An Analytical Study For The Role Of Fuzzy Logic In Improving Metaheuristic Optimization Algorithms

Submitted: 21st November 2018; accepted: 07th December 2018

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DOI: 10.14313/JAMRIS_4-2018/22

Abstract:
The research applications of fuzzy logic have always been multidisciplinary in nature due to its ability in handling vagueness and imprecision. This paper presents an analytical study in the role of fuzzy logic in the area of metaheuristics using Web of Science (WoS) as the data source. In this case, 178 research papers are extracted from it in the time span of 1989-2016. This paper analyzes various aspects of a research publication in a scientometric manner. The top cited research papers, country wise contribution, topmost organizations, top research areas, top source titles, control terms and WoS categories are analyzed. Also, the top 3 fuzzy evolutionary algorithms are extracted and their top research papers are mentioned along with their topmost research domain. Since neuro fuzzy logic poses feasible options for solving numerous research problems, hence a section is also included by the authors to present an analytical study regarding research in it. Overall, this study helps in evaluating the recent research patterns in the field of fuzzy metaheuristics along with envisioning the future trends for the same. While on one hand this helps in providing a new path to the researchers who are beginners in this field as they can start exploring it through the analysis mentioned here, on the other hand it provides an insight to professional researchers too who can dig a little deeper in this field using knowledge from this study.

Keywords: *Fuzzy Logic, Metaheuristics, Evolutionary Computing, Genetic Algorithm, Particle Swarm Optimization, Ant Colony Optimization, Fuzzy Evolutionary Algorithms, Fuzzy Cuckoo, Fuzzy Simulated Annealing, Fuzzy Swarm Intelligence, Fuzzy Differential Evolution, Tabu, Fuzzy Mutation, Fuzzy Natural Selection, Fuzzy Fitness Function, Big Bang Big Crunch, Fuzzy Bacterial, Neuro Fuzzy Logic*

1. Introduction

While dealing with mathematical and computer science application based optimizations, metaheuristics are considered to be among the best computing solutions [1]. Evolutionary computing is a subset of metaheuristics that are motivated by the concept of biological evolution. Instances include genetic algorithm, differential evolution and genetic programming. Swarm intelligence includes methods like, particle swarm optimization, artificial bee colony algorithm etc. Genetic algorithm is one of the most popular metaheuristic algorithms that is based on the notions of "natural selection" [2]. It follows the concept of the "survival of the fittest" and utilizes a fitness function for optimization. It finds its applications in various domains ranging from control engineering to natural language processing.

Another category of metaheuristic algorithms is particle swarm optimization (PSO) which uses an iterative method of evaluation for optimization [3]. A particular population of candidate solutions is moved in the search space till an optimum solution is achieved. Various other algorithms also exist that help in optimization using nature inspired computing such as the artificial bee colony (ABC) algorithm which replicates the behavior of the "honey bee swarm" for practical engineering applications [4].

Fuzzy logic has also been closely associated to optimization, mainly because of its ability to handle uncertainty, vagueness and imprecision. Due to this it is applied in amalgamation with existing metaheuristic algorithms to give better results. This gives rise to the fuzzy genetic algorithm, fuzzy particle swarm optimization and fuzzy artificial bee colony algorithm. These algorithms have been applied on various applications mainly in the field of computer science. Fuzzy evolutionary computing also provides a way to implement real life natural language processing applications like text summarization. Hence one can say that fuzzy logic and metaheuristics go hand in hand.

In this paper, an analytical study has been performed to highlight the role of fuzzy logic in metaheuristics, evolutionary computing and neuro fuzzy logic. The source of research papers is taken to be Web of Science (WoS). 178 research papers are extracted from it from the time span 1989-2016 [5-182]. The top cited research papers, top research areas, top WoS core categories, fuzzy evolutionary based algorithms, topmost organizations, country wise contribution, top source titles and various control terms are analyzed. The control terms help in identifying the most commonly discussed research concepts in this field. The top 3 fuzzy evolutionary algorithms obtained are highlighted along with their top research papers and topmost research domain. This study helps in evaluating the recent research patterns in the field of fuzzy metaheuristics and fuzzy evolutionary computing. Also, it assists in predicting the future trends that might occur.

The rest of the paper is organized as follows: Section 2 describes the data and methodology; Section 3 highlights the results of the study with corresponding visualizations; Section 4 concludes the work.

2. Data and Methodology

The data for this study is collected using Web of Science as the data source, which is a huge database of research papers indexed in Science Citation Index-Expanded (SCI-E), SSCIA&HCI and ESCI. A total of 178 research papers are extracted for the concerned search query [5-182]. The details of the data collected are shown in Table 1.

3. Analytical Study

The research patterns using WoS as the data source during the time span of 1989-2016, in the field of fuzzy metaheuristics and fuzzy evolutionary computing are evaluated in the following sub-sections.

3.1. Top Cited Research Papers

The top 5 research papers in the field of fuzzy metaheuristics and fuzzy evolutionary computing are evaluated for their respective citation and average citation score per year. The details for the same are shown as in Figure 1. Any researcher who is new to this field can have a look at this study and can start exploring with the help of these top cited research papers.

3.2. Research Areas

Fuzzy logic has found its application for optimization in various disciplines and research areas ranging from computer science to energy fuels. The record count for the top 10 research areas are recorded as shown in Table 2 and can be visualized as illustrated in Figure 2.

3.3. WoS Core Categories

WoS defines various research categories that can be used to define the domain of the various research papers. These categories and the record count of their respective research papers are tabulated as presented in Table 3. The radar chart for the same is shown as illustrated in Figure 3.

