Research Trends on Fuzzy Logic Controller for Mobile Robot Navigation: A Scientometric Study

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Abstract: *The present study shows the scientometric analysis of the publications on the fuzzy logic controller in autonomous mobile robot navigation during the period 2000 to 2018. The data is collected using Web of Science core collection database and analyzed at various levels such as Web of Science categories, publication years, document types, funding agencies, authors, research areas, countries or region, control terms, and organization to evaluate the research patterns. An extensive study is done to find the research trends in this area.*

Keywords: *Fuzzy Logic Controller, Autonomous Mobile Robot Navigation, type-2 Fuzzy logic, Optimized Fuzzy Controller*

1. Introduction

The research in the field of robotics has shown great advancement in recent years. One of the latest applications in the robotics is autonomous navigation of robots when the surrounding environment is unstructured. Handling navigation and obstacle avoidance become very crucial in an unstructured environment. Fuzzy logic controller deemed to be appropriate for handling the navigation and obstacle related problems. Therefore, in this paper, the analysis is performed on the articles that have shown ways or methods to solve navigation and obstacle related problems in mobile robots using the fuzzy logic controller. This paper presents, a scientometric study on the fuzzy logic controller for autonomous mobile robot navigation. Web of Science is taken as the source to retrieve and analyze the data. A total of 307 documents which include 302 articles, 4 proceeding papers, and 1 book chapter are extracted from the period 2000-2018[1 to 307].

The scientometric study in this paper helps to understand various research patterns by answering the following research questions:

- Which research domain has the maximum number of publications in the field of fuzzy logic controller for mobile robot navigation?
- What is the growth rate of publication through the year 2000 to 2018?
- What are the various document types published in this area?
- Which funding agencies have the maximum number of research grants?
- Which author has the maximum number of publications in this field?
- Which research area has the maximum number of research papers in the field of the fuzzy logic controller for mobile robot navigations?
- Which country has contributed the most to this field?
- What are the various control terms associated with the fuzzy logic controller and mobile robot navigation?
- Which organization has the maximum number of publications?

In section 2, the methodology and material used for this study is discussed. Data interpretation and analysis of collected data at various levels such as Web of Science categories, publication years, document types, funding agencies, authors, research areas, countries or region, control terms, and organization are discussed in section 3. This study is concluded in section 4.

2. Methodology and Material

Web of Science is used as the data source to collect the data used in this study. It is a multidisciplinary database that supports 256 disciplines. The data is indexed in Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI) and Arts & Humanities Citation Index (A&HCI).

A total of 307 publications were retrieved for the queries listed in table 1. The table shows the source of data, Indexing, period, queries and total number of documents retrieved.

An analysis of collected data from the WoS using the searched queries as listed is performed at various levels such as WoS categories, publication years, document types, funding agencies, top authors, research areas, country or region, network plot of control terms and organization. A descriptive analysis of the data using various charts and graphs has been done in the next section.

Tab. 1. List of queries used to collect data

Source of Data	Indexing	Period	Queries	Total number of documents retrieved
Web of Science	Science Citation Index-Expanded (SCI-E), SSCIA&HCI and ESCI.	2000-2018	"Fuzzy logic controller for robot navigation", "Optimised fuzzy controller", "type 1 OR type 2 Fuzzy logic for autonomous robot navigation", "mobile robot motion planning", "autonomous mobile robot navigation using soft computing", "genetic algorithm-based path planning for mobile robots", "autonomous robot* navigation* AND Fuzzy* logic controller*", "autonomous robot navigation AND fuzzy controller AND fuzzy logic AND Mobile robot navigation", "soft computing based mobile robot navigation".	307

3. Data Interpretation and Analysis

Interpretation of research trends on publications in the field of fuzzy logic controller in the mobile robot navigation is performed in this section.

