1	20	2007	15	40	2017	601

Figure 3: Publication growth model

2016 when articles number reached to 823 as reported by WOS. Figure 2 and Figure 3 depicts the trend analysis of the entire period in 2 phases. The first phase is from 1981-2007 and from 2008-2017 is 2nd phase.

It is very clear that in the early period of 20 years (1981-2007), there is not much attention paid by researchers to the IIoTs research area and the publications growth model follows as $y = 0.606e^{1.1253x}$ $R^2 = 61.53$ % illustrated in Figure 2 . Only a little incremental increase in number of publications appeared in the literature. However, after 2008 onward, a regular increase on a continuous basis has been recorded.

In the last 10 years (2008- 2017); there is a strong indication of researcher's interest in the IIoT research with an exponential growth of publications $y = 74.041e^{1.2562x}$ with $R^2 = 92.98$ % and presented in a trend chart in Figure 3.

3.2 Trend Analysis of Research Application Areas in IIoT

Usage of IIoTs devices is expanding to different areas of applications. So, the research articles encompassing these application areas have been analyzed and the outcome is depicted in Figure 4. The results indicate that most of these articles belong to Engineering followed by Computer Sciences and Telecommunications research areas. The next 2 application areas automation control systems and instrumentations are basically belonging to Engineering as well, which clearly indicates that IIoT systems are gaining more interest from engineering and industry instead of other domains.

Figure 4 also shows a trend analysis of IIoT articles classified by research area. One can notice that most of the articles are published in the last ten years. Also Figure 4 indicates that new areas such as basic sciences (chemistry, physics and material sciences) are also getting attraction of IIoT systems.

3.3 Influential journals

Many international journals are publishing in the area of Industrial IoTs and the number of journals is increasing over time. The top ten most influential journals are shown in Table 2. These journals and international conferences are ranked (first column in Table 2) based on the total number of research articles published in this domain.

According to total number of publication criterion; IEEE Transactions on Industrial Informatics is the leading journal which has published 92 articles in IIoTs followed by the international journal "Sensors" with 79 publications. It is noticeable that based on H-index criterion; IEEE Transactions on Industrial Electronics (ITIE) holds the 2nd position.

Table 2 also illustrates the impact factor (IF) of the selected journals. However, IF criterion does not apply to the three highly publishing international conferences which are IEEE International Conference on Emerging Technologies and

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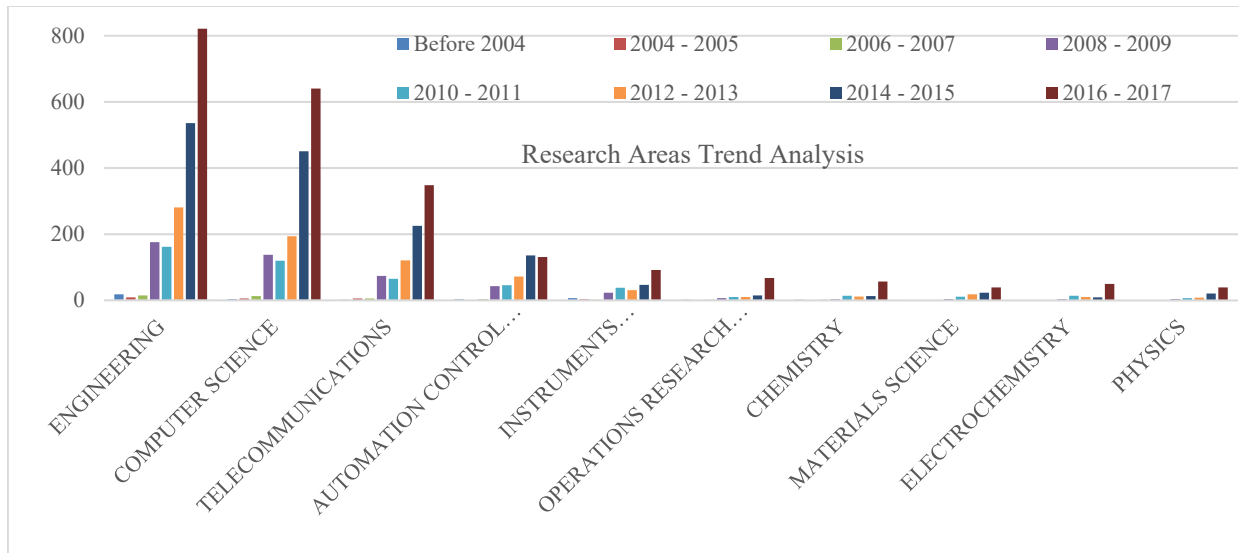
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Figure 4: Trend Analysis of Research Areas in Process Capability

Factory Automation (ETFA), Procedia Corp (PC), and IEEE International Conference on Industrial Informatics (IICI).

