



Bibliometric analysis of fuzzy theory research in China: A 30-year perspective



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ABSTRACT

The past half-century has witnessed fast development in the field of fuzzy theory (FT), however, few researches have focused on mapping the development of this area in China. Based on the samples of 12,936 publications authored by Chinese scholars on FT researches during the past 30 years, this paper intends to explore the patterns and dynamics by analyzing the geographic distribution of publications, international collaboration, research hot spot, subject categories and journals, and publication contributors. The results indicate that the scientific publications are highly unbalanced at regional levels in China, and the USA is China's most important partner in FT cooperative researches. Collaborations are not indispensable for high-quality research outputs in FT area. The existing researches in the field of FT from Chinese scholars focus primarily on Computer Science and Engineering. The emerging trends of FT researches from Chinese scholars have shifted away from basic FT researches to the applications, such as the areas of decision making, optimization, modeling and design.

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1. Introduction

Since Zadeh authored the seminal paper titled “fuzzy sets” (published on *Information and Control* in 1965), fuzzy theory (FT) has attracted great attention and controversies [30,44]. FT mainly includes fuzzy set [31], fuzzy logic [70,82], fuzzy reasoning and fuzzy control [34,51]. At present, FT is a very popular and well established scientific field [39,83]. According to incomplete statistics, there are thousands of scholars from different disciplines participating in the research of FT theoretically or practically. The evidence from scholar Google shows that the number of the publications about FT has been well over two million. Many important academic journals focused only on fuzzy researches such as *Fuzzy Sets and Systems*, *IEEE Transactions on Fuzzy Systems* and *Fuzzy Optimization and Decision Making* were founded. Furthermore, some previous studies have focused the structures and patterns of the research area based on bibliometric measures. For example, López-Herrera et al. [43] studied the development of FT researches carried out by the Spanish community. Cobo et al. [19] proposed a

method to analyze the thematic evolution of a given research field, and as example, they analyzed the FT area.

In the 70s of twentieth century, Chinese scholars began to study FT. Many Chinese scholars have done the massive research works on FT theoretically or practically. In the early 1990s, the founder of the FT, Zadeh had recognized that US, Japan, Europe, and China were the main force of FT researches. The scientific research outcomes from Chinese scholars have obvious influences in the home and abroad. Currently, tens of thousands of publications have appeared on Chinese and international professional journals. In the applications of FT, a lot of practical applications of research results from Chinese scholars have sprung up in the past few decades [73,84,89]. For example, Chinese scholars have successfully applied the FT to the weather forecasting [18,38], earthquake prediction [27,88], traditional Chinese medicine [21], blast furnace control [37], economics [23,28,72,77,91] and management [1,25,40,56–58,90]. Undisputedly, China has become a significant force in the FT scientific research community.

However, the current status of development about FT researches in China is still unclear, and so are the intellectual structures, research focus as well as emerging trends of FT in China. To fill these gaps, this study applies China's publications indexed in Science Citation Index Expanded (SCIE), Social Science Citation Index (SSCI), and Arts & Humanities Citation Index (AHCI)

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(1986–2015) to explore the current status and development trends of China's academic research performances in FT area based on bibliometric analysis methods.

Bibliometrics is the interdisciplinary science of quantitative analysis of all knowledge carriers by mathematical and statistical methods [7]. It is a comprehensive knowledge system which integrates mathematics, statistics and philology as a whole and pays attention to quantitative analysis. At present, more and more attention has been paid to this research. The most obvious advantage is that it allows scholars to investigate the specific research areas by analyzing the citations, co-citations, geographical distribution, and term frequency, thus drawing very useful conclusion [26,74]. In other words, it is possible to explore the inner publication structure and citation landscape in a research area [78,79]. At present, it has been widely used in research trend detection [2], author cooperative analysis [47,53,86], development of journal [10,13], development of the whole subject field [45], research topic clustering [22,54,55] and so on.

The objective of this paper is to adopt the bibliometric analysis methods to assess the current state and explore the development trends of fuzzy domain in China based on the literature data retrieved from Web of Science. The innovations of our research have three points: First, a large number of publications related to FT in China have been analyzed systematically and scientifically to find out the underlying information. Second, not only the statistical information based on different periods is used to analyze the structures and dynamics of China's FT publications, but also the links analysis and text mining based on social networks are used to explore further features. Third, the developments of China's FT publications are analyzed from different perspectives, which not only include the basic information, such as authors, journals, cited references, and subject category, but also include the research hot spot, international collaboration, and highly cited authors and papers. In addition, our research has some difficulties: On the one hand, the unifications of institutions need to be handled by combining variant institutions' names, and then the province of each institution needs to be recognized to make further analysis of regional distribution of China's TF research. On the other hand, the disambiguation of Chinese author names needs to be identified based on their full names and affiliations as some authors have same initials, even same full names.