Table 1. Details of the collected data

Source of research papers	Query entered	Time Span	Total number of research papers	Indexing
WOS (web of science)	TI=(„fuzzy metaheuristics" OR „fuzzy bat" OR „fuzzy genetic" OR „fuzzy PSO" OR „fuzzy particle swarm optimization" OR „fuzzy ACO" OR „fuzzy ant colony optimization" OR „fuzzy ant colony" OR „fuzzy evolutionary" OR „fuzzy cuckoo" OR „fuzzy simulated annealing" OR „fuzzy swarm intelligence" OR „fuzzy differential evolution" OR „fuzzy tabu" OR „fuzzy memetic" OR „fuzzy ABC" OR „fuzzy artificial bee colony" OR „fuzzy harmony" OR „fuzzy mutation" OR „fuzzy natural selection" OR „fuzzy fitness function" OR „fuzzy big bang big crunch" or „fuzzy bacterial")	1989-2016	178 [5-182]	Science Citation Index-Expanded (SCI-E), SSCIA&HCI and ESCI.

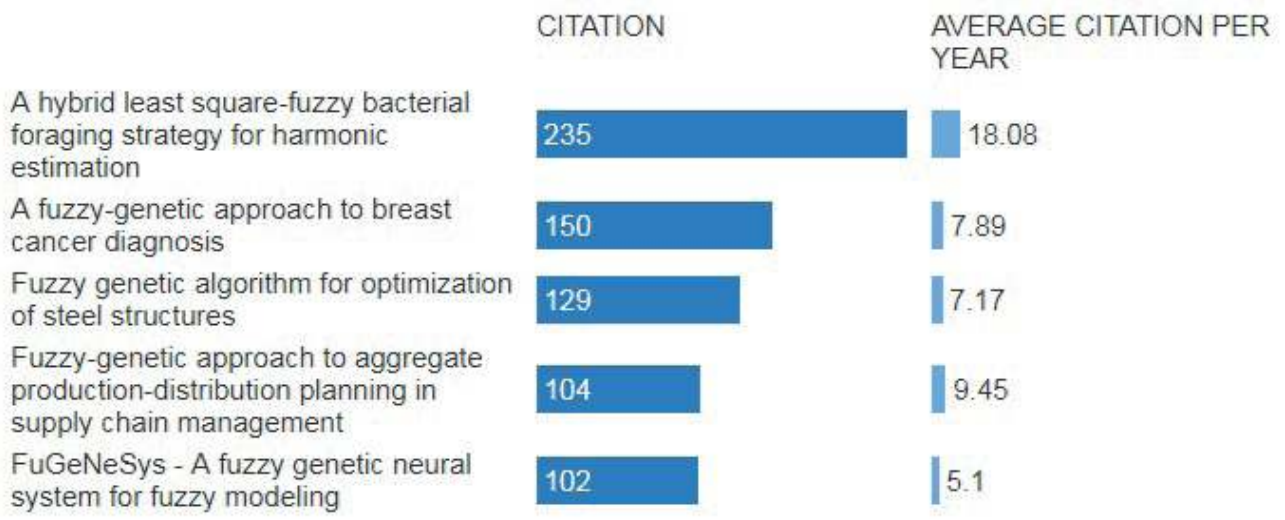

Fig. 1. Citation and average citation per year of the top 5 research papers

Table 2. Record count for top 10 research areas

S.NO.	RESEARCH AREAS	RECORD COUNT
1	Computer Science	99
2	Engineering	96
3	Operations Research Management Science	20
4	Mathematics	16
5	Automation Control Systems	15
6	Water Resources	8
7	Energy Fuels	5
8	Telecommunications	5
9	Mechanics	4
10	Science Technology Other Topics	4

Table 3. Record count for top 10 WoS core categories

S.NO.	WOS CATEGORIES	RECORD COUNT
1	Computer Science Artificial Intelligence	63
2	Engineering Electrical Electronic	47
3	Computer Science Interdisciplinary Applications	22
4	Operations Research Management Science	20
5	Engineering Multidisciplinary	18
6	Computer Science Theory Methods	16
7	Automation Control Systems	15
8	Computer Science Information Systems	15
9	Engineering Civil	13
10	Mathematics Applied	9