It is worth mentioning that ITIE has obtained the highest impact factor (IF= 7.168) among the selected ten most influential journals followed by IEEE Transactions on Industrial Informatics (IF=6.764). Trend analysis for the selected journals publishing in different application areas of IIoTs is presented in Figure 5. It is worth mentioning that the number of publications in the last ten years are increased exponentially.

3.4 Most Influential Articles

The articles which receive significant attentions from the researchers and scientific community of the respective field of study are considered the most influential and productive articles. In this regard, the most influential articles are classified according to the number of citations received by the articles in Table 3. The articles with high number of citations are considered more popular and ranked high in the classification list as presented in Table 3.

The results in Table 3 provides the list of most influential articles receiving highest number of citations as reported in the WOS. Article by Akyildiz, et al. published in Computer Networks journal in 2005 has received more than 1600 citations followed by 2nd and 3rd most cited articles are by

Table 2. Most influential journals publishing articles in IIoTs Research Field

R	Name	Industrial IOTs				IF	All Publications		
		H	TC	TP	%TP		TP	TC	H
1	ITII	30	3029	92	5.44	6.764	1,690	33533	73
2	S	14	793	79	0.59	2.677	13,307	124315	107
3	ETFA	4	64	64	3.60	-	1,779	610	9
4	LNCS	5	166	55	0.03	0.402	214,819	-	194
5	IJDS	6	253	52	1.63	1.239	3,196	6088	24
6	IIES	4	59	51	0.66	-	7779	9838	21
7	PC	6	209	48	0.96	-	4987	11392	24
8	IA	8	343	46	1.32	3.244	3,491	9185	32
9	IICI	6	128	45	3.04	-	1,482	1546	12
10	ITIE	18	2248	37	0.38	7.168	9,759	319591	186

Abbreviations: R: Journal Rank; H: H-index only in control charts, TC and TP: total citations and total publications, %TP: percentage of IIoTs articles in the journal, TP and TC, total papers and citations; IF, impact factor 2016; ITII: IEEE Transactions on Industrial Informatics, S: Sensors, ETFA: IEEE International Conference on Emerging Technologies And Factory Automation, LNCS: Lecture Notes In Computer Science, IJDS: International Journal of Distributed Sensor Networks, IIES: IEEE Industrial Electronics Society, PC: Procedia Corp, IA: IEEE Access, IICI: IEEE International Conference On Industrial Informatics, ITIE: IEEE Transactions on Industrial Electronics,
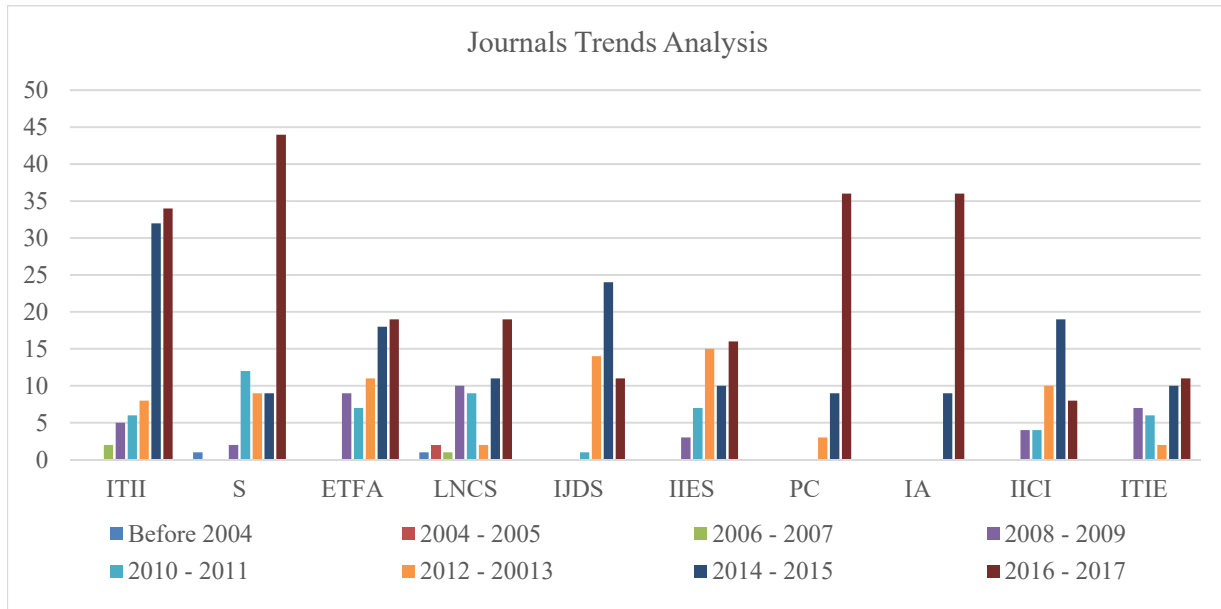
Figure 5: Trend analysis for Journals

Table 3 : 10 most cited IIoT papers of all time.