3.1. Web of Science Categories

Web of Science core collection gives multiple options to search the queries such as basic search, author search, cited reference search and advanced search. In this section, the searched queries are analysed at WoS categories level which defines the domain of articles. A table for these categories with their respective record count is shown in table 2. The result shows that the maximum number of articles are published in computer science artificial intelligence category with record count of 139 articles. The second most frequent category is automation control systems with record count of 89 articles. A tree map corresponding to these categories is shown in figure 1.

Tab. 2. Top 10 Web of Science Categories with record count

S. No.	WoS Category	Record Count
1	Computer Science Artificial Intelligence	139
2	Automation Control Systems	89
3	Robotics	81
4	Engineering Electrical Electronic	62
5	Computer Science Interdisciplinary Applications	27
6	Instruments Instrumentation	26
7	Engineering Multidisciplinary	20
8	Engineering Mechanical	16
9	Computer Science Information Systems	14
10	Engineering Manufacturing	13

3.2. Publication Years

Figure 2 depicts the year-wise distribution of articles to show the number of articles published in a particular year. Most numbers of the articles are published in the year 2018 with a record count of 32 as opposed to the year 2000 with a record count of 11.

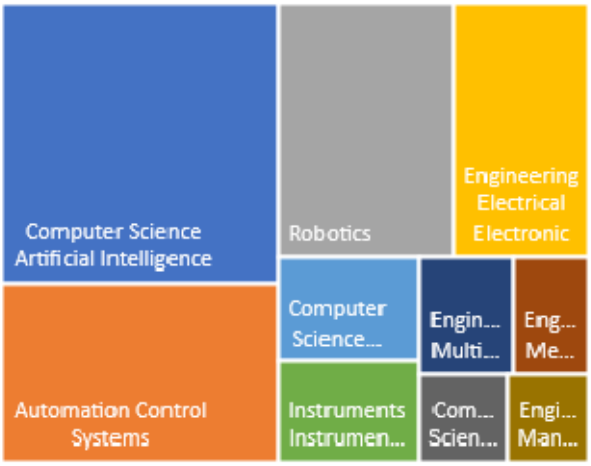

Fig. 1. Tree map for Web of Service categories with their respective record count

To observe the growth trends, we have used two scientometric measures i.e., Relative Growth Rate and Doubling Time. RGR and DT are used as a measure in growth analysis. The growth of any systm per unit time is referred to as Relative Growth Rate. RGR is calculated using the formula-

$$RGR = \frac{\ln w2 - \ln w1}{T2 - T1} \tag{1}$$

where,
$\ln(w1)$: Natural logarithm of the number of publications at time T1.
$\ln(w2)$: Natural logarithm of the number of publications at time T2.
$T1$: Initial time
$T2$: Final time
$T2 - T1$: Difference between initial time and final time.

Because we are calculating RGR for successive years, the difference between initial time and final time is equal to 1.