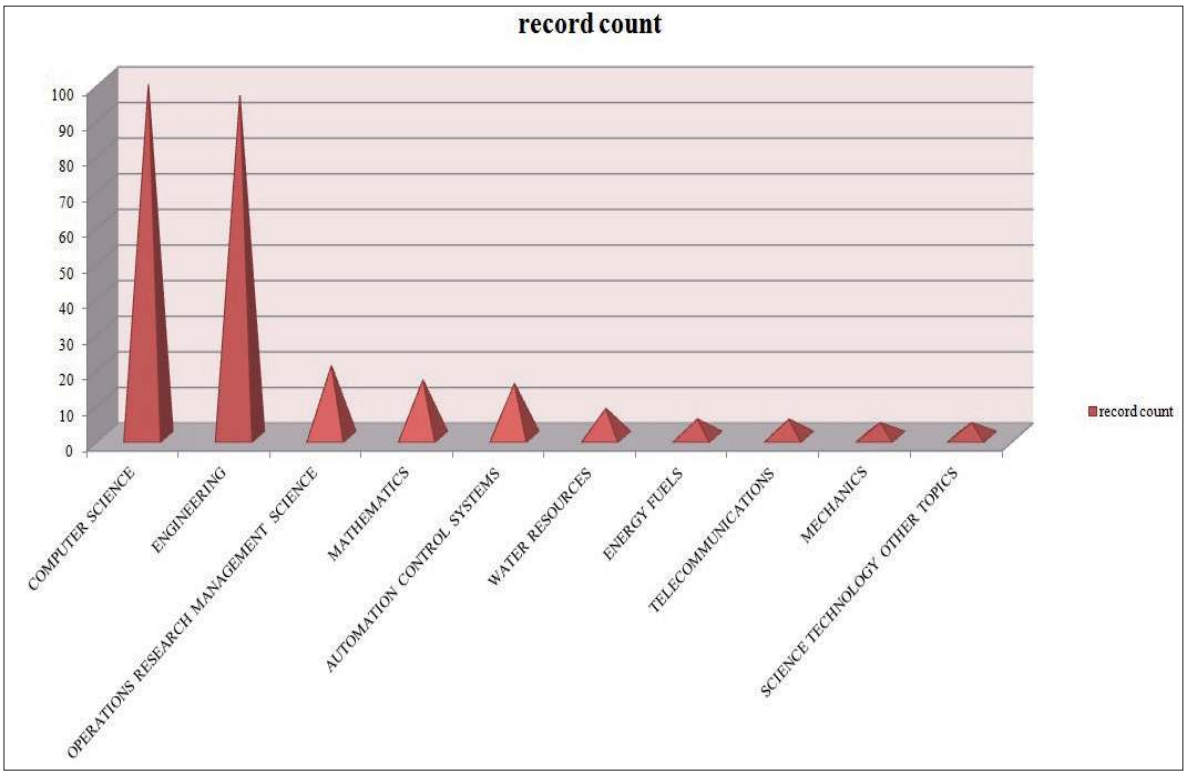

Fig. 2. Record count for top 10 research areas

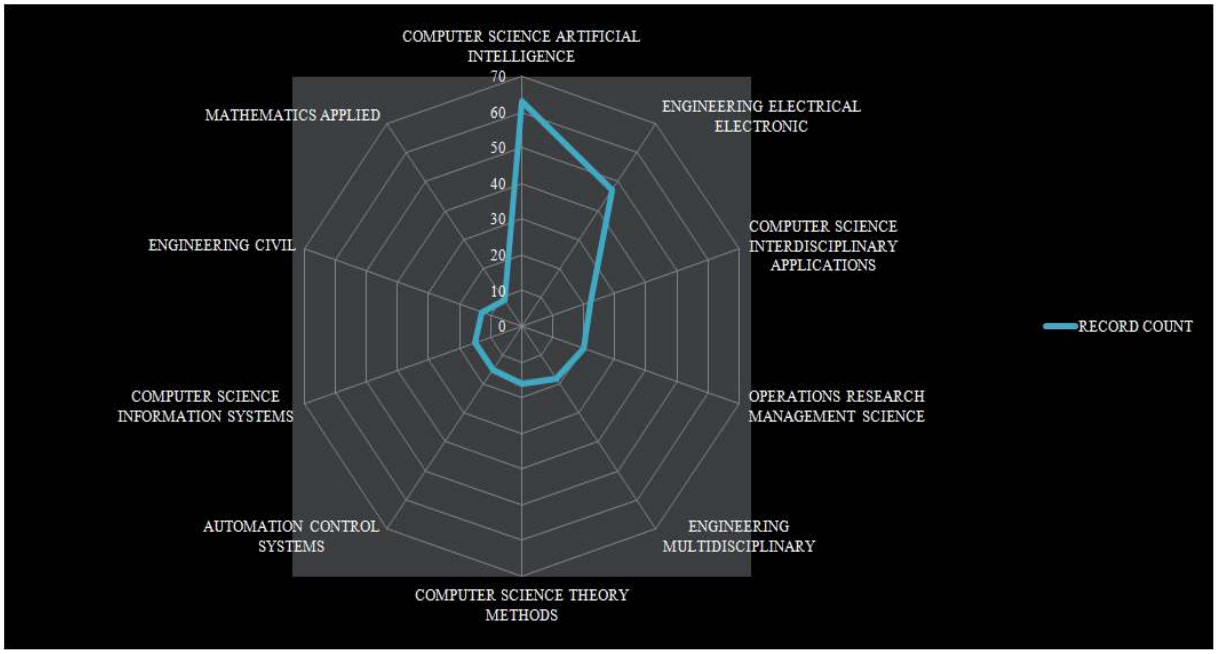

Fig. 3. Radar chart for record count of top 10 WoS core categories

3.4. Fuzzy Evolutionary Algorithm Based Analysis

The popularity of various fuzzy evolutionary algorithms among researchers was analyzed using their record count. The top 3 fuzzy evolutionary algorithms were found to be fuzzy genetic, fuzzy PSO and fuzzy ACO. Their corresponding topmost research areas were extracted so as to analyze in which domains they are being currently applied. The top cited research paper for each fuzzy evolutionary algorithm is also mentioned for reference of the researchers. All these credentials are recorded as shown in Table 4 and visualized in the form of a cluster dendrogram as illustrated in Figure 4.