R	J	TC	References	Author/s	Year	C/Y
1	CN	1,642	[15]	Akyildiz, IF; Wang, XD; Wang, WL	2005	126.31
2	ITIE	560	[16]	Gungor, Vehbi C.; Hancke, Gerhard P.	2009	62.22
3	ITIE	506	[17]	Gungor, Vehbi C.; Lu, Bin; Hancke, Gerhard P.	2010	63.25
4	ICM	438	[18]	Demirkol, I; Ersoy, C; Alagoz, F	2006	36.50
5	ITIE	353	[19]	Yin, Shen; Li, Xianwei; Gao, Huijun; et al.	2015	117.67
6	ITIE	352	[20]	Xu, Li Da; He, Wu; Li, Shancang	2014	88.00
7	ITIE	336	[21]	Willig, Andreas	2008	33.60
8	PI	317	[22]	Willig, A; Matheus, K; Wolisz, A	2005	24.38
9	ITCE	192	[23]	Han, Dae-Man; Lim, Jae-Hyun	2010	24.00
10	S	165	[24]	Buratti, Chiara; Conti, Andrea; Dardari, Davide; et al.	2009	18.33

Abbreviations for 2nd column "J": CN: Computer networks, ITIE: IEEE Transactions on Industrial Electronics, ICM: IEEE Communications Magazine, ITIE: IEEE Transactions on Industrial Electronics, ITII: IEEE Transactions on Industrial Informatics, PI: Proceedings of the IEEE, ITCE: IEEE Transactions on Consumer Electronics, S: Sensors,

Gungor et al. published in 2009 and 2010 in the IEEE Transactions on Industrial Electronics. Other influential articles with their citation index are listed there as well.

3.5 The Most Influential Authors

Table 4 depicts the top 10 authors with highest number of publications in the IIoTs research. The number of papers are considered an indicative factor only. Number of other factors should be considered such as article size, number of co-authorships and the rank of the journal and impact factor in the subject area.

From Table 4, Gidlund M and Akerberg J from Sweden are ranked at 1st and 2nd with highest number of publications (49, 22 articles respectively), followed by Wang Q

and Shu L from Peoples Republic of China. It is worth mentioning that all the authors are contributing very closely in number of publications as recorded in the WOS.

Moreover, some other authors who are not in the top 3 positions of the most productive and influential authors, but they have received a large volume of citations such as Zeng P from China at 7th position got more than 2300 citations. It is worth mentioning that in the IIoT field, Li D (9th position) from China and Vilajosana X (10th position) from Spain have obtained the highest number of citations 321 and 252 respectively and became the top cited authors as reported in WOS records for the last 10 years.

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Table 4: Most influential authors

R	Name	Country	IIoT					All		
			TP	TC	H	TP_{10}	TC_{10}	TP	TC	H
1	Gidlund M	Sweden	49	239	9	49	239	90	*365*	10
2	Akerberg J	Sweden	22	*61*	4	22	*61*	54	*121*	6
3	Wang Q	Peoples R China	20	199	6	20	199	64	*926*	16
4	Shu L	Peoples R China	19	167	6	19	167	367	*2128*	*23*
5	Bjorkman M	Sweden	18	45	4	18	45	62	*304*	6
6	Watteyne T	France	18	*261*	6	*18*	261	61	*821*	12
7	Zeng P	Peoples R China	17	32	3	17	32	300	*2337*	24
8	Zhang Y	Peoples R China	17	48	3	17	48	56	203	8
9	Li D	Peoples R China	16	321	8	16	321	87	772	16
10	Vilajosana X	Spain	16	252	6	16	252	58	557	11

Abbreviations: R: Journal Rank; H: H-index only in control charts, TC and TP: total citations and total publications, TP and TC, total number of articles and total number of citations; IF, impact factor 2016; TP_{10}, TC_{10}: Total number of papers and total number of citations in the last 10 years

