Bibliometric study of state observer research applied to internal combustion engine

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Abstract. The present study was conducted to evaluate the worldwide scientific production related to observers applied to internal combustion engines by taking information from the Web of Science (WoS) database and taking the papers published between $2001 - 2017$. The works found are mostly research articles with a total of 130 articles equivalent to 97.01%, of the 134 articles studied, and it was also noted that the production of this type of work increased in the last 3 years, with the maximum value in 2015 being 22 articles, even in those 3 years, the greatest number of references were also found. The United States is the country with the highest number of publications with 42 followed by People´s Republic of China, France and UK with $41, 11$ and 11 respectively. Although the USA is the country with the highest number of publications, China has consolidated its position as the country with the highest number of publications and citations in the last 3 years. However, within the top 10 institutes with the highest number of publications, 4 of them are from the United States, among which Ohio State University stands out as the institute with the highest number of publications with 16 (11.9%). On the other hand, the most commonly used words in the documents were observer (91), control (47), engine (47), based (42) and estimation (41).

1. Introduction

Since the beginning of industrialization, human beings have always sought ways to optimize and minimize downtime in their operational processes [1], in modern times and following such thinking and with the help of the most recent, emerging and advanced technology, industrial automation is becoming increasingly common. One of the processes in which there has been a notable development in automation processes is power generation, more specifically in power generation through internal combustion engines [2]. This continuous advance in automation is mainly due to the strict and restrictive regulations associated with the generation of pollutants, such as the EURO [3] Standard, which encourage much stricter control and automation of them. This is why different types of emission control and regulation such as EGR technologies [4,5] and regulation of injection times and quantity of fuel injections [6,7] are very common.

From the above, and in order to simplify the control process in certain specific thermodynamic engine phenomena, a type of model called "medium value models" [8,9] was developed, which, given their simplicity and robustness, are ideal for this type of application. Among the types of models, authors

from the late 20th and early 21st centuries, such as Hendrikcs, Chevalier and Anderson, who proposed medium-value models for naturally aspirated and turbocharged engines with or without EGR technology, stand out. It is also very common to see in this type of modeling a discretization by categories, since there are models that focus on the description of volumetric efficiency [10], others on the modeling of the correct behavior of the air-fuel ratio of the engine [11-13] and finally there are those that model the torque and power generation of the engine [14]. Based on the previous models, equations called "observers" are used to observe the behavior of a given variable of interest in the engine or in general of any specific phenomenon of a system [15]. Observers can be used in applications such as fault detection and can even be used as a kind of "pseudo sensor", as they allow the "measurement" of a variable which the measuring instrument is very expensive or impossible to measure [16]. For the specific application in internal combustion engines, the most common observers of the fuel air ratio [11,13] and observers of volumetric efficiency stand out [10].

Based on the above, the present work seeks through a bibliometric analysis the identification of significant contributions to the application of observers to internal combustion engines, where it is possible to highlight in which topics or variables of interest have not been developed/applied.

2. Methodology

2.1. Bibliometric analysis

Bibliometric analysis is a systematic approach that allows the user to quickly and quantitatively analyze scientific publications, in order to identify milestones in certain niches of research fields [17,18].

2.2. H- index

This indicator was first proposed by Hirsch [18,19] in 2005, and is used to assess the research achievements of a researcher/publication/journal in both quality and quantity aspects. According to what Hirsh [3] developed and raised, the definition of h-index is that an author with a given h-index has published h articles, and each of those h articles has been cited in other articles at least h times. In this study, h-index was used to assess the influence of countries/territories and institutes.

2.3. Sources of data

The Institute for Scientific Information (ISI) Web of Science (WoS) published by Thomson Reuters is commonly used to search for high quality or hard-to-reach scientific literature through public sources of information [20]. WoS is an important data source for any bibliometric analysis that wants to be performed [21-22], because it allows access to a large number of bibliographic databases to its users, in addition to having the ability to provide the most consistent and standardized records compared to other databases such as Scopus [18,22,23]. With this in mind, a total of 134 publications were collected for analysis.

