



An overview of fuzzy research with bibliometric indicators



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ABSTRACT

Bibliometrics is a discipline that analyzes bibliographic material from a quantitative perspective. It is very useful for classifying information according to different variables, including journals, institutions and countries. This paper presents a general overview of research in the fuzzy sciences using bibliometric indicators. The main advantage is that these indicators provide a general picture, identifying some of the most influential research in this area. The analysis is divided into key sections focused on relevant journals, papers, authors, institutions and countries. Most of the results are in accordance with our common knowledge, although some unexpected results are also found. Note that the aim of this paper is to be informative, and these indicators identify most of the fundamental research in this field. However, some very influential issues may be omitted if they are not included in the Web of Science database, which is used for carrying out the bibliometric analysis.

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1. Introduction

Research in the fuzzy sciences originated almost 50 years ago with the seminal paper of Lotfi A. Zadeh [1] published in Information and Control. This paper analyzed the concept of fuzzy sets, allowing classical Boolean sets to use a multi-valued logic. Initially, this research did not attract very much attention, and it received many criticisms in the scientific community. In the mid-1970s, and after much skepticism about this new theory, an increased number of scientists started to analyze the work of Zadeh more seriously. This group of researchers consolidated the field in 1978 with the creation of Fuzzy Sets and Systems in 1978, the first international journal exclusively devoted to fuzzy theories. Later, they started to organize in professional associations, such as the North American Fuzzy Information Processing Society (NAFIPS), created in 1982 by James Bezdek, Piero Bonissone, King Sun Fu, Enrique Ruspini, Richard Tong, Ronald Yager and Lotfi Zadeh. The first NAFIPS conference was held in Utah (USA) on May 18–20, 1982.

This group grew very quickly because it was especially motivated by the increased attention received by Asian and European researchers since the 1970s. The fuzzy community became a

world entity with the creation of the International Fuzzy Systems Association (IFSA), which held its first conference in Palma de Mallorca (Spain) on July 1–6, 1985. Since then, many other associations have appeared, and many other journals with a strong focus on fuzzy research or being strictly dedicated to it have been launched, including the Journal of Japan Society for Fuzzy Theory and Intelligent Informatics (1989); the IEEE Transactions on Fuzzy Systems (1993); the International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems (1993); the Journal of Intelligent & Fuzzy Systems (1993); the Fuzzy Economic Review (1995); the International Journal of Fuzzy Systems (1999); Fuzzy Optimization and Decision Making (2002); and the Iranian Journal of Fuzzy Systems (2003). For an overview of fuzzy theories, see [2–6].

A strong consolidation process was performed in the 1990s with the creation of the Institute of Electrical and Electronics Engineers Computational Intelligence Society (IEEE CIS), which included fuzzy research as one of its three main branches. This implied the official recognition by the IEEE of the acceptance of fuzzy research as a strong entity in the scientific community. Today, it has over 7000 members. It is worth noting that this research field is also known as Soft Computing [7–9]. Briefly, it is composed of fuzzy systems, neural networks, evolutionary computation, probabilistic reasoning and other related areas, such as chaos theory. Currently, there is significant growth in this area with the creation and consolidation of new associations, including the World Federation on Soft Computing (WFSC), and journals, such as Mathware & Soft Computing

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(1994), the Journal of Multiple-Valued Logic and Soft Computing (1995), Intelligent Automation and Soft Computing (1995), Soft Computing (1997), Applied Soft Computing (2001) and the International Journal of Computational Intelligence Systems (2008).

Today, fuzzy research is a very general and established scientific field, with thousands of researchers studying different theoretical or practical aspects of this theory. The present organization of fuzzy sciences can be divided into two main blocks. The first block is based on the IEEE CIS society, and the second block has its nucleus in the IFSA association. IFSA is divided into 17 other associations that encompass researchers from a specific region or topic.

Bibliometric analysis is a research field that analyzes publications, citations and their sources of information. Currently, it is receiving more attention due to the strong development of computers and the internet. There have been many definitions and discussions concerning bibliometrics [10,11]. One of the key advantages is that it permits one to analyze a specific research field by considering papers, journals, authors, institutions and countries. Thus, it is possible to construct a general picture of a research field. However, there are many limitations, especially because of the particular research style followed by each researcher, which may imply a different volume of self-citations and co-authored papers.

In the literature, many studies have provided a general bibliometric overview of a research field. Among others, it is worth noting some key areas, including management [12], econometrics [13], health economics [14], marketing [15], statistics [16], ecological economics [17], ant colony optimization [18], pricing research [19], entrepreneurship [20], production and operations management [21–23], data envelopment analysis [24], gray systems [25] and innovation [26]. However, no paper has been published providing a general overview of fuzzy research. Some authors have studied some specific aspects, including a bibliometric mapping in computational intelligence that included fuzzy systems as one of its main components [27,28], tools for analyzing the evolution of topics in fuzzy research [29] and an application in the Spanish region [30].