Table 4. Record analysis of various fuzzy evolutionary algorithms

S.NO.	FUZZY EVOLUTIONARY ALGORITHMS	QUERY	RECORD COUNT	TOP CITED PAPER	TOP RESEARCH AREA
1	Fuzzy Genetic Algorithm	TI= ("fuzzy genetic" OR „fuzzy mutation" OR „fuzzy natural selection" OR „fuzzy fitness function")	114	A fuzzy-genetic approach to breast cancer diagnosis	Engineering
2	Fuzzy PSO	TI= ("fuzzy PSO" OR „fuzzy particle swarm optimization" OR „fuzzy swarm intelligence")	25	Scheduling jobs on computational grids using a fuzzy particle swarm optimization algorithm	Computer Science
3	Fuzzy ACO	TI= („fuzzy ACO" OR „fuzzy ant colony optimization" OR „fuzzy ant colony")	10	Developing a diagnostic system through integration of fuzzy case-based reasoning and fuzzy ant colony system	Computer Science

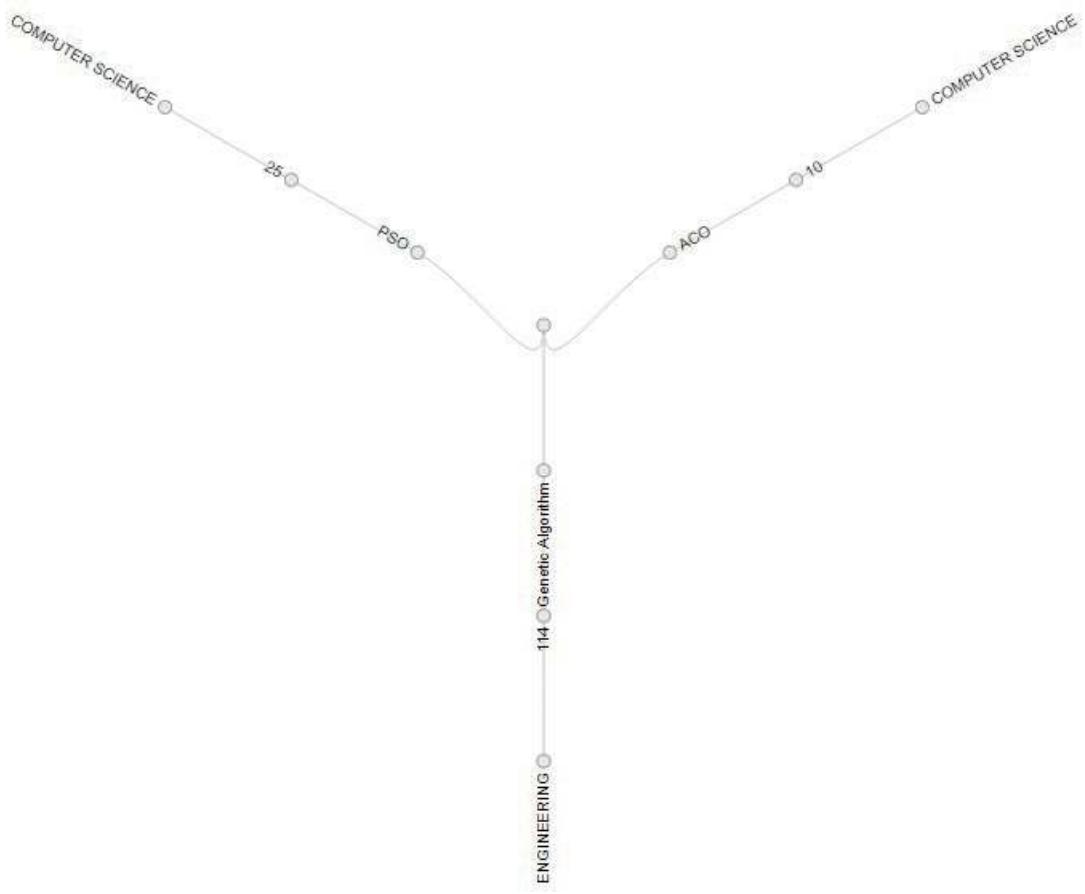

Fig. 4. Cluster Dendrogram for fuzzy evolutionary algorithms record details

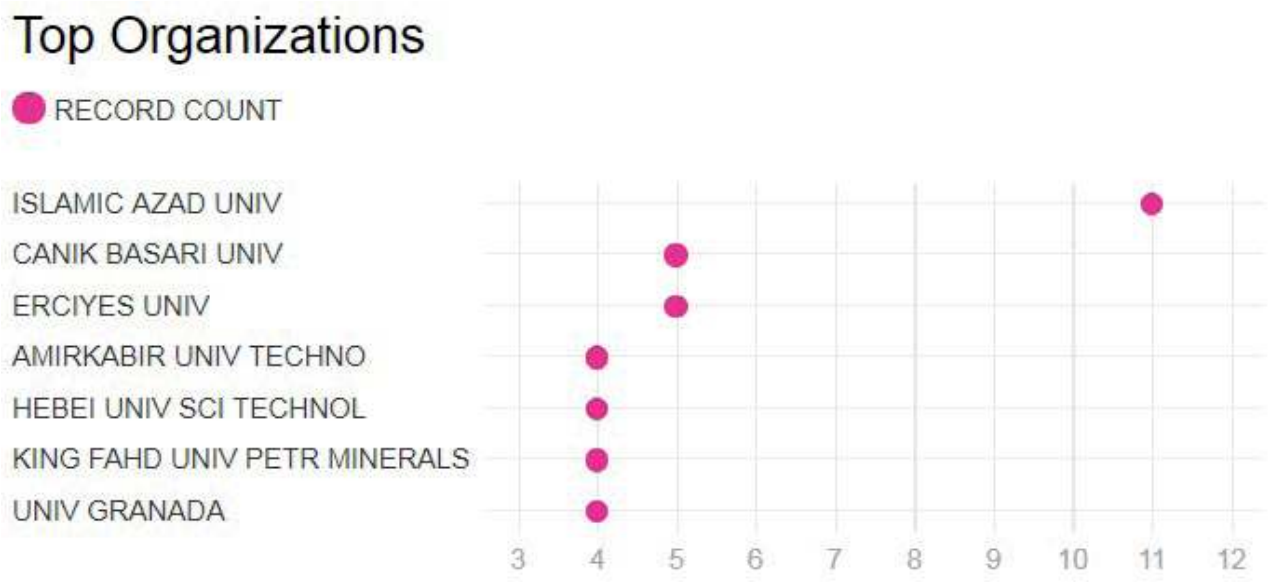

Fig. 5. Scatter plot graph for the top organizations

The cluster dendrogram shown in Figure 4 is a representation of the data summarized in Table 4. The attributes of the cluster dendrogram are all inter related and they are seen as a way of performing hierarchical clustering. The three aspects of this cluster dendrogram illustrated in Figure 4 show that:

a) PSO (fuzzy) has 25 research publications associated with it and the corresponding research area that the papers belong the most is computer science.
b) Genetic algorithm (fuzzy) has 114 research publications associated with it and the corresponding research area that the papers belong the most is engineering.
c) ACO (fuzzy) has 10 research publications associated with it and the corresponding research area that the papers belong the most is computer science.

3.5. Top Organizations

The top organizations that have made significant contributions in terms of research papers in the field of fuzzy metaheuristics and fuzzy evolutionary computing are analyzed. These are listed as indicated in Table 5. The credentials are visualized in the form of a scatter plot graph as highlighted in Figure 5. Organizations working in this field may take motivation from the top contributing research organizations to promote research and provide more resources to increase their research contribution, giving rise to a healthy and constructive research competition in this area.

3.6. Countrywise Contribution

The country wise contribution in terms of research paper publications can be seen in terms of record count in WoS. The summary for the same are recorded as in Table 6.

Table 5. Top organizations in terms of research papers

S.NO.	ORGANIZATION NAME	RECORD COUNT
1	ISLAMIC AZAD UNIV	11
2	CANIK BASARI UNIV	5
3	ERCIYES UNIV	5
4	AMIRKABIR UNIV TECHNO	4
5	HEBEI UNIV SCI TECHNOL	4
6	KING FAHD UNIV PETR MINERALS	4
7	UNIV GRANADA	4

Table 6. Country wise record count

S.NO.	COUNTRY	RECORD COUNT
1	IRAN	28
2	PEOPLES R CHINA	26
3	INDIA	24
4	TURKEY	17
5	TAIWAN	14
6	USA	13
7	ENGLAND	11
8	MALAYSIA	7
9	SPAIN	7
10	SAUDI ARABIA	5

The topmost countries according to research paper publication count, as listed above are mapped (highlighted in purple color) as illustrated in Figure 6. The country wise contribution can change with time as upcoming publications are lined up for the year 2017.