i.e., $T2 - T1 = 1$

$$RGR = \ln w2 - \ln w1 \tag{2}$$

Thus,

$$RGR = \ln\left(\frac{w2}{w1}\right) \tag{3}$$

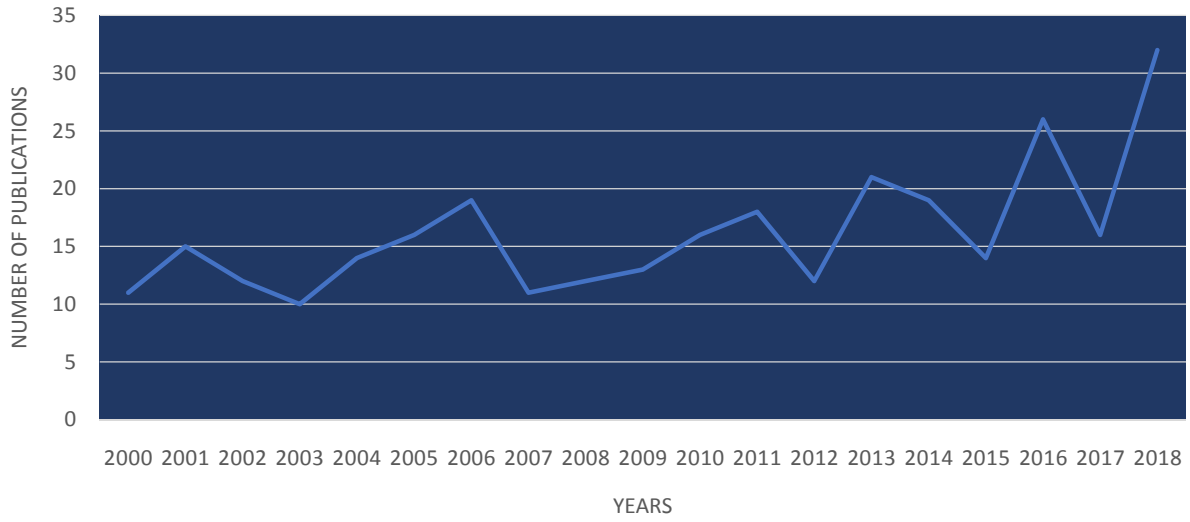

Fig. 2. Year wise distribution of articles from year 2000 to 2018

Tab. 3. RGR and DT of publications from year 2000 to 2018

S. No.	Year	NoP	CF	RGR	DT
1	2000	11	11	0.00	0.00
2	2001	15	26	0.86	0.80
3	2002	12	38	0.37	1.87
4	2003	10	48	0.23	3.01
5	2004	14	62	0.25	2.77
6	2005	16	78	0.22	3.15
7	2006	19	97	0.21	3.3
8	2007	11	108	0.10	6.93
9	2008	12	120	0.10	6.93
10	2009	13	133	0.10	6.93
11	2010	16	149	0.11	6.3
12	2011	18	167	0.11	6.3
13	2012	12	179	0.06	11.55
14	2013	21	200	0.11	6.3
15	2014	19	219	0.09	7.7
16	2015	14	233	0.06	11.55
17	2016	26	259	0.10	6.93
18	2017	16	275	0.05	13.86
19	2018	32	307	0.11	6.3

Doubling time (DT) is directly related to RGR. It is defined as the double-time of the existing growth rate. In [308], the author elaborated that the doubling time equates to the logarithm of 2 when the time required for the number of publications in a particular year to become double of its current publications.

$$DT = \frac{0.693}{RGR} \tag{4}$$

It can be observed from table 3 that the RGR is increased from the year 2000 (0.00) to 2018 (0.11). The highest RGR observed in the year 2001 and the lowest RGR is observed in the year 2015. On the other hand, the highest DT is observed in the year 2017 while the lowest DT observed in the year 2001.

In figure 3, a line graph is given to depict the relative growth rate and doubling time during the period of 2000 to 2018.

A table for top the 10 journals and their publication house with their respective count is also given in table 4. From this table, it can be observed that the maximum number of research articles are published in the journal "Robotics and Autonomous Systems" by ELSEVIER with a record count of 42. The second most frequent journal is "IEEE Transactions on Fuzzy Systems" by IEEE with a record count of 20.