3. Results

All the publications found were written in English. Of which 130 are journal articles (97%), 2 are reviews (1.5%), 1 procedure-related publication (0.75%) and 1 editorial material (0.75%), the above is shown in Table 1, where Recs is “records”, TLCS is "total local citation score" and TGCS is "total global citation score".

3.1. Selected publications performance

Table 2. Presents the main performance of observer-related work on internal combustion engines published during the period 2001 to 2017. The results show that there was a noticeable growth in the total number of annual papers related to this topic, while both the average number of authors for each article and the references cited per article also increased especially in the last 3 years. The average number of authors per publication increased from 2 in 2001 to 3 in 2017, and references cited per publication increased from 25 in 2001 to 61.29 in 2017. These figures indicate significant

improvement, communication and cooperation between specialists associated with this type of research topic.

Table 1. Distributions of publications.

Document Type	Recs	TLCS	TGCS	Percentage
Article	130	67	1688	97.01
Review	2	0	26	1.49
Proceedings Paper	1	0	0	0.75
Editorial Material	1	0	0	0.75

Table 2. Principal performance about observers in internal combustion engines.

Year	Publications	Percentage	Authors	References cited	AU/PUB	RC/PUB
2001	1	0.7	2	25	2.00	25.00
2002	2	1.5	8	67	4.00	33.50
2003	1	0.7	5	27	5.00	27.00
2004	4	3	13	118	3.25	29.50
2005	5	3.7	12	73	2.40	14.60
2006	8	6	25	191	3.13	23.88
2007	3	2.2	11	61	3.67	20.33
2008	7	5.2	23	184	3.29	26.29
2009	8	6	25	164	3.13	20.50
2010	5	3.7	12	125	2.40	25.00
2011	9	6.7	29	282	3.22	31.33
2012	11	8.2	31	292	2.82	26.55
2013	10	7.5	37	305	3.70	30.50
2014	9	6.7	25	247	2.78	27.44
2015	22	16.4	71	660	3.23	30.00
2016	15	11.2	47	522	3.13	34.80
2017	14	10.4	42	858	3.00	61.29

3.2. Journals distribution

The 134 publications studied are distributed in 67 journals, with topics associated with automation, energy and ergonomics, where the journals with the highest number of publications were: IEEE Transactions on control system technology with 15 (11.2%), Journal of Dynamic System Measurement and Control-Transactions of the ASME with 14 (10.4%), IEE Transactions on Industrial Electronics with 8 (6%), Proceedings of the Institution of Mechanical Engineers Part D-Journal of Automobile Engineering and for last Control Engineering practice. Figure 1. Shows the impact of the above-mentioned top 5 from $2001-2017$, which highlights the notable growth of the Journal of Dynamic System Measurement and Control-Transactions of the ASME in the last 7 years, where it reached the maximum of 5 publications associated with the implementation of observers in internal combustion engines in 2012.

3.3. Contributions from countries and institutions

Of the 134 publications found, 3 are of no origin, so 131 papers were analyzed, with 25 countries and 165 institutions contributing to the development of observer studies applied to internal combustion engines during the period $2001-2017$.

3.3.1. Country contributions. Figure 2 shows the global distribution of publications by observers, covered by 26 countries, where the USA is highlighted as the country with the highest number of publications (42 documents), followed by the People´s Republic of China (41), France (11), UK (11) and Germany (8).