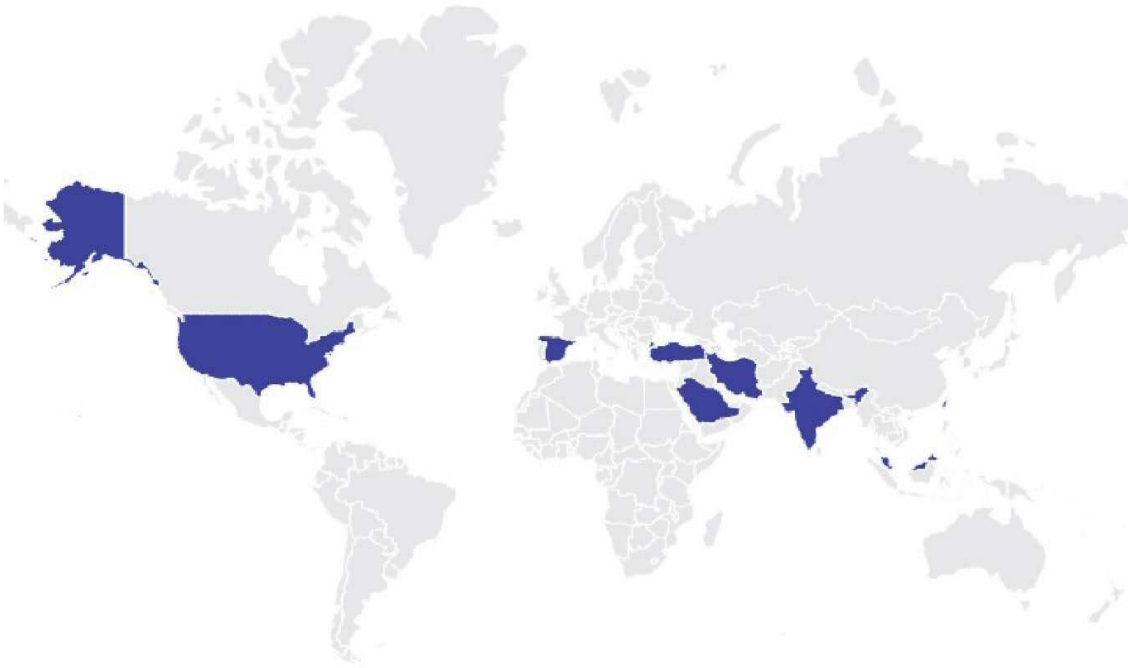

Fig. 6. Mapping the top countries

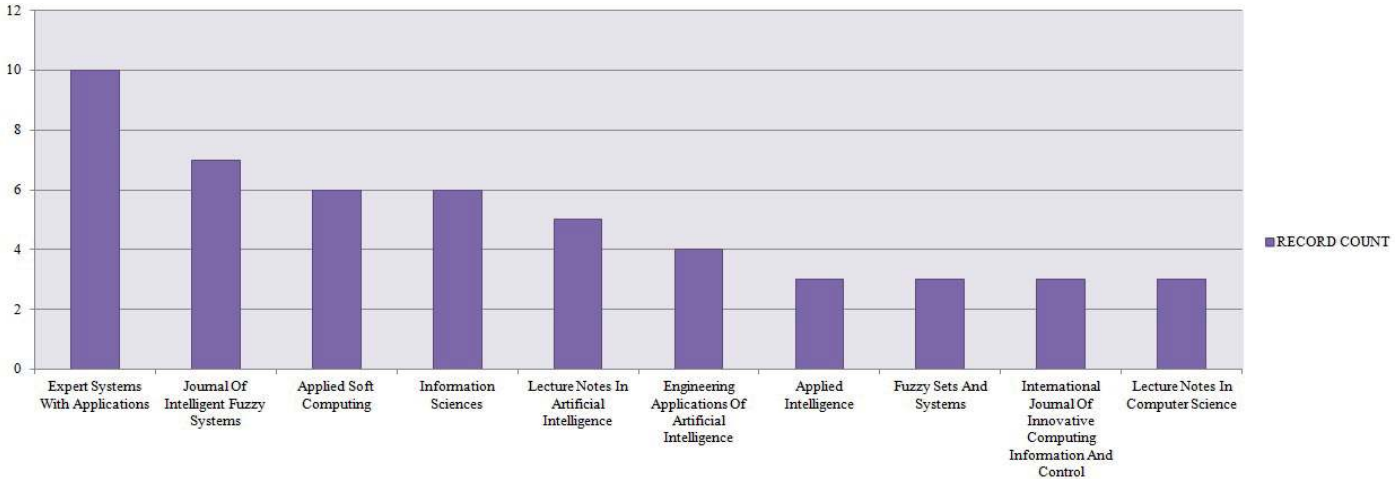

Fig. 7. Area graph for the top source titles

3.7. Top Source Titles

The topmost journals publishing research work in the area of fuzzy metaheuristics and fuzzy evolutionary algorithms were extracted. The data for the same is visualized as shown in Figure 7. It can be observed that expert system with applications has been associated with the maximum record count in this field, followed by the journal of intelligent fuzzy systems and applied soft computing.

3.8. Analysis of the Control Terms

Control terms are the ones that help in determining the most commonly studied concepts in a particular field and therefore are the ones that are the most frequently mentioned in the corresponding research papers. In this study, several control terms are identified manually (using VOSviewer) in the field of fuzzy metaheuristics and fuzzy evolutionary computing. These control terms are shown as in figure 8, in the form of cluster density visualization.

The terms in the same cluster are shown in the same color. The fact that these terms lie in the same cluster show that these terms have a higher probability of occurring in the same research paper. The density plot of these control terms is as shown in Figure 9. The research community can benefit from these control terms in the sense that if they want to study fuzzy metaheuristics or fuzzy evolutionary computing then they can begin by studying these concepts first.

Figure 10 shows the keyword co-occurrence network visualization for the identified control terms. These are the top ranked keywords according to the frequency of occurrence. The larger is the size of the bubbles in this bubble plot, greater is its significance in the given context.

