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Bibliometric Review of Predictive Maintenance using Vibration Analysis

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ABSTRACT

Every day the world is depending more and more on machines in almost every aspect of life. With the increasing use of machines, there also needs to be an evolution in the maintenance of these machines. Predictive maintenance is a process used to monitor the equipment and machinery during its operation to detect any damages and/or deteriorations and enable the required maintenance plan in advance, resulting in reduced operational costs and full utilization of tools and parts. The fundamental goal of this bibliometric review paper is a comprehension of the extent and sources of the literature available for predictive maintenance systems. The bibliometric review is based on the Scopus database and data visualization tools like ScienceScape. The time series dataset considered is from 2006 to 12th May 2021, as these years saw a rise in research in the field of predictive maintenance. The articles on Predictive Maintenance revealed a remarkable improvement that again emphasizes the importance of paper reviews. This research paper shows some significant analysis about the focus of research in this field and shows future perspectives and improvements for research in this field.

Keywords: Predictive Maintenance, Vibration Analysis, Artificial Intelligence, Machine Learning

1. INTRODUCTION

As higher demands are being placed on existing resources in higher yields and expanded effectiveness, the need to predict and comprehend the deterioration of machines is becoming increasingly significant. Adding to this the expanding intricacy, motorization and automation of plants and hardware, it is vital to have an appropriately organized, coordinated and financed support upkeep methodology [1]. Predictive maintenance is a set of new and latest scientific

technologies that can detect any potential failure. If the fault characteristics and parameters of the equipment are already known, Predictive Maintenance can help detect faults in advance with much more ease, and the appropriate actions can be implemented in an organized method [2]. Machine Learning (ML) techniques have arisen as a promising tool in Predictive Maintenance applications. The execution of Predictive Maintenance applications relies upon the suitable machine learning technique chosen to create the model [3]. The faults and anomalies formed in internal structures enable a plan for maintenance action [4]. All machines generally have some degree of vibration. When this machine vibration increments or gets inordinate, it shows mechanical flaws or inadequacy of some kind. Vibration Analysis detects the presence of these vibration developments using instruments such as an accelerometer. The results of these readings of the Vibration Analysis can be plotted on a 'Magnitude Vs Frequency plot' by utilizing a mathematical algorithm known as the Fast Fourier Transform [2]. There are numerous Predictive Maintenance techniques such as Vibration Analysis, Acoustic emission, Oil analysis, Particle analysis, Corrosion Monitoring, Thermography, Performance monitoring. The Machine Learning algorithms which can be used for predictive maintenance are Random forests, Artificial Neural Networks, Support Vector Machines and K-means clustering algorithms.

This review article is the result of a detailed bibliometric analysis of the numerous publications found in the field of predictive maintenance systems. In our view, this is the main such review that has been completed in this field. This paper highlights some significant analysis results and will help researchers for future research scope in the field. This research paper has picked up the research publications mainly from Scopus databases, and after the survey, it also carries out a bibliometric analysis of all the survey results and records grouping and learning theories based on the survey.

2. FRAMING KEYWORDS

This section focuses on the keywords used to search the publication database. Keeping the focus on Predictive Maintenance, we used the words Predictive and Maintenance as the primary keywords. These words were accompanied by secondary and optional keywords. Table 1 encapsulates the three keyword groupings: primary, secondary and optional.

Table 1: *Framing keywords for database search*

Primary Keyword	Predictive Maintenance
Secondary Keyword **(AND)**	Vibration Analysis
Optional Keywords **(OR)**	Artificial Intelligence, Machine Learning, TinyML, Deep learning, Industry 4.0, Data-driven model

3. ANALYSIS USING SCOPUS DATABASE

For this bibliometric review, we made use of the Scopus Database to search for publications related to Predictive Maintenance for Machines. We focus on Predictive Maintenance through Vibration Analysis for the purpose of this paper. We made use of the inbuilt analysis features of Scopus and made use of the data visualization tool "ScienceScape". In this section, we analyze the publications through many parameters. This paper reviews all publications on the Scopus database as of 12th May 2021.

3.1 Year-wise Trend

As can be seen from Fig 1, the oldest available publication on Predictive Maintenance and Vibration Analysis is from 1974. For the next four decades, the number of publications remained low, with a steady increase between the years 2015-2018. A substantial increase in interest in these topics can be seen in the last few years.