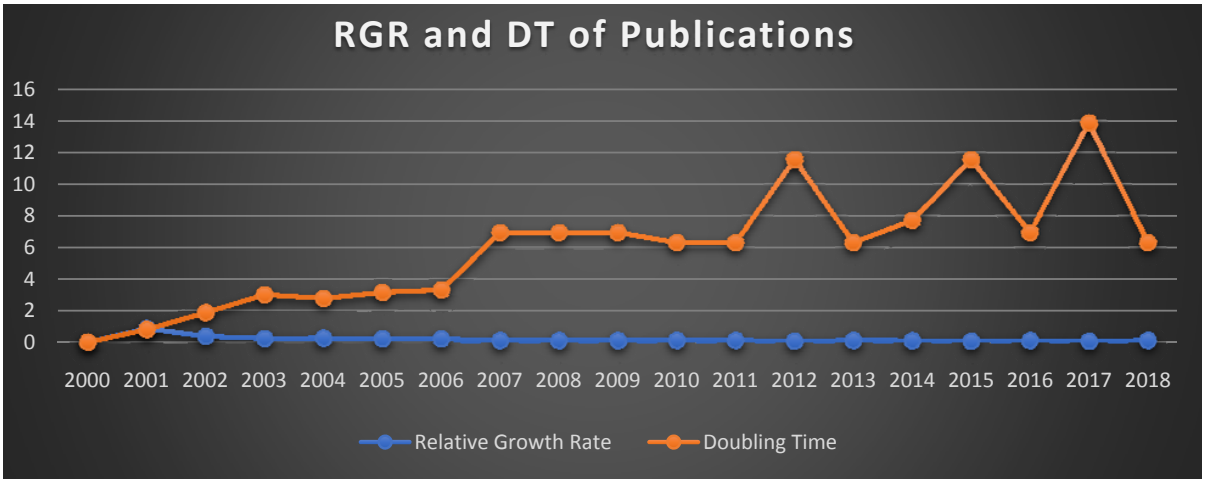

Fig. 3. RGR and DT analysis of publications during the period of 2000-2018

Tab. 4. Top 10 journals and publication house with record count

S. No.	Journal	Publication House	Record Count
1	Robotics and Autonomous Systems	ELSEVIER	42
2	IEEE Transactions on Fuzzy Systems	IEEE	20
3	Applied Soft Computing	ELSEVIER	9
4	IEEE Transactions on Instrumentation and Measurement	IEEE	7
5	Information Sciences	ELSEVIER	6
6	International Journal of Control Automation and Systems	INST CONTROL AUTOMATION & SYSTEMS ENGINEERS	5
7	International Journal of Approximate Reasoning	ELSEVIER	5
8	IEEE Transactions on Systems Man and Cybernetics Part B-Cybernetics	IEEE	4
9	IEEE Transactions on Industrial Electronics	IEEE	3
10	IEEE Transactions on Robotics and Automation	IEEE	2

3.3. Document Types

The documents types selected for the analysis of the data are articles, proceeding papers, and book chapters. The maximum number of documents is of article type with a record count of 302. Only 4 proceeding papers and 1 book chapter is retrieved for the above-mentioned queries.

A table for document type with their respective record count is shown in table 5.

Tab. 5. Document types with respective record count

S. No.	Document Types	Record Count
1	Articles	302
2	Proceeding Papers	4
2	Book Chapters	1

3.4. Funding Agencies

Various funding agencies have contributed to the publication of articles in order to carry out research in a specific domain. The name of the top 10 funding agencies that contributed to the field of the fuzzy logic controller for autonomous mobile robot navigation is listed in table 6. It can be observed from the table that the National Science Council of Taiwan with a record count of 13 has granted the maximum number of researches and the Ministry of Education and Science Spain has granted the minimum number of researches in this field. The top 10 countries corresponding to these funding agencies are mapped (in yellow color) on the world map as shown in Figure 4.

3.5 Authors

A list of top 15 authors who have contributed to field of the fuzzy logic controller for mobile robot navigation is given table 7.

From the table, it can be seen that the Parhi DR, Mbede JB, Lin CJ, Alsulaiman M, Pratihar DK, Algabri M, Chen CC, Faisal M, Juang CF, Mathkour H, Yang SX, Castillo O, Gosine RG, Mann GKI, and Mohanty PK are the top 15 authors who have published their work in this field.

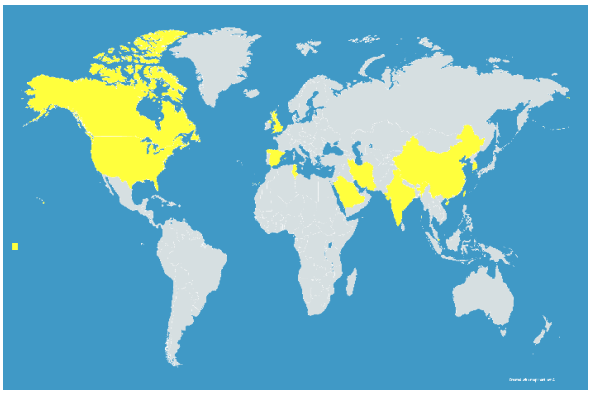

Fig. 4. World mapping of top 10 countries with maximum number of grants from funding agencies and maximum number of publications