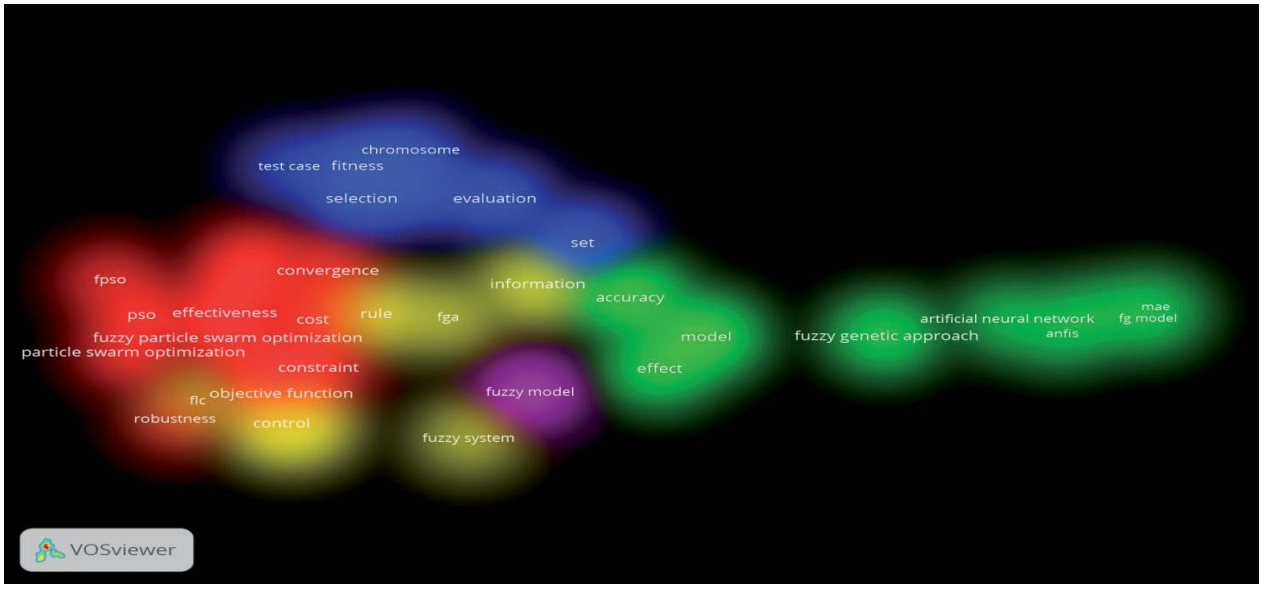

Fig. 8. Cluster density visualization for the control terms

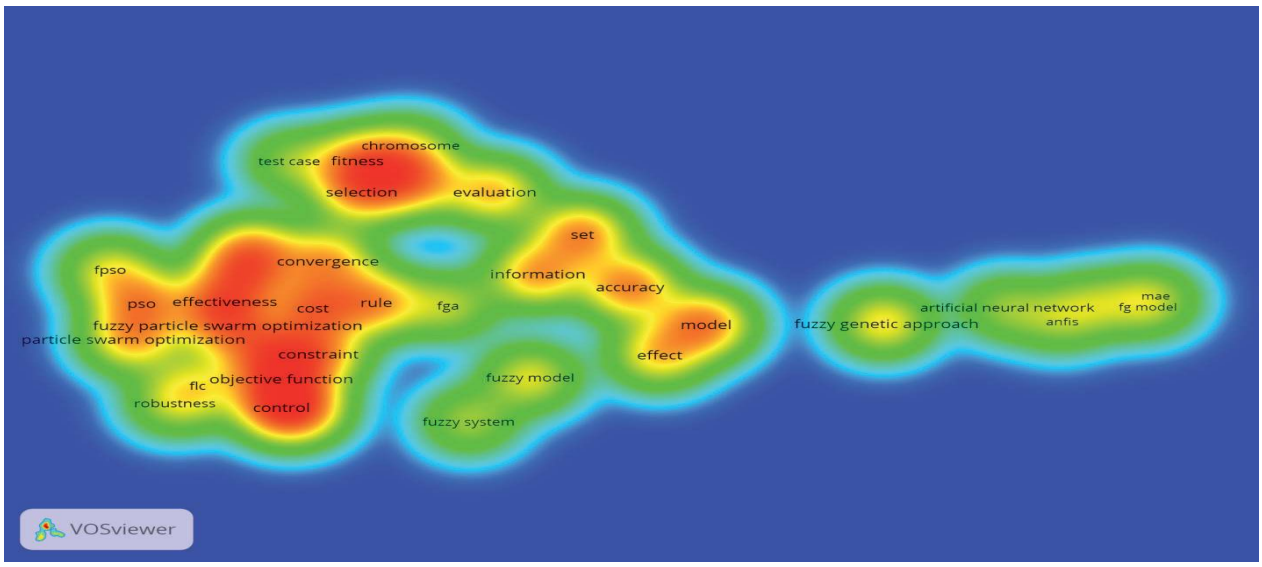

Fig. 9. Density plot for control terms

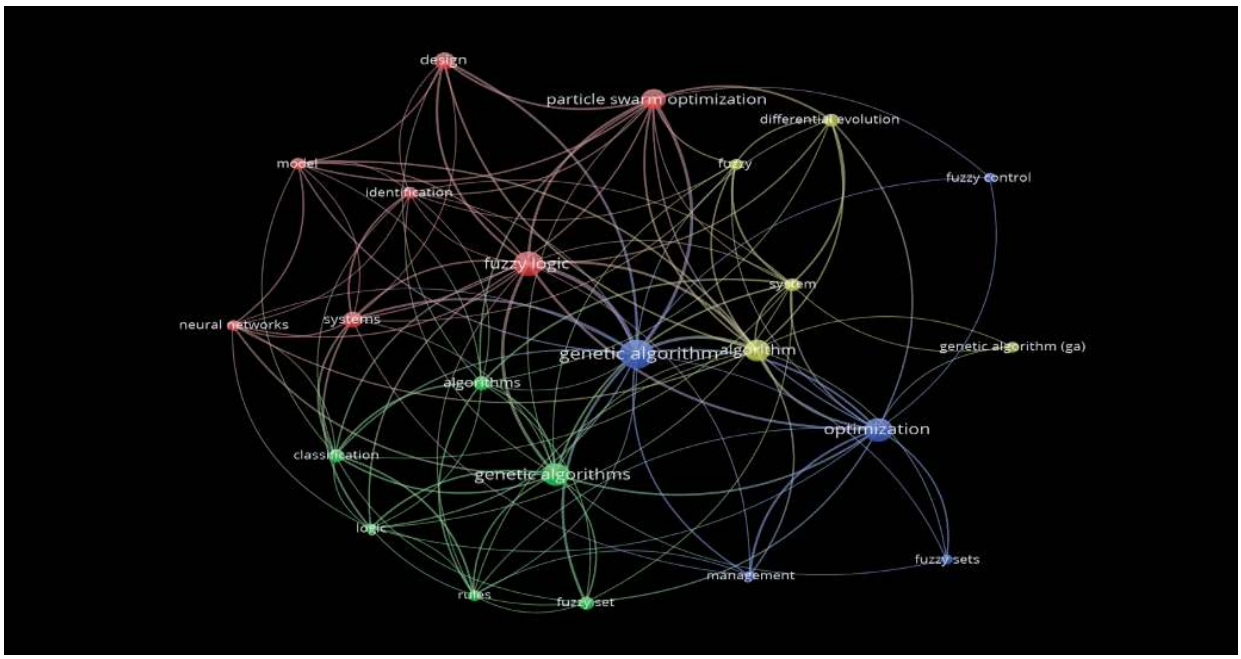

Fig. 10. Keyword co-occurrence network visualization

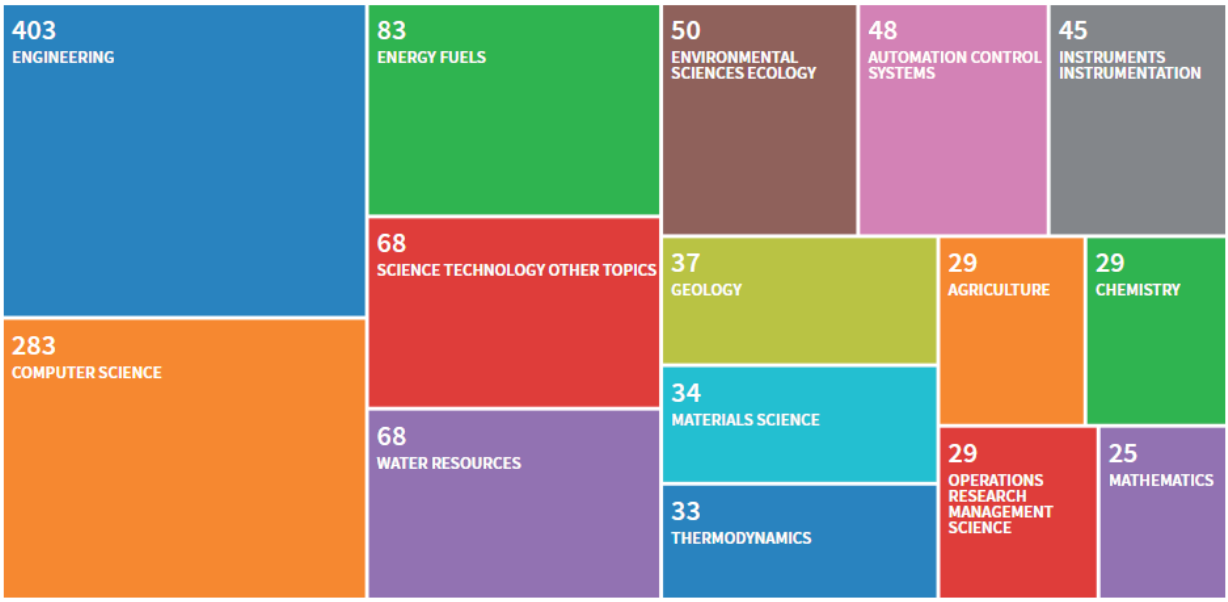

Fig. 11. Tree Map for top 15 WoS categories of research areas for neuro fuzzy research publications

3.9. Neuro Fuzzy Logic

It is worth mentioning that neuro fuzzy logic plays an integral role in the research related to the domain of fuzzy metaheuristics. In the web of science, the total record count for research publications catering to neuro fuzzy logic is 2568. If the past 5 years data from web of science is to be analyzed then one can notice that a total of 918 papers are extracted in this field. This proves the progress in research in neuro fuzzy logic. These 918 papers are cited to a total of 4461 times, which is huge. Figure 11 has been taken as a screenshot from Web of Science for depicting the tree Map for top 15 categories of research areas for neuro fuzzy research publications. This data was visualized for research papers in this field in the last 5 years i.e. 2013-2018. It could be well observed that neuro fuzzy finds application in areas ranging from computer science to energy fuels.

The top 5 research domains catering to neuro fuzzy research are:

i. Engineering
ii. Computer science
iii. Energy fuels
iv. Science technology and other topics, Water resources
v. Environmental science ecology

The top 5 research publications in this field, ranked according to the times they are cited are as follows:

a) Neuro-fuzzy modeling and control, with a citation score of 1105
b) Neuro-fuzzy rule generation: Survey in soft computing framework, with a citation score of 415
c) A neuro-fuzzy computing technique for modeling hydrological time series, with a citation score of 321
d) Adaptive neuro-fuzzy inference system for prediction of water level in reservoir, with a citation score of 260
e) A comparative study on the predictive ability of the decision tree, support vector machine and neuro-fuzzy models in landslide susceptibility mapping using GIS, with a citation score of 258