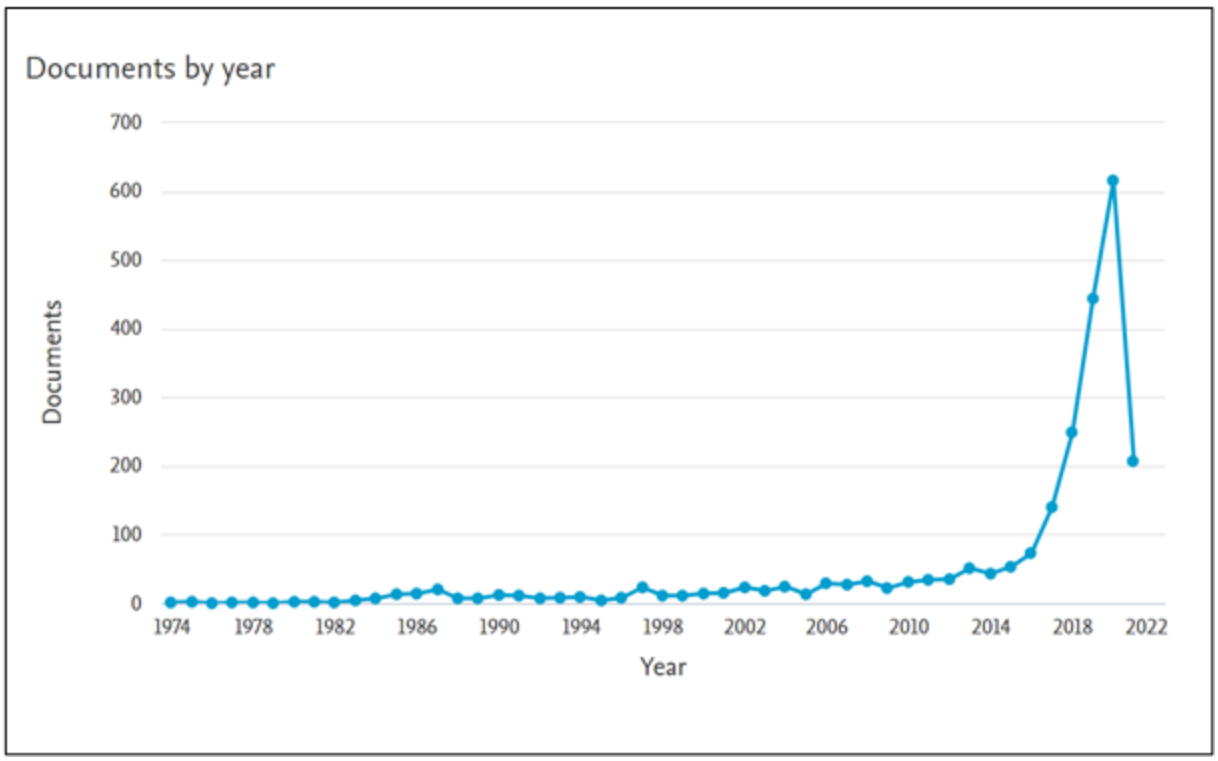

Fig 1: *Year-wise trends of publications (as accessed on 12th May 2021)*
Source: *www.scopus.com*

Even though the publications on Predictive Maintenance and Vibration Analysis have been in existence since 1974, for the purpose of analysis, we take into account the publications from only the last 15 years, which amount to a total of 2,086 publications. All the analysis in this paper shall focus on the publications of this time period, that is, 2006 to 12th May 2021, as shown in Fig 2.

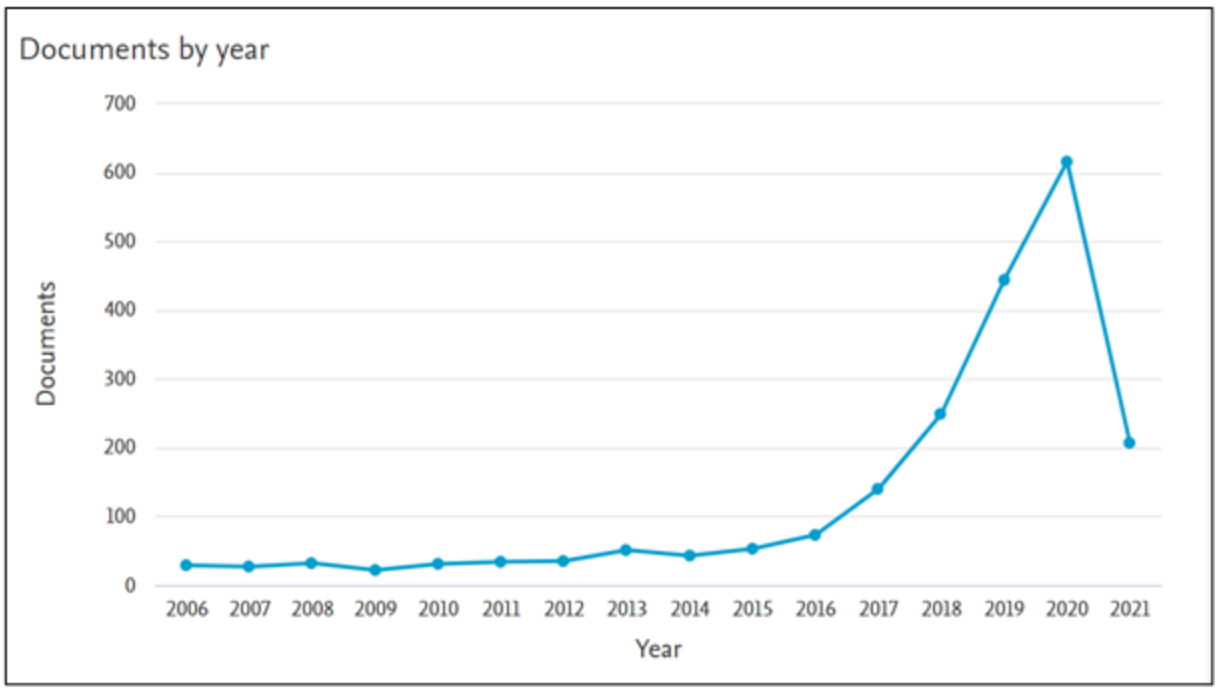

Fig 2: *Year-wise trend for last 15 years (as accessed on 12th May 2021)*
Source: *www.scopus.com*

3.2 Language-wise trend Analysis

The majority of the publications available are in the English language. However, there exist some in German, Chinese, Spanish, Portuguese, Russian, Turkish and Korean. The publication languages are summarized in Table 2.

Table 2: *The language-wise trend of Scopus indexed publication (accessed on 12th May 2021)*

Language	Number of Publications
English	2031
German	19
Chinese	18
Spanish	10
Portuguese	3
Russian	3

Turkish	3
Korean	2
French	1
Italian	1
Polish	1
Romanian	1

Source: *www.scopus.com*

3.3 Keyword Analysis

Fig 3 gives a visual representation of the most used keywords across the publications. It helps visualize the evolution of the most important keywords (>10 papers in the file). Unsurprisingly, "Predictive Maintenance" is at the top of the list. Some other common keywords are "machine learning", "Industry 4.0" and "condition monitoring".