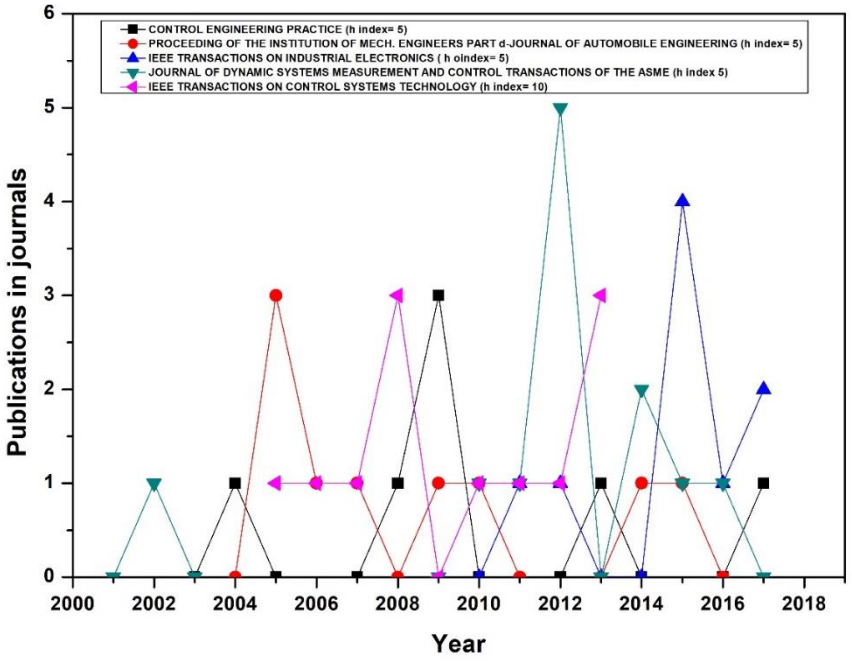

Figure 1. H-index of the top 5 journals.

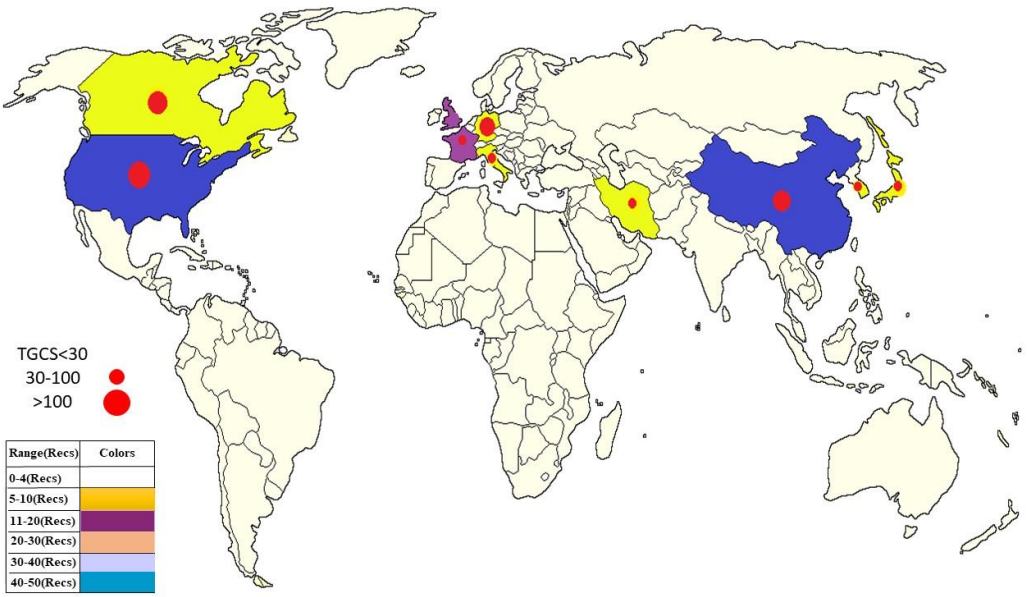

Figure 2. Global citations in the countries.

Similarly, and in order to make a comparison, Figure 3(a) show the amount of paper published, with respect to the rest of the countries, which shows the growth of 2008 – 2012, and in turn the decline in the following years, until 2015 when it reached the top of publications. The People's Republic of China, on the other hand, consolidated solidly from 2015, being a leader interrupted for the last 3 years. It is also possible to appreciate the h-index of each country, where it is evident that since 2013 the USA has shown little interest in continuing to develop the topic studied, as shown in Figure 3(b).

3.3.2. Institutions contributions. Table 3 shows the main performance of the 10 most productive institutions in research related to the topic of study from 2001 – 17. The Ohio State University ranks first in the ranking, with 11.2% of the 134 paper processed in the search, and the highest total global

citation score with a value of 202, it is followed by the University of Michigan with 4.5% of the jobs, followed by Ford Motor Company with 3.7%, the ranking also shows that 4 of the most important institutions are from United States and at the same time have high global citation score, which shows why, despite the fact that this country has not had a notorious amount of development of scientific work on this subject, they continue to remain in the first place of the most cited publications.