Tab. 6. Table for top 10 funding agencies with record count

S. No.	Funding Agencies	Record Count
1	National Science Council of Taiwan	13
2	National Natural Science Foundation of China	11
3	Ministry of Science and Technology Taiwan	9
4	Fundamental Research Funds for The Central Universities	5
5	Natural Sciences and Engineering Research Council of Canada	4
6	Science and Technology Development Fund	4
7	European Union Eu	3
8	King Saud University	2
9	Memorial University of Newfoundland	2
10	Ministry of Education and Science Spain	2

The research trend shows that the Parhi DR has contributed to this field with the maximum publications with count of 16.

Tab. 7. Record count of top 10 Authors

S. No.	Authors	Record Count
1	Parhi DR	16
2	Mbede JB	8
3	Lin CJ	7
4	Alsulaiman M	6
5	Pratihar DK	6
6	Algabri M	5
7	Chen CC	5
8	Faisal M	5
9	Juang CF	5
10	Mathkour H	5
11	Yang SX	5
12	Castillo O	4
13	Gosine RG	4
14	Mann GKI	4
15	Mohanty PK	4

A scattered plot is also given in figure 6 to visualize the number of papers published by the respective authors.

3.6. Research Areas

In this section, top 15 research areas in which the maximum number of publications has been published is discussed.

From the result, as shown in the table 8, it can be observed that the highest number of articles are published in the computer science area with a record count of 169 articles as opposed to educational research area with a record count of 2 articles. A pie chart and a radar chart for 5 and 10 major research areas is also shown in figure 5 and figure 7 respectively.

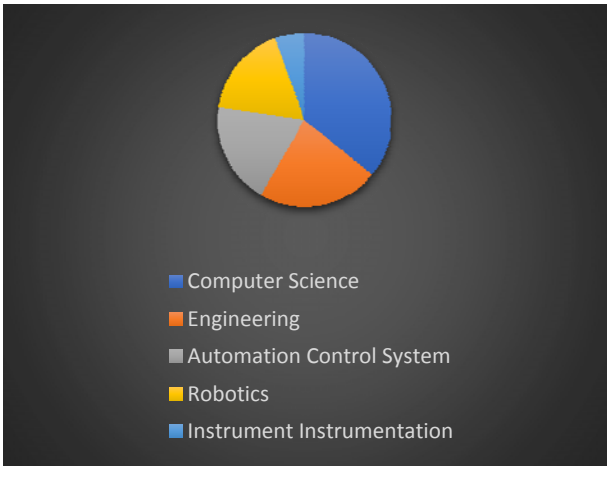

Fig. 5. Top 5 Research Areas

3.7. Country or Region

Top 10 countries across the globe have been visualized in figure 4 to depict the top 10 countries that have maximum number of publications in the field of fuzzy controller for mobile robot navigation. Table 9 shows top 10 countries contributed to this field.

Tab. 8. Record Count of top 15 Research Areas

S. No.	Research Area	Record Count
1	Computer Science	169
2	Engineering	106
3	Automation Control System	89
4	Robotics	81
5	Instrument Instrumentation	26
6	Mathematics	17
7	Agriculture	6
8	Chemistry	6
9	Telecommunications	6
10	Operations Research Management Science	5
11	Science Technology	4
12	Mathematical Computational Biology	3
13	Neurosciences Neurology	3
14	Transportation	3
15	Education Educational Research	2

Tab. 9. Top 10 Countries with maximum number of publications

S. No.	Country	Record Count
1	China	39
2	Taiwan	36
3	India	35
4	USA	33
5	Canada	24
6	England	20
7	Spain	20
8	South Kora	17
9	Iran	13
10	Tunisia	12

