An Analytical Insight to Investigate the Research Patterns in the Realm of Type-2 Fuzzy Logic

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Abstract:
Fuzzy logic has always been one of the key research areas in the field of computer science as it helps in dealing with the real world vagueness and uncertainty. In recent years, a variant of it, Type-2 Fuzzy Logic has gained enormous popularity for research purposes. In this paper, an analytical insight is provided into the research patterns of Type-2 Fuzzy logic. Web of Science has been used as the data source which consists of Science Citation Index-Expanded (SCI-E), SSCI, A&HCI and ESCI indexed research papers. 600 research papers were extracted from it in the field of Type-2 fuzzy logic from the year 2000 to 2016, which are analyzed both manually and in an automated manner. The performed study is Scientometric in nature and helps in answering research questions like control terms and top authors in this field, the growth pattern in research publications, top funding agencies and countries etc. The major goal of this study is to analyze the research work in type-2 fuzzy logic so as to track the growth of this discipline through the years and envision future trends in this area.

Keywords: scientometric analysis, Type 2 fuzzy logic, Type 2 fuzzy systems, Type 2 fuzzy control, Type 2 fuzzy set

1. Introduction

Type-2 fuzzy logic can help solving or improving solutions in many fields, as can be seen by the diversity of the papers covered in this review paper, and as such in theory it could be considered as a general form of modeling and coping with uncertainty in any area of application. However, there are limitations and challenges in this area, for example: how to optimally design the structure of the type-2 fuzzy systems, how to find the optimal parameter values for a particular application, when to apply modularity or granularity to improve results, just to mention a few. In addition, the particular form of type-2 fuzzy models could be application dependent, and if this is the case, finding these forms for particular classes of problems is a crucial task. In this sense, this paper is the first step in analyzing what has been achieved to the moment by the type-2 fuzzy research community, and then what can also be done in the future.

This paper presents an in-depth analysis to chart and map the progress of research work in the field of Type-2 fuzzy logic from the year 2000-2016 based on the research papers retrieved from web of science. The major goal of this study is to analyze the research work in type-2 fuzzy logic so as to track the growth of this discipline through the years. The study performed in this paper helps in answering the following imperative research questions:

1) What has been the growth rate in the field of type-2 fuzzy logic in terms of research publications?
2) Which journals account for the maximum publication in the field of type-2 fuzzy logic?
3) Which countries and institutes offer higher participation in the field of type-2 fuzzy logic?
4) Which authors have contributed significantly in the research publications pertaining to the field of type-2 fuzzy logic?
5) What has the ratio been of paid vs. open access publications in the field of type-2 fuzzy logic?
6) Which funding agencies have contributed the maximum in providing grants for the concerned research project based papers in the field of type-2 fuzzy logic?
7) What are the various types of research papers available in the field of type-2 fuzzy logic? Whether they are articles or proceeding papers or do they lie in any other category?
8) Which are the most cited research papers in the field of type-2 fuzzy logic and in which research domain do they lie?
9) Which control terms are associated with type-2 fuzzy logic?
10) What is the scenario regarding the inter country collaboration for research in type-2 fuzzy logic?

This paper assists in answering the above mentioned research questions, which would in turn help in understanding the discipline in a more elaborate manner. This type of work in the field of type-2 fuzzy logic is one of its kinds as it statistically highlights the various aspects related to it. Section 2 of the paper describes the data source and the methodology adopted for study in this paper; while Section 3 presents the results along with a detailed analysis. The work is concluded in Section 4.

2. Data and Methodology

The analysis is performed on a set of research papers obtained by using WOS (Web of Science) as the data source. WOS (Web of Science) is a database that consists of Science Citation Index-Expanded (SCI-E), SSCI, A&HCI and ESCI indexed research papers of various types (articles, reviews, proceeding papers etc.) in several languages. The details of the dataset used are given as in Table 1.

3. Detailed Analysis

This section presents the data collected through WOS [2-601] which is analyzed both manually and in an automated manner for studying the patterns of research in type-2 fuzzy logic.

a) Year-wise publication and growth pattern analysis:

The 600 research papers were analyzed to present the data about the number of research publications in each year from 2000 to 2016. It can be noted from Table 2 that recent years (2015 and 2016) have seen a boost in terms of type-2 fuzzy logic research publications. In order to track the growth in the number of research papers, we have calculated two scientometric measures namely Relative Growth Rate (RGR) and Doubling Time (DT). Figure 1 shows the number of research publications each year.