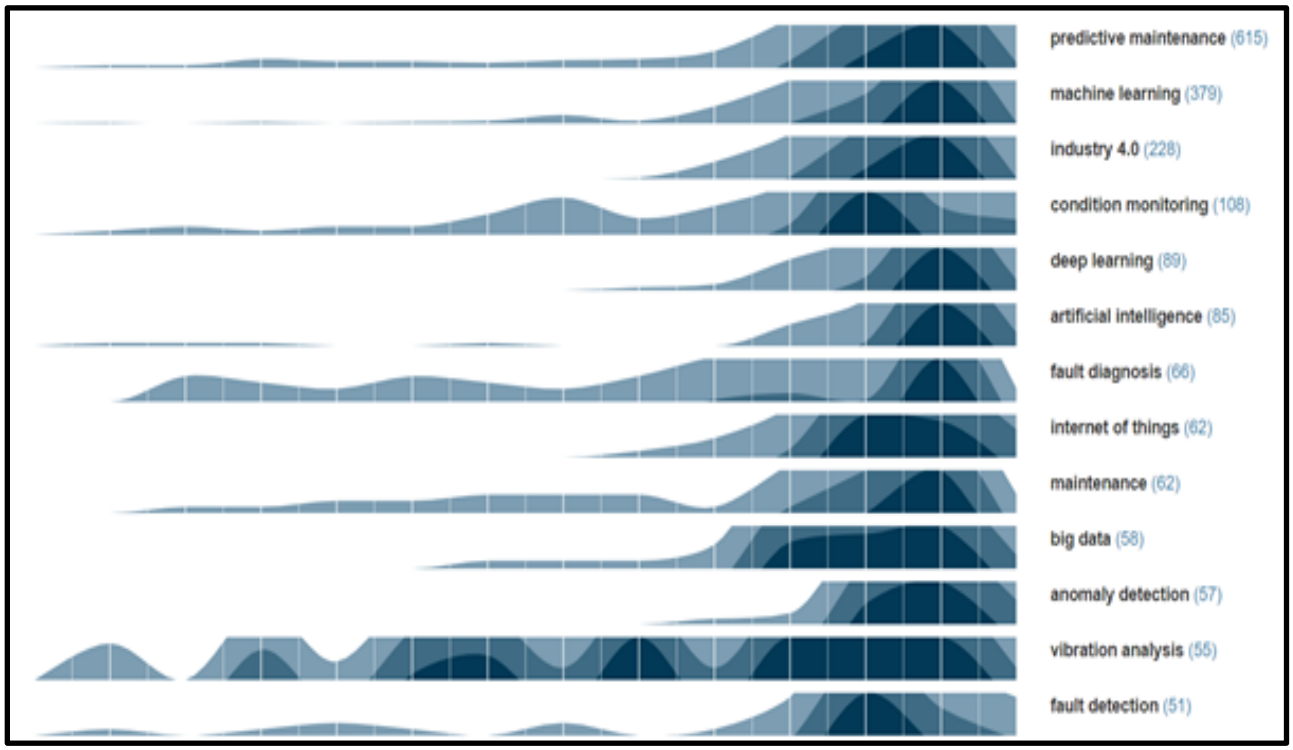

Fig 3: *Top keywords used in the publications of the last 15 years (as accessed on 12th May 2021)*
Source: *https://medialab.github.io/sciencescape/*

3.4 Document type-wise

While analyzing based on publication type, the researchers in the area of Predictive Maintenance have published nearly 56.0% of total publications as conference papers and 36.5% in articles, as shown in Fig 4. It additionally shows only 1.8% of the total publications are Review publications, while there is 2.0% as Book Chapters and 2.8% as Conference Review papers.

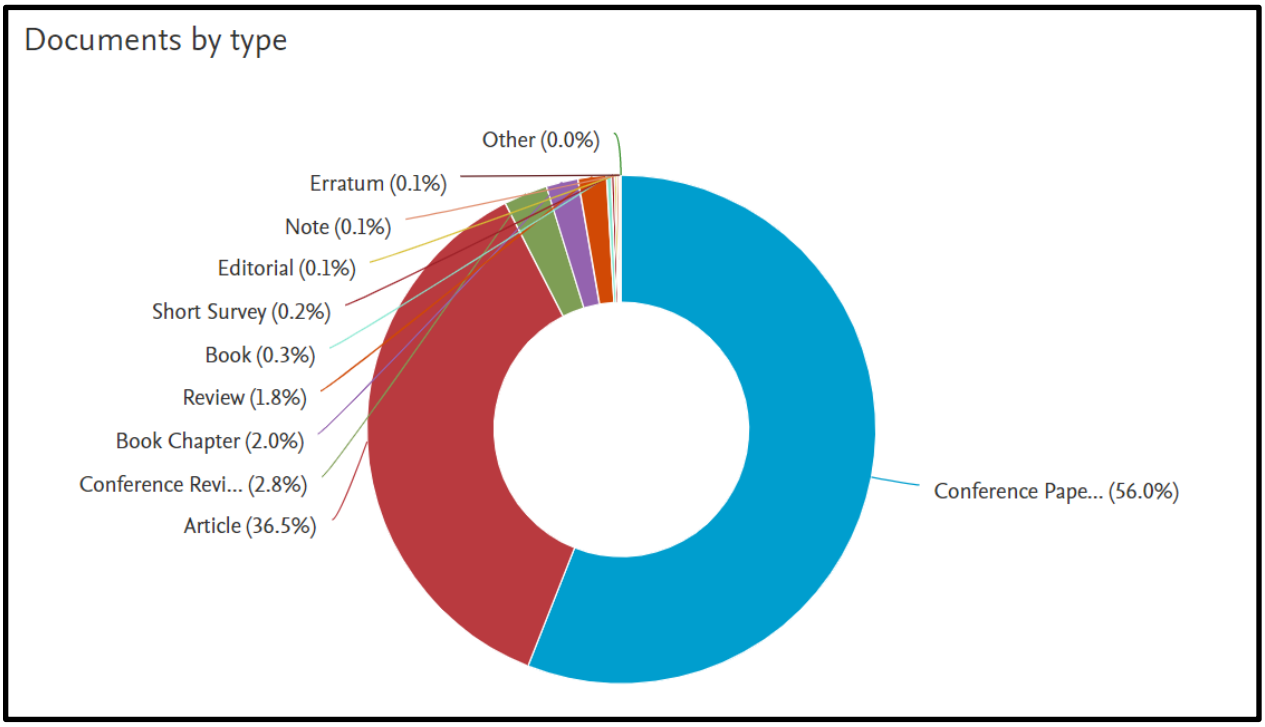

Fig 4: *The Publication types wise trend (accessed on 12th May 2021)*
Source: *www.scopus.com*

3.5 Documents by source analysis

When analyzing the Documents per year by source, we can see from Fig 5 that 'Communications in Computer and Information Science' tops the chart in the years 2020 with more than 30 publications. The most constant source, although since 2006, has been the 'Lecture Notes in Computer Science including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics. The other top contributors by source are 'IEEE Access', 'Procedia CIRP' and 'Procedia Manufacturing'.