4. BIBLIOGRAPHIC CO-AUTHORSHIP GRAPHICAL ANALYSIS

In this section, a graphical representation of IIoT research articles is presented by using VOS Viewer software. It provides a visualized picture of co-authorship between organizations and between countries in the field of research study [13]. The VOS Viewer software uses bibliographic material from the WOS to work out the co-authorship, co-occurrence, citations, bibliographic coupling and co-citation relationships. It is worth mentioning that the VOS Viewer visualizes and present those variables which are mostly meeting the bibliographic representation criterion. To understand the VOS Viewer graphs and maps; it is important to note that the circles are representing the set (e.g., the organizations or the countries having co-authorship links), thus; the bigger the circle the more the corresponding set has published articles in the respective field of study. The line between two sets is representing the repetitions of co-authorship or co-occurrence between them, which is called the link strength (for example, in co-authorship analysis, if the link strength between two organizations is 10, that means the two organizations (universities) exist together in 10 articles in the respective field of study, so the thickest provides the strongest relationship [14].

4.1. Co-authorship between organizations

Co-authorship describes the publication count of research institutions and / or countries and their respective collaboration. In this section, the co-authorship between research institutions is depicted in Figure 6. Chinese Academy of Sciences is a leading IIoT research institution in terms of co-authorship (i.e., 78) followed by Shanghai Jiao Tong University which has 72 co-authorships as shown in Table 5. In addition, both of these institutions have very strong collaboration with

Table 5 : The Most 10 Co-authorships Organizations

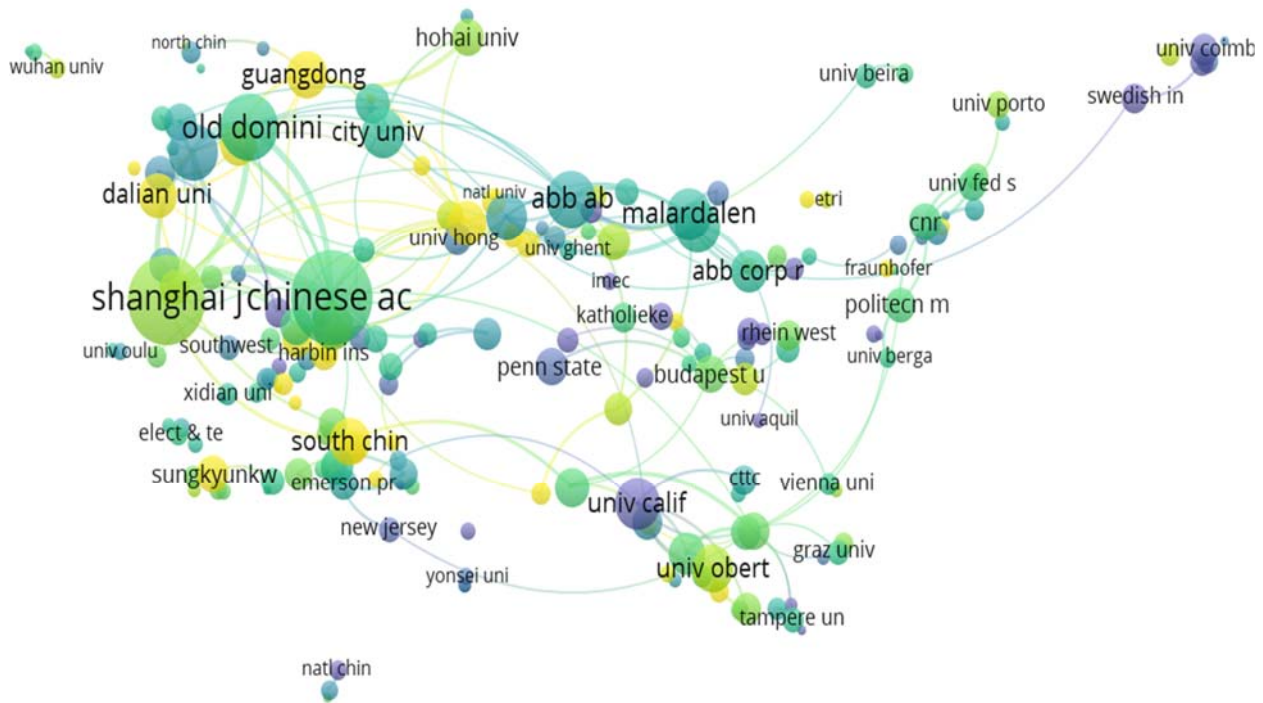| R	Organization	Publications	Citations	Total link strength
1	Chinese Acad Sci	58	1076	78
2	Shanghai Jiao Tong Univ	47	903	72
3	Old Dominion Univ	17	1042	40
4	Univ Sci & Technol China	9	736	30
5	Abb Ab	17	88	29
6	Malardalen Univ	21	56	25
7	Mid Sweden Univ	29	168	25
8	Univ Calif Berkeley	27	366	24
9	City Univ Hong Kong	19	223	22
10	South China Univ Technol	20	118	21