Tab. 10. Record count of publications of Top 10 organizations

S. No.	Organization Name	Record Count
1	National Institute of Technology	10
2	Huazhong University of Science and Technology	9
3	National Chung Hsing University	8
4	Indian Institute of Technology	7
5	King Saud University	7
6	National Cheng Kung University	7
7	Nanyang Technological University	6
8	National Chin-Yi University of Technology	6
9	University of Essex	6
10	University of Guelph	6

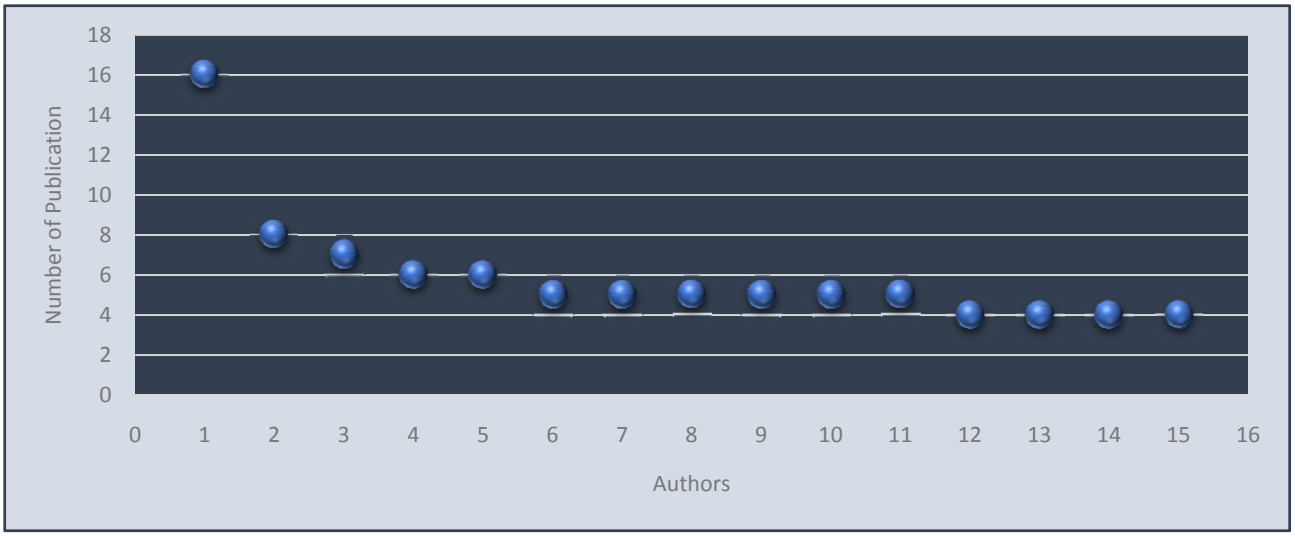

Fig. 6. Scattered plot for top 15 authors

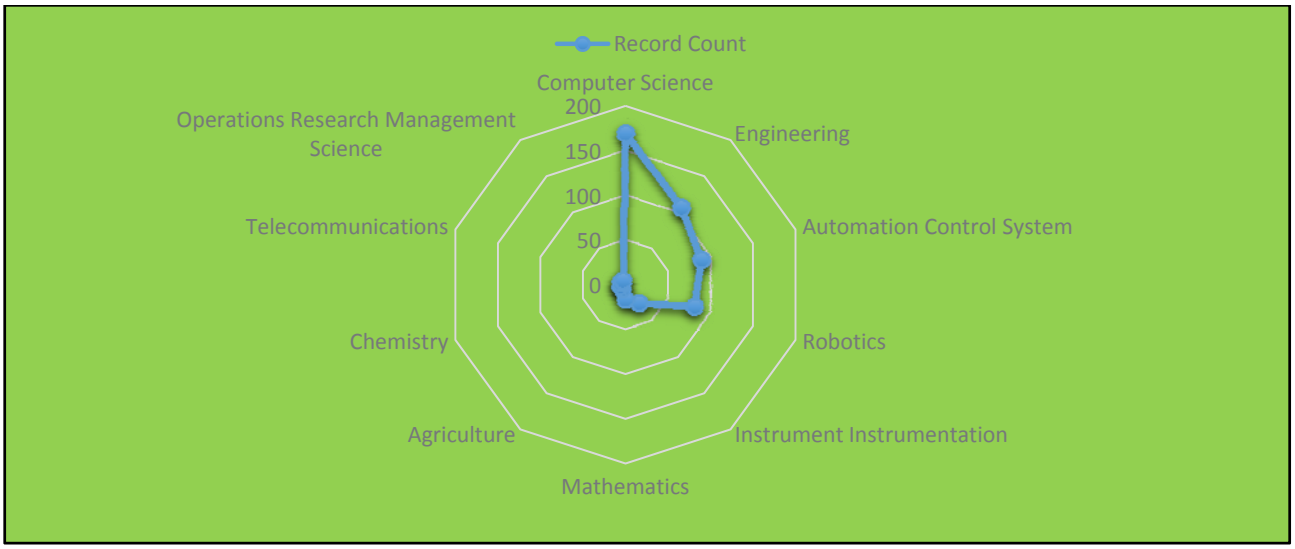

Fig. 7. Radar chart for record count of top 10 Research Areas

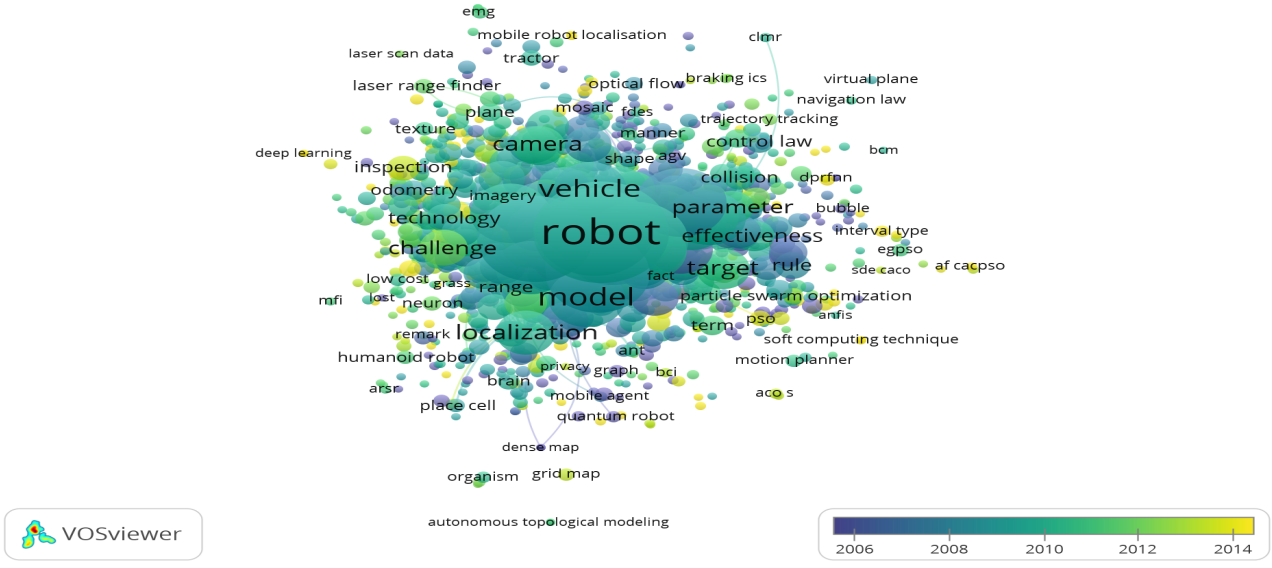

Fig. 8. Network Plot of Control terms

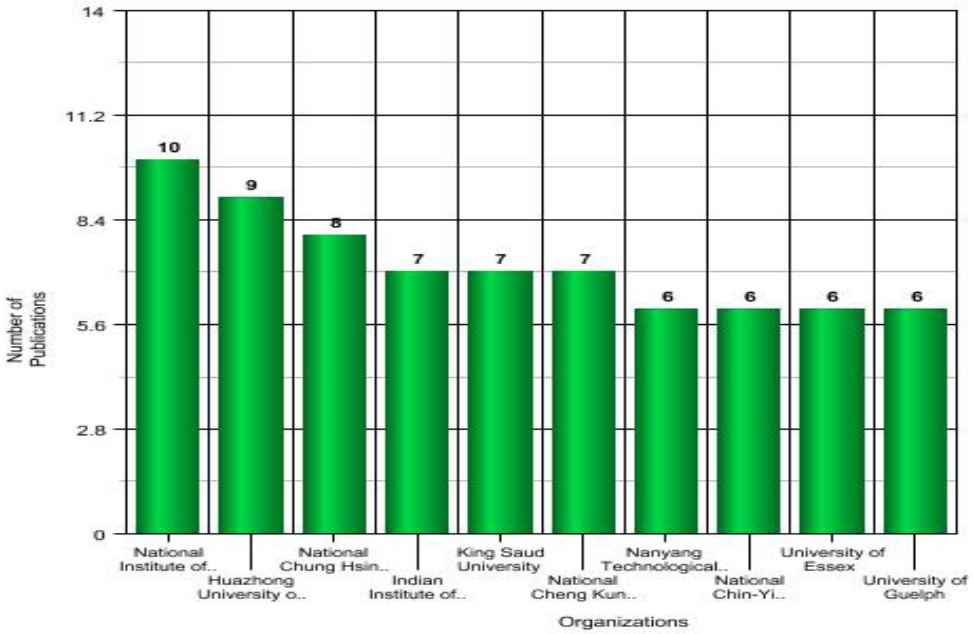

Fig. 9. Bar graph for top 10 organizations with number of publications

3.8. Network Plot of Control Terms

Control terms refer to terms that have thought of interlinked with the study when an author does his research. We have taken 1260 control terms to visualize them using the network plot as shown in figure 9.

3.9. Organization