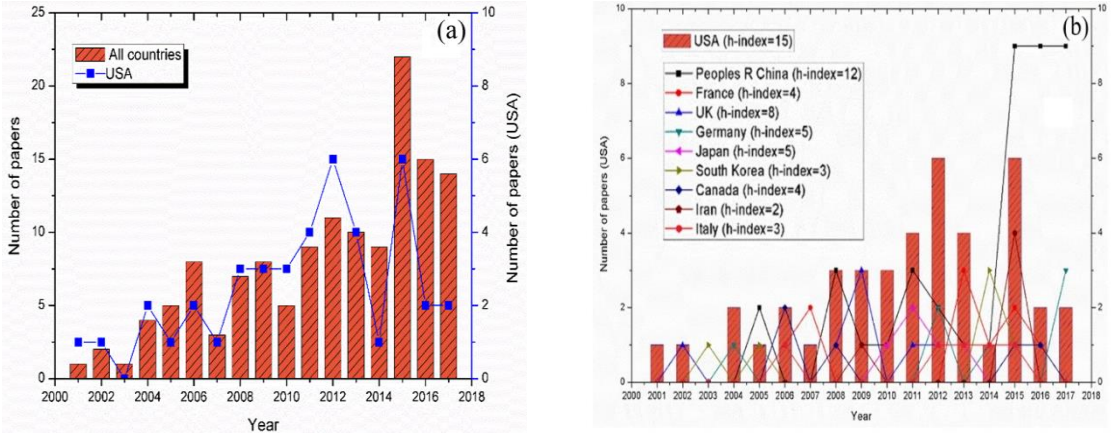

Figure 3. (a) Number of papers vs. number of USA papers; (b) H-index of top 10 countries.

Table 3. Top 10 most productive institutions.

Position	Institution	Recs	Percent	TLCS	TGCS
1	Ohio State Univ	16	11.9	17	202
2	Univ Michigan	6	4.5	6	108
3	Ford Motor Co	5	3.7	8	85
4	Beihang Univ	4	3	0	49
5	Hanyang Univ	4	3	1	23
6	Leuphana Univ Lueneburg	4	3	11	107
7	Nanjing Univ Aeronaut & Astronaut	4	3	0	4
8	Sharif Univ Technol	4	3	0	4
9	Sophia Univ	4	3	1	37
10	Tianjin Univ	4	3	2	65

Table 4. Most commonly used words.

Position	Word	Recs	TLCS	TGCS
1	Observer	91	49	1141
2	Control	47	20	598
3	Engine	47	22	389
4	Based	42	16	418
5	Estimation	41	32	361
6	Engines	29	29	372
7	Mode	29	18	340
8	Diesel	27	27	266
9	Sliding	27	10	274
10	Systems	26	17	524
11	Using	23	6	261
12	Design	22	14	473
13	Fault	18	2	250
14	Nonlinear	18	9	543
15	Application	17	7	204

3.4. Highlights words

The 15 most commonly used words in the 134 publications studied are presented in Table 4. The most frequently quoted word with the highest overall citation score is OBSERVER, which is not surprising given that they are associated with observers. From the rest of the highlighted words, an indication of the type of applications received by observers in internal combustion engines can be seen, ranging from estimating parameters and therefore replacing or "creating" a sensor of a difficult or impossible variable to measure to parameter control and engine failure detection.

4. Conclusions

It is possible to be evidenced from the developed and consulted that the subject of observers applied to internal combustion engines is something relatively recent, and that it is presenting a remarkable boom in countries like the People's Republic of China, which is one of the countries where the last three years has maintained a high number of publications associated to the subject. It should also be noted that all the work aims to apply observation and control to three specific engine issues, which are the flow of the air-fuel mixture, the generation of pollutants and the generation of engine torque. It also highlights the clear trend in the application of observers to diesel engines, which opens up the possibility of a clear development of this issue to engines with induced ignition (natural gas, gasoline, etc.).

Therefore, a possible new view of application for observers in internal combustion engines would be the observation of parameters such as the effective efficiency of the engine or the amount of heat rejected by the engine, as they are very difficult variables to measure or estimate and are of vital importance when evaluating or rectifying the performance of an engine.

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