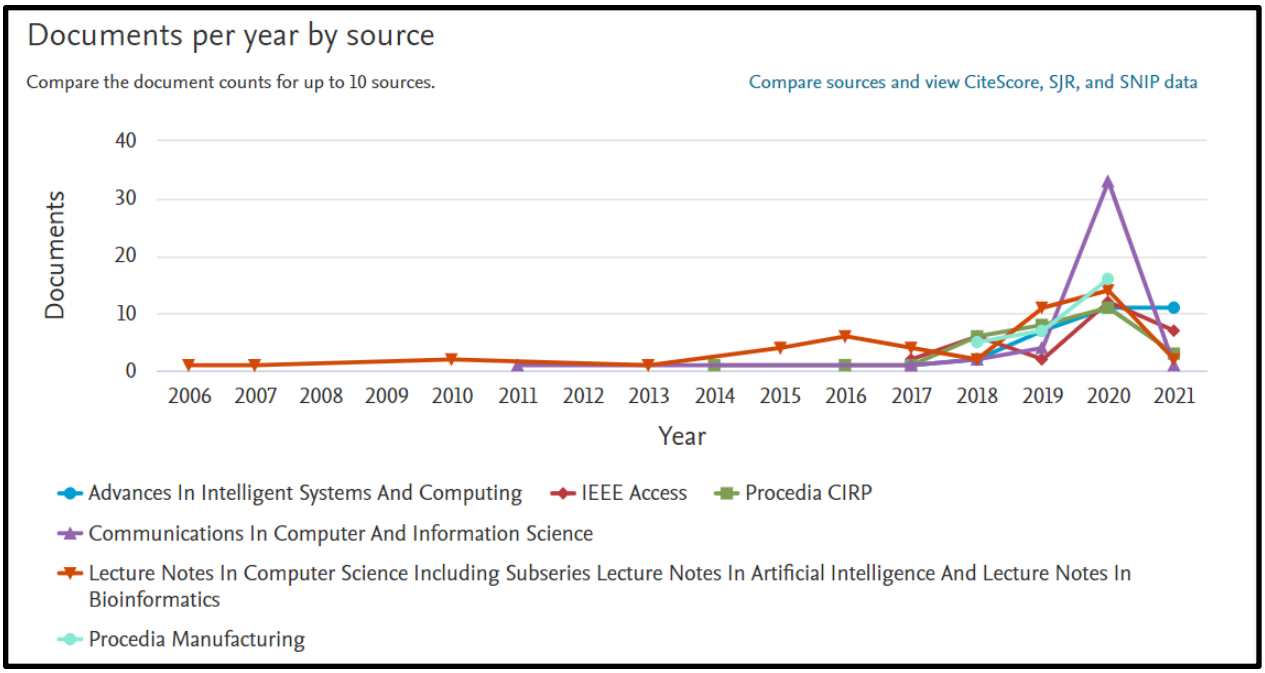

Fig 5: *The Documents by source wise trend (accessed on 12th May 2021)*
Source: *www.scopus.com*

3.6 Country wise trend

It is very interesting to see that many research publications come from the United States. The USA has contributed more than 300 of them with the most related and the most-visited articles among all the articles. China comes next with more than 200 publications, closely followed by Germany. Italy and India follow next with almost 150 publications each. This is shown in Fig 6. Articles of China, India, Germany, and Italy developed a lot quicker than other countries in the most recent 15 years.

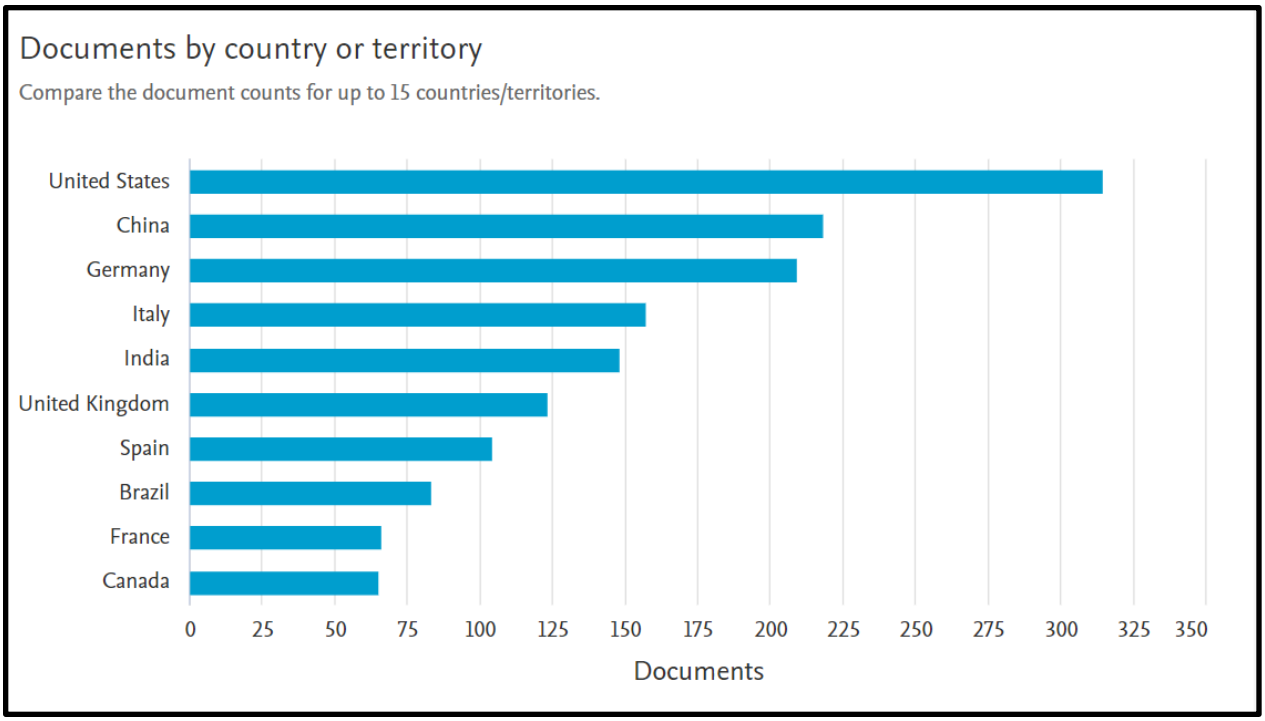

Fig 6: *The Country wise trend of Predictive Maintenance characteristics (accessed on 12th May 2021)*

Source: *www.scopus.com*

3.7 Documents by subject area

Fig 7 gives a view of the subject or research areas that have largely contributed to the research. As is seen from Figure 8, Engineering and Computer Science have contributed more than 50% of the research publications and gradually turned into the mainstream of Predictive Maintenance research. In terms of the number of publications, Engineering has 1290 publications, followed by Computer Science with 1107 and Mathematics with 330. It is seen that there is a significant drop in the amount of research that is done in Energy, Materials Science, Social Sciences, Decision Science and Others.