Various organizations have continuously contributed to this field in recent years among which the National Institute of Technology has the maximum number of publications with a record count of 10 articles followed by Huazhong University of Science and Technology with a record count of 9 articles. The name of top 10 organizations and the record count of number of papers published by authors from these organizations is given table 10 and a bar graph is also shown in figure 10.

Tab. 10. Record count of publications of Top 10 organizations

S. No.	Organization Name	Record Count
1	National Institute of Technology	10
2	Huazhong University of Science and Technology	9
3	National Chung Hsing University	8
4	Indian Institute of Technology	7
5	King Saud University	7
6	National Cheng Kung University	7
7	Nanyang Technological University	6
8	National Chin-Yi University of Technology	6
9	University of Essex	6
10	University of Guelph	6

4. Conclusion

The present study gives the analytical description of publications in the field of the fuzzy logic controller for autonomous mobile robot navigation. In this paper, the publication history is explored. A total of 307 research papers are collected using the web of science database during the period 2000 to 2018. The assessment of the productivity of research in this area is performed at various levels such WoS categories, publication years, document types, funding agencies, top authors, research areas, country or region, network plot of control terms and organization, to get the deep insights in this field. From this study, it can be observed that the highest number of publications came in the year 2018. The most popular WoS category is computer science artificial intelligence with 139 publications in this field. The journal "Robotics and Autonomous Systems" has the highest number of publications. National Science Council of Taiwan is the most productive funding agency in this field that has shown the maximum number of research grants. Parhi DR is the most influential author and the National Institute of Technology has played a prominent role in the field of the fuzzy logic controller for autonomous mobile robot navigation.

In conclusion, the fuzzy logic controller for autonomous mobile robot navigation has played an important role in shaping academic research since its inception. Analysis of publications in a few more years to determine and explore the evolution and growth in this field can be a good future scope of this study.

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