The number of research papers for fuzzy metaheuristics, evolutionary computing and neuro fuzzy logic is expected to further grow in the coming years which would open new doors of research for scientists and academicians across the globe.

4. Conclusion

This paper presents an analytical study in the field of fuzzy metaheuristics and fuzzy evolutionary computing. The study is performed on 178 research papers extracted from the Web of Science, in the time span of 1989-2016. The top cited research papers, country wise contribution, top source titles, topmost organizations, control terms, top research areas and WoS core categories are analyzed. Also, the top 3 fuzzy evolutionary algorithms are obtained and their top research papers are highlighted along with their topmost research domain. This type of an analytical study is expected to assist the researchers working in this domain in exploring the discipline.

Researchers can study in depth the practical applications of these algorithms and then apply it according to its relevance in their corresponding research domains. Any researcher who is new to this field can also have a look at this study and start exploring with the help of the top cited research papers that are mentioned here. The country wise contribution can change with time as upcoming publications are lined up for the year 2017 and 2018. Other organizations working in this field may take motivation from the top contributing research organizations mentioned here to promote research and provide more resources to

increase their research contribution, giving rise to a healthy and constructive research competition.

Various control terms that are identified during this study, will help in guiding the researchers to explore the individual research topics in detail. The top 3 fuzzy evolutionary algorithms are identified which shall assist the research community in exploring their counterparts as well so that research is done in varied fields. A section presents analytical study regarding research in neuro fuzzy as well since it poses feasible options for solving numerous research problems. As a part of the future work, this study can be performed using other databases as well.

Acknowledgments

We thank the Division of Graduate Studies and Research of Tijuana Institute of Technology and the financial support provided by CONACYT contract grant 122.

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