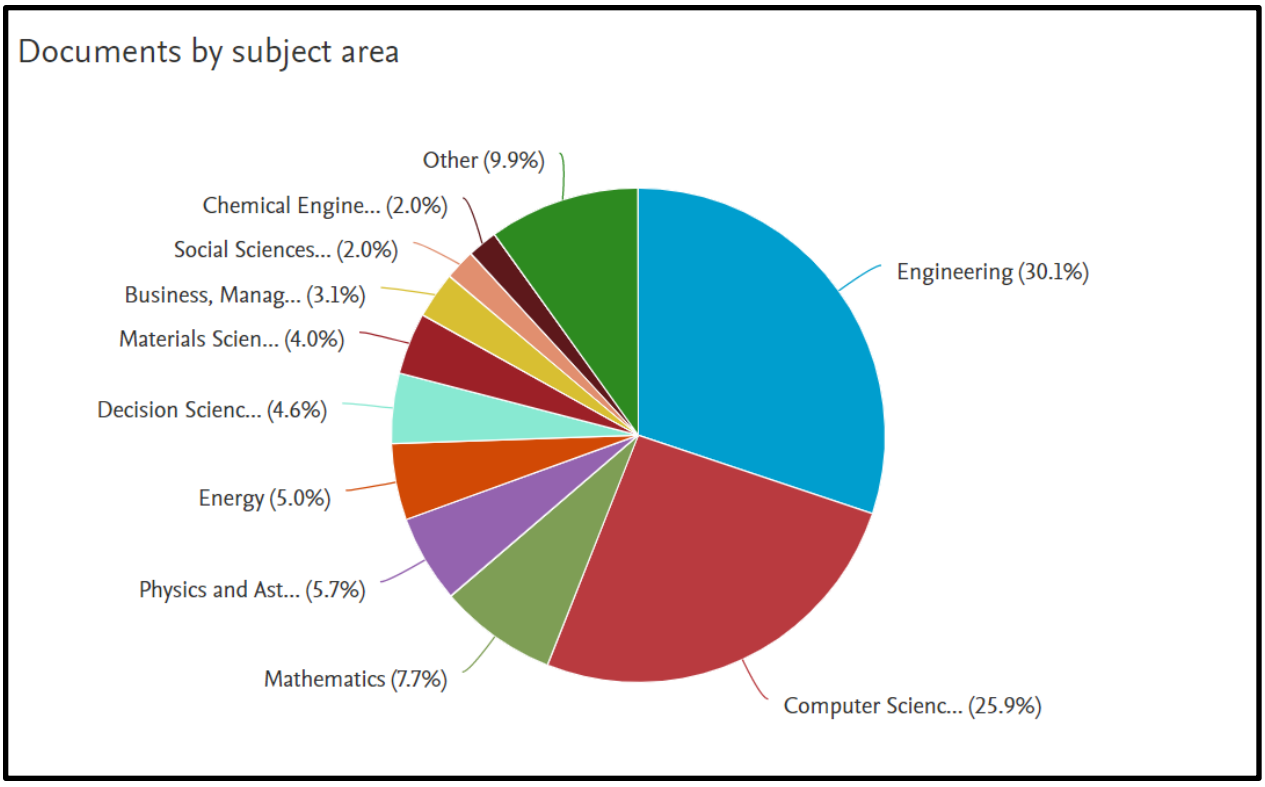

Fig 7: *The subject area-wise percentage spread of the publications (accessed on 12th May 2021)*
Source: *www.scopus.com*

3.8 Author wise trend

In Fig 8, the number of publications of the top 10 most prolific researchers is given as a bar chart. Yang C from the United States, University Politehnica of Bucharest, leads the pack with 10 publications in the period under review.

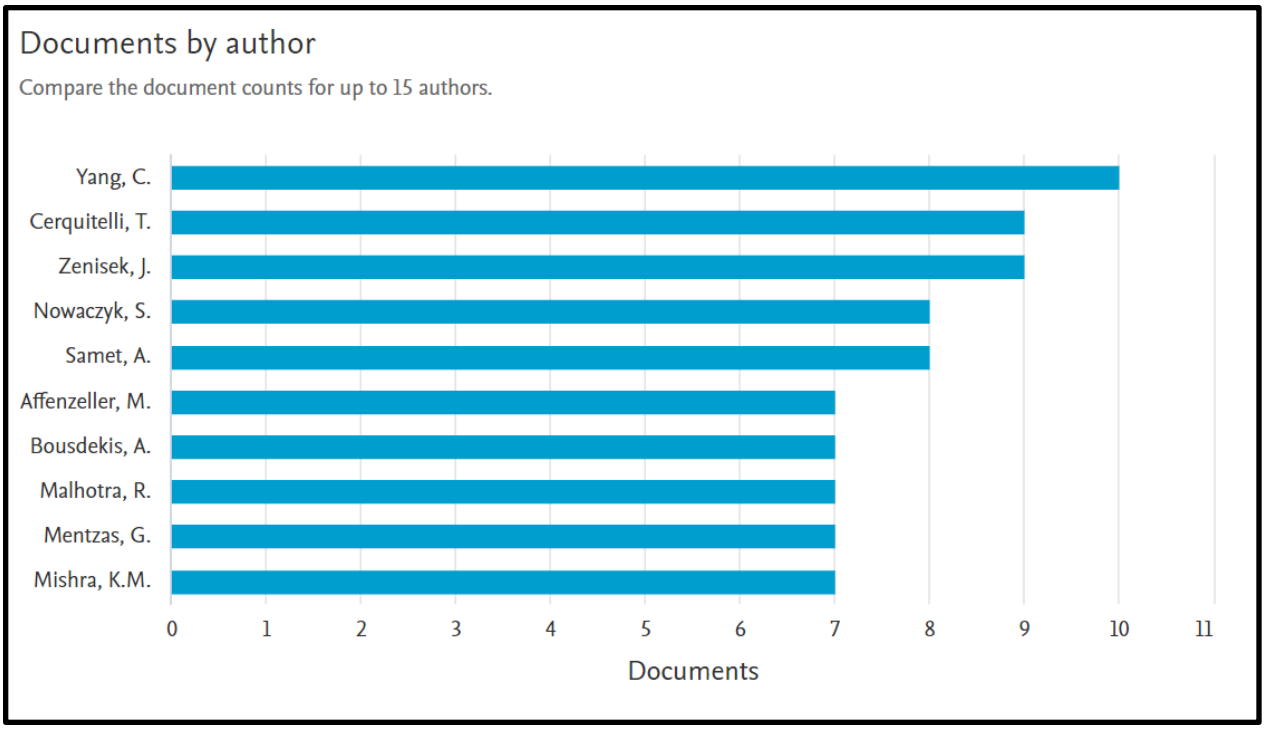

Fig 8: *Top ten authors published in this field (accessed on 12th May 2021)*
Source: *www.scopus.com*