This paper is organized as follows: Section 2 briefly describes the data source and methodology. Section 3 explores the intellectual structure of China's FT studies from co-authorship and geographical distribution analysis. Section 4 uses citation analysis technique and CiteSpace to visualize the highly cited references, disciplinary distributions, keyword co-word networks, journal co-citation networks and highly cited authors in FT research area from 1986 to 2015.

2. Data source and methodology

The literature data used in this study were downloaded from Web of Science: SCIE, SSCI, and AHCI. "Fuzzy" was used as the keyword to search the documents from 1986 to 2015 that contain this word in the abstract, title or keywords list. We set the CU=(China OR Peoples Republic of China OR Chinese NOT Taiwan), where CU represents country. Furthermore, the document types were limited to "article" and "review". In total, 12,936 documents met the selection criteria. Downloaded document included the title, publication date, keywords, journal information, the addresses of the authors and subject categories. All documents were downloaded on June 2, 2016, in plain text format.

Science mapping is an important procedure of bibliometrics. It aims at showing the structural and evolution of the scientific research field [9,19,48,49]. At present, there is a lot of software tools

proposed to develop science mapping analysis [20]. CiteSpace II is the main tool used in this paper which is effective in information visualization and it was designed by Professor Chaomei Chen [11]. It has been used for obtaining quantitative information and visualizing information in special field [12,61], and recognized as one of the very influential software in the fields of bibliometrics and information visualization [71]. There is no doubt that the scholars from various disciplines have conducted their studies with the help of CiteSpace [75]. For example, Yu focused on the development of information aggregation operators and made a scientometrics review on this field [71]. Zhang et al. [85] visualized the development path of the researches on social media from a comprehensive perspective. Wei et al. [61] explored the geographic information systems knowledge domain with the help of CiteSpace. In order to identify the status of the public-private partnerships researches, Song et al. [50] used the CiteSpace to discover the trends and global patterns among the related publications. Chen et al. [14] detected the emerging trends and current status of the global scientific researches in the field of energy among 637 publications with the help of CiteSpace. All the above research results have shown that the CiteSpace is very effective in exploring the research trends and hot topics in a specific domain. Therefore, in this paper, we select the CiteSpace as the analyzing tool to discover the research trends and patterns among China's publications in the field of FT researches.

3. Development of FT

In this section, we study the concentration of FT researches in China at regional levels. It should be pointed out that the regions referred here are defined by province, autonomous region or municipality. The FT publications authored by Chinese scholars are shown in Table 1 by regions. For further exploring the structures and dynamics of China's FT publications, we split the whole period into three 10 year phases: 1986–1995; 1996–2005 and 2006–2015. Table 1 displays that the China's publications of FT vary widely across the whole country. Beijing, Jiangsu and Liaoning contributed 40.4% of all publications among the whole period. Furthermore, Beijing led with 2946 publications (20.36%) and it was followed by Jiangsu with 1613 publications. Liaoning ranked the third place and it contributed 1287 publications during 1986–2015. On the other hand, the ten least productive regions together contributed a total of 2.57% which is a very small share.

The statistical results indicate that the FT publications authored by Chinese scholars seem to increase substantially from 1986 to 2015. In three different stages, Beijing is always in the first place. The number of FT publications rose from 59 in the first period to 2314 in the third period. Jiangsu ranked the third place in the first two periods, however, it jumped to the second place in the third period with 1404 publications. Also, there are blanks of the FT researches in some regions. However, this phenomenon changed as time went on. During 1996–2005, the regions with blank only refer to Guizhou, Inner Mongolia and Tibet. Furthermore, the Tibet has become the only one, which is of very little contribution on FT developments during the third period.

The geographic information software was applied to visualize the publications distributions among different regions. The production of visualization was shown in Fig. 1 in detail. In Fig. 1, the red shades on the map represent the China's FT publication distributions from 1986–2015, the green shades with cylindrical shape represent three 10 year phases' distribution of top 20 regions ranked based on the total records during 1986–2015, and the three adjacent cylinders represent the three stages of 1986–1995, 1996–2005, and 2006–2015 from left to right, respectively. Also, the regions marked in white indicate the blanks of the FT researches, and both color depth and size of the cylinders can be used to measure the

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