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Figure 6: Co-authorship among organizations

each other in terms of joint IIoT publications. We would like to clarify that the "total link strength" does not represents the publication count rather it only indicates co-authorship connection set with others. This is to avoid duplicate count as a set may have multiple co-authorships in the same publication with other organizations.
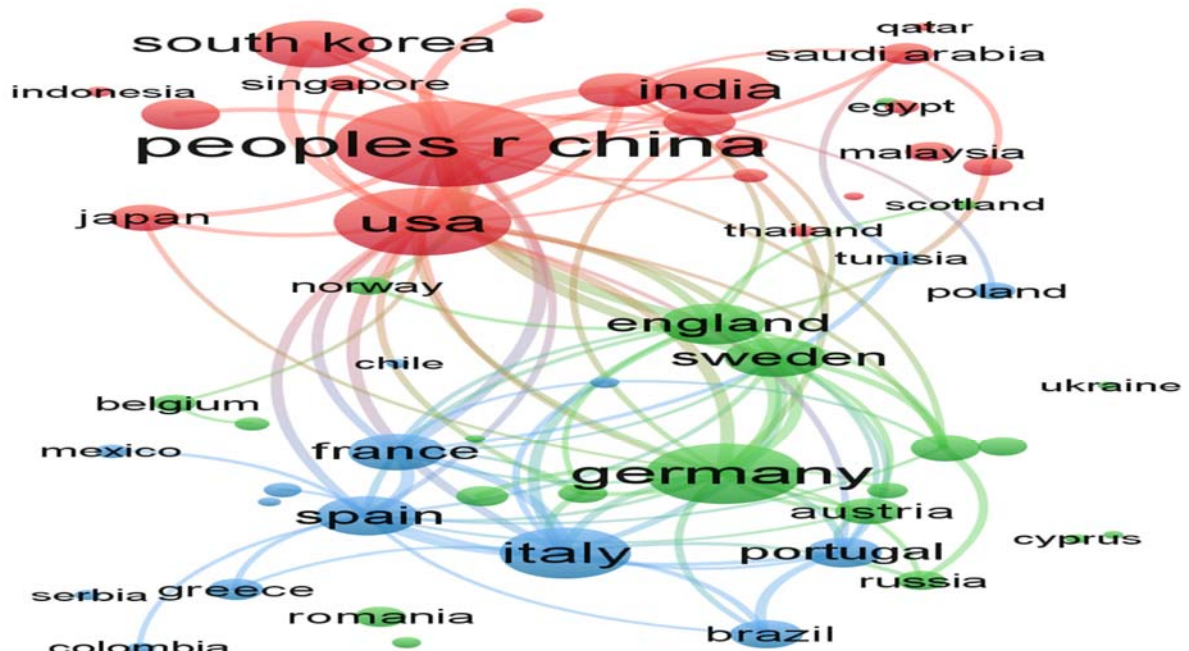
4.2. Co-authorship between Countries

Figure 7: Co-authorship among countries

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Regarding the co-authorship between countries in the field of Industrial IoTs, Figure 7 shows that the Peoples Republic of China has the greatest co-authorship among all other countries.

From Table 6, China occurs 689 times (total link strength) with other countries which has 311 published articles in the field of IIoT research.

A noticeable point is that the link strength may be counted multiple times from the same publication. For instance, if a country address exists in a paper with two other countries, the link strength from this article will be doubled. USA is the most partnering country with China; the two countries exist together in 88 articles. Table 6 and Figure 7 also illustrates the other countries with their co-authorship relations and link strengths.

5. CONCLUSION

The current study discussed bibliometric perspectives of the industrial IoTs and major contributors to the research of this topic in the past 30 years. The study has shown that IIoT is a rapidly growing area of research among the scientific community. Applications of IIoT systems is significantly increasing in many fields; however, Engineering stands first in all times with IIoT research followed by Computer Sciences and Telecommunications. The main objective of this study is to highlight research trends as well as its extraordinary growth in the past 10 years. The data also indicates that Gidlund M is the most influential and active author followed by some other main leaders in this field are Akerberg J and Wang Q. The two most influential journals are IEEE Transactions on Industrial Informatics and Sensors. The most influential country is Sweden followed by China in this research field.

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