3.9 Affiliation Statistics

Fig 9 shows the top ten universities / organizational affiliations which contribute. It is observed that Romania concentrates most in the research in Predictive Maintenance with more than 18 publications. Alma Mater Studiorum - Università di Bologna and Siemens AG follow closely with 17 publications each.

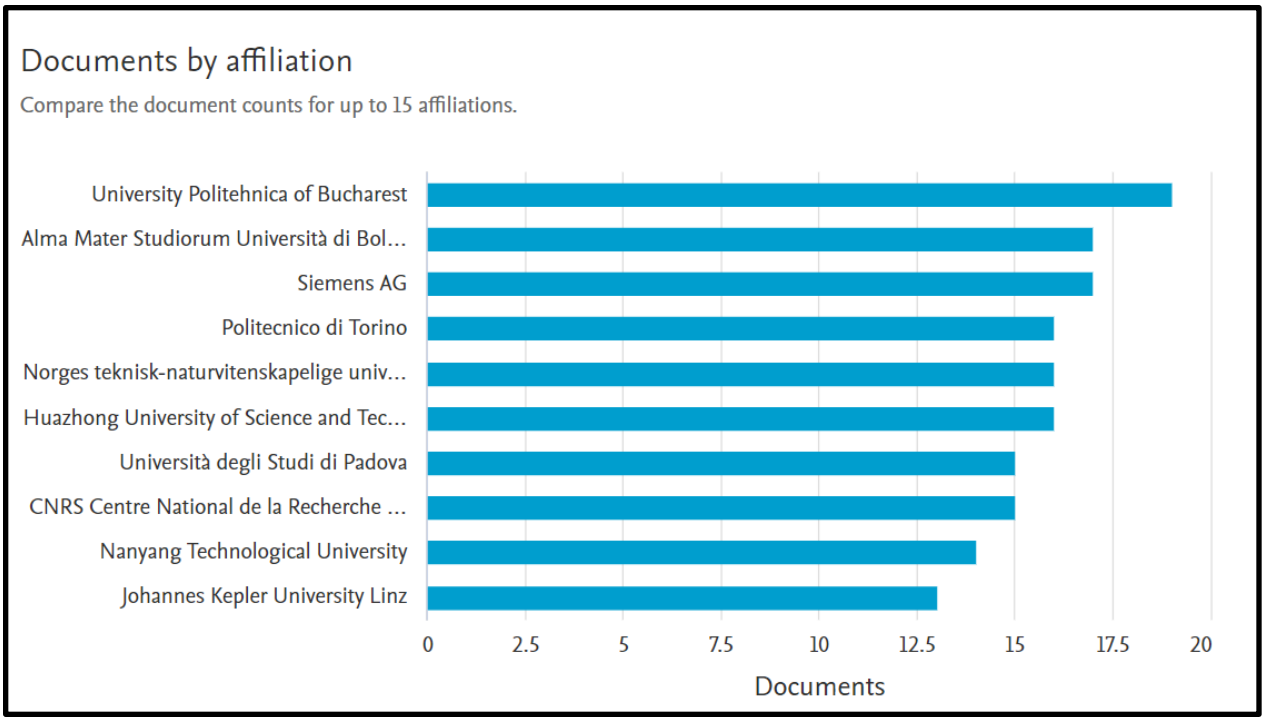

Fig 9: *Top 10 Affiliation-wise institutes for research centres (accessed on 12th May 2021)*
Source: *www.scopus.com*

3.10 Funding sponsor wise trend

Fig 10 shows the top ten sponsors who have funded for research in the field of Predictive Maintenance and Vibration Analysis. The majority of the research funding sponsorship comes from the European Commission, which is acknowledged by more than 120 publications. The funding by the National Natural Science Foundation of China secured second place with 80 plus publications. The Horizon 2020Framework Program and the European Regional Development Fund follow with more than 50 publications each. The European countries and China have been the most major contributors in the past 15 years.