The aim of this paper is to present a general overview of fuzzy research from its inception 50 years ago using bibliometric techniques. The objective is to show the most productive and influential research in the scientific community according to information found in the Web of Science (WoS). The information is classified by articles, authors, journals, institutions and countries. Most of the results found are in accordance with our common knowledge, whereby Zadeh is the most influential author in fuzzy research and most of the main leaders are also found in the first author positions, including Yager, Sugeno, Dubois, Prade, Bezdek, Pedrycz and Mendel. Fuzzy Sets and Systems and the IEEE Transactions on Fuzzy Systems are the main outlets for the dissemination of fuzzy theories, and the USA is the most influential country, although Asian countries have shown a substantial increase in publications during the last years. However, it is worth noting that many limitations may appear in the classification process because the focus is on the WoS; however, to provide a complete picture, many other factors should be considered, including editorial appointments in main journals and involvement in associations and conferences. Therefore, the aim of the paper is to be informative to show the current results found in the WoS regarding fuzzy research, although fundamental research developed in this field may be omitted if it is not included in this database.

The paper is organized as follows. Section 2 describes the methodology to be used. Section 3 presents the 50 most cited papers of all time in fuzzy research, and Section 4 presents the most productive and influential authors. Section 5 analyzes the main institutions in this area, and Section 6 presents the most relevant countries. Section 7 discusses the main conclusions of the paper.

2. Methodology

An important issue when analyzing the information is to select the methods and tools that are going to be used. To be informative and neutral with the information, the search process is based on the results found in the WoS database, which is currently owned by Thomson & Reuters. The WoS includes many databases for addressing this information. In this paper, the main focus is on the Web of Science Core Collection, which considers several sub databases, including the Conference Proceedings Citation Index. It includes research from almost all the known sciences and currently covers information from more than 15,000 journals and 50,000,000 papers. It classifies the information in 251 subject categories and in 151 research areas. Note that there are many other databases that could be considered, including SCOPUS and Google Scholar. However, in this paper, the focus will be given to the WoS.

To develop the search process, we have used the keyword “fuzzy” in the “topic” section. Therefore, the query should provide all the papers related to fuzzy research. One of the main limitations of this analysis is that many papers that address fuzzy sciences do not use the keyword “fuzzy”. This problem is relevant because during the last few years, fuzzy research has become part of a more general field known as soft computing. Thus, the interaction of its subfields may bring about this limitation. Note that an additional manual search process with the “Cited Reference Search” has been developed to avoid the omission of key research in this field. However, when analyzing all the production in this area, it is very easy to omit papers, in particular, because it is not clear where the boundaries between fuzzy research and related fields are. Additionally, some papers that use the keyword “fuzzy” are not related to fuzzy research. The most relevant papers with this problem have been omitted to avoid relevant disequilibrium in the citation count. From a general perspective, it has been assumed that the general numbers representing the total production are valid because these two limitations should be approximately compensated between them. Note that this can also be proved by observing Table 2. The percentage of fuzzy papers in Fuzzy Sets and Systems and in the IEEE Transactions on Fuzzy Systems is over 90%, clearly indicating that all papers focused on fuzzy research are included. The percentage is not 100% because some papers may be at the intersection between fuzzy research and other general areas, such as soft computing and computational intelligence. Observe that in this paper, the aim is to focus strictly on fuzzy research.

In February 2013, there were 115,000 papers that used the keyword “fuzzy”. Note that this number includes all the publications covered by the WoS. Currently, it considers 15 different types of publications, including journal articles, proceedings, book reviews, notes, comments, reviews and editorial material. To focus on the main articles, this information has been filtered by only looking for journal articles and reviews. Thus, the total number of publications found has been reduced to 56,500 papers. Note that most of these publications come from the last decade, with 78,300 papers between 2003 and 2012, which is reduced to 45,700 papers if only journal articles and reviews are considered. Observe that this represents 68% and 80.8% of the total volume. More specifically, it is clear that fuzzy research is becoming more influential in the scientific community by looking to the strong increase found in the last years as shown in Fig. 1. Obviously, this increase is also explained by the increase in the number of researchers worldwide and by the expansion of the WoS, which now includes more journals. However, the increasing influence of fuzzy research is demonstrated by the creation of new fuzzy journals and other related ones that have recently been indexed in the WoS. As observed in Fig. 1, the percentage of fuzzy papers out of the total number of papers included in the database each year has increased. Specifically, the ratio

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