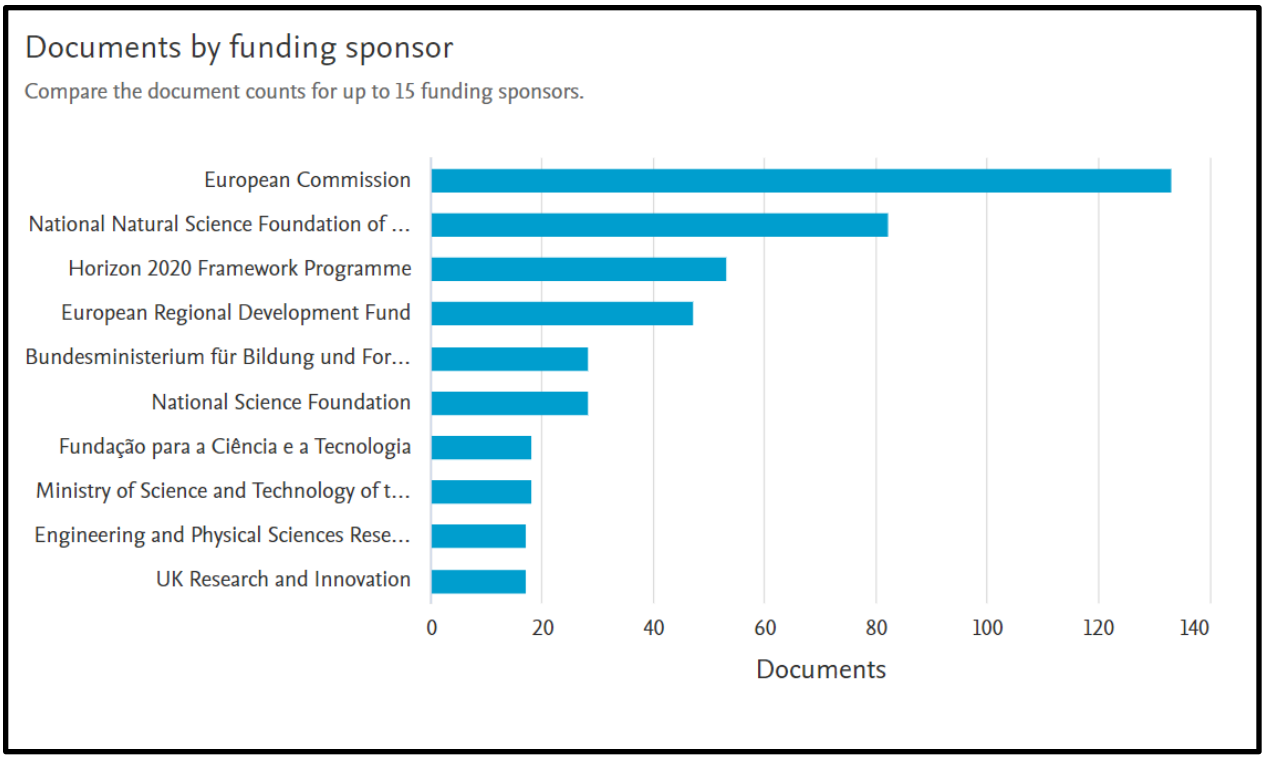

Fig 10: *Leading top ten funding sponsors in Predictive Maintenance research domains (accessed on 12th May 2021)*

Source: *www.scopus.com*

3.11 A-K-J Sankey

Fig 11 shows the Author-Keyword-Journal Sankey showing the link between the authors, keywords used and the subsequent publishing journals with the length of node increasing with the frequency of occurrence. The highest occurring keyword in the papers reviewed was Predictive Maintenance, with Machine Learning coming a close second and Industry 4.0 being third.

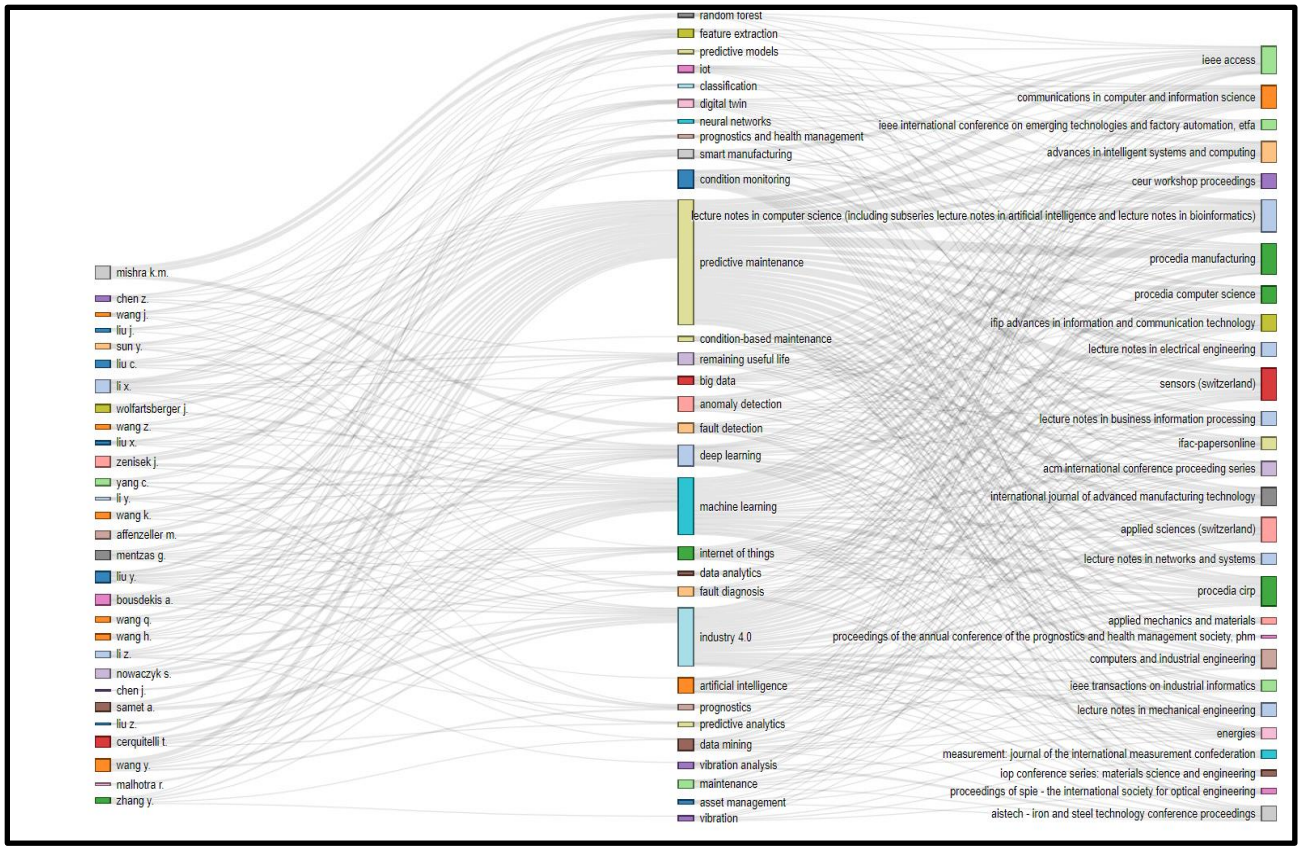

Fig 11: *Author-Journal-Keyword Sankey Diagram*
Source: *https://medialab.github.io/sciencescape/*

3.12 Citation wise Trend Analysis

Table 3 reveals annual citations collected from publications taken from the Scopus database for Predictive Maintenance. Citation analysis shows that this research area pulls in the attention of specialists more in the past 15 years. The publication from Procedia CIRP journal with the highest number of citations is 881, which is the first paper that has the maximum number of citations since it was published in 2014.

Table 3: *10 most cited publications of Predictive Maintenance (accessed on 12th May 2021)*

Authors	Title	Year	Source Title	Cited By
Lee J., Kao H.-A., Yang S.	Service innovation and smart analytics for industry 4.0 and big data environment	2014	Procedia CIRP	881
Wang G., Gunasekaran A., Ngai E.W.T., Papadopoulus T.	Big data analytics in logistics and supply chain management: Certain 0 investigations for research and applications	2016	International Journal of Production Economics	496
Peng Y., Dong M., Zuo M.J.	Current status of machine prognostics in condition-based maintenance: A review	2010	International Journal of Advanced manufacturing technology	405
Kim S., Whitehead Jr. E.J., Zhang Y.	Classifying software changes: Clean or buggy?	2008	IEEE Transactions on Software Engineering	367
Qi Q., Tao F.	Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison	2018	IEEE Access	325
Susto G.A., Schirru A., Pampuri S., McLoone S., Beghi A.	Machine learning for predictive maintenance: A multiple classifier approach	2015	IEEE Transactions on Industrial Informatics	259
Wang J., Zhao R., Wang D., Yan R., Mao K., Shen F.	Machine health monitoring using local feature-based gated recurrent unit networks	2017	IEEE Transactions on Industrial Electronics	255
Garcia M.C., Sanz-Bobi M.A., del Pico J.	SIMAP: Intelligent System for Predictive Maintenance. Application to the health condition monitoring of a windturbine gearbox	2006	Computer in Industry	237
Watson S.J., Xiang B.J., Yang W., Tavner P.J., Crabtree C.J.	Condition monitoring of the power output of wind turbine generators using wavelets	2010	IEEE Transactions on Energy Conversion	178
Wang D., Tsui K.-L, Miao Q.	Prognostics and Health Management: A Review of Vibration Based Bearing and Gear Health Indicators	2017	IEEE Access	166

Source: *www.scopus.com*

3.13 Patent Analysis

For Predictive Maintenance as per the Scopus database, 25,015 patents have been filed in the last 15 years. Fig 12 shows, The United States Patent & Trademark Office is driving universally with 20,962 patents. The Japan patent office is next to follow with 1,872 patents, closely followed by the European Patent Office with 1,361.

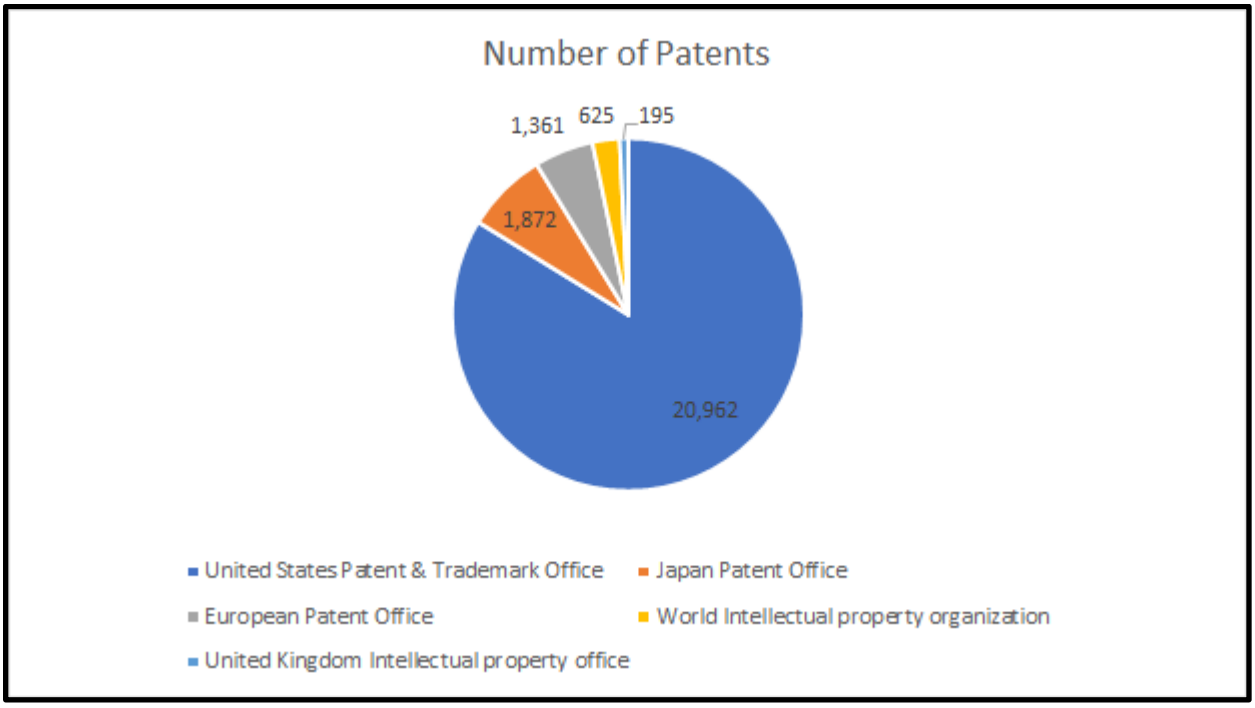

Fig 12: *Patent office wise analysis of Patents published as per data (accessed on 12th May 2021)*

Source: *http://www.scopus.com*

4. CONCLUSION

This paper reviews and analyses all the currently available research publications on the keywords "Predictive Maintenance and Vibration Analysis" available in the Scopus database. The first available record of a publication on this topic is from 1974. However, the interest in this area has been substantially amplified in recent years only. For this paper, we took into account all publications of the last 15 years, the time frame of which is 2006-12th May 2021. This provides us with a total of 2,086 publications, the majority of which are published in the English language. The keywords "Predictive Maintenance", "Machine Learning", and "Industry 4.0" are the most common keywords across all available publications. Out of the total publications found, 56.0% are

conference papers, and 36.5% are articles. The nation-wise trend analysis shows that the USA is leading in this field of study followed by China, while India ranks fourth in the list. The two biggest subject areas in this field are Engineering and Computer Science with 30.1% and 25.9% of publications respectively. The paper also analyses the institutions, authors, funding agencies, academic journals, affiliations and in which the work has been published. It can be concluded that "Predictive Maintenance and Vibration Analysis" has seen an increased interest in recent years and has a huge potential for growth in multiple fields.

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