\[
RGR = \frac{\ln N_2 - \ln N_1}{T_2 - T_1} \quad \text{........... (1)}
\]

\[
DT = \frac{\ln 2}{RGR} \quad \text{......... (2)}
\]

RGR is a measure that represents the relative growth in the number of research publications with respect to time. On the other hand DT highlights the time that is needed for the number of research papers in a particular year to become double of its current amount. From Figure 2 it can be seen that RGR and DT are inversely proportional to each other.

b) Country-wise contribution:

The top 30 countries contributing to the research publications in type-2 fuzzy logic are presented in Table 3 and illustrated pictorially as in Figure 3. For performing this type of analysis, the search query was further filtered to extract countries where the research publication record was greater than 1. It can
be observed that China accounts for the maximum number of research papers while USA gets the second rank. Iran and Taiwan also contribute significantly to the research publications in this field.

**Table 3. Top 30 countries contributing to the research publication in type-2 fuzzy logic**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Country</th>
<th>Record Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Peoples R China</td>
<td>117</td>
</tr>
<tr>
<td>2</td>
<td>USA</td>
<td>85</td>
</tr>
<tr>
<td>3</td>
<td>Iran</td>
<td>78</td>
</tr>
<tr>
<td>4</td>
<td>Taiwan</td>
<td>78</td>
</tr>
<tr>
<td>5</td>
<td>England</td>
<td>64</td>
</tr>
<tr>
<td>6</td>
<td>Turkey</td>
<td>49</td>
</tr>
<tr>
<td>7</td>
<td>Mexico</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>Canada</td>
<td>31</td>
</tr>
<tr>
<td>9</td>
<td>India</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>Australia</td>
<td>19</td>
</tr>
<tr>
<td>11</td>
<td>Saudi Arab</td>
<td>19</td>
</tr>
<tr>
<td>12</td>
<td>Italy</td>
<td>18</td>
</tr>
<tr>
<td>13</td>
<td>Singapore</td>
<td>17</td>
</tr>
<tr>
<td>14</td>
<td>Malaysia</td>
<td>14</td>
</tr>
<tr>
<td>15</td>
<td>South Korea</td>
<td>14</td>
</tr>
<tr>
<td>16</td>
<td>Poland</td>
<td>13</td>
</tr>
<tr>
<td>17</td>
<td>Algeria</td>
<td>11</td>
</tr>
<tr>
<td>18</td>
<td>Spain</td>
<td>9</td>
</tr>
<tr>
<td>19</td>
<td>Egypt</td>
<td>8</td>
</tr>
<tr>
<td>20</td>
<td>France</td>
<td>6</td>
</tr>
<tr>
<td>21</td>
<td>Vietnam</td>
<td>5</td>
</tr>
<tr>
<td>22</td>
<td>Belgium</td>
<td>4</td>
</tr>
<tr>
<td>23</td>
<td>Japan</td>
<td>4</td>
</tr>
<tr>
<td>24</td>
<td>Brazil</td>
<td>3</td>
</tr>
<tr>
<td>25</td>
<td>Lithuania</td>
<td>3</td>
</tr>
<tr>
<td>26</td>
<td>Slovakia</td>
<td>3</td>
</tr>
<tr>
<td>27</td>
<td>Czech Republic</td>
<td>2</td>
</tr>
<tr>
<td>28</td>
<td>Norway</td>
<td>2</td>
</tr>
<tr>
<td>29</td>
<td>Pakistan</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>Venezuela</td>
<td>2</td>
</tr>
</tbody>
</table>

**Fig. 2. RGR and DT for research papers published in type-2 fuzzy logic from 2000 to 2016**

**Fig. 3. Top 30 countries in terms of research publication count in type-2 fuzzy logic from 2000 to 2016**

**c) Top journals:**

Table 4 and Figure 4 show the data for record count of research papers published in various journals. As far as the publication of research works for type-2 fuzzy logic is being concerned in WOS from the period of 2000 to 2016, the IEEE Transactions on fuzzy systems holds the top position. The second and third spots go to Information Sciences and Applied Soft Computing respectively. It is also worth observing that about 41.67% of the top 10 journals are from Elsevier publishers while 16.67% are from IEEE publishers.

**Table 4. Record count of research papers published in various journals**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Journal</th>
<th>Record Count</th>
<th>Publication house</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IEEE Transactions on Fuzzy Systems</td>
<td>87</td>
<td>IEEE</td>
</tr>
<tr>
<td>2</td>
<td>Information Sciences</td>
<td>60</td>
<td>ELSEVIER</td>
</tr>
<tr>
<td>3</td>
<td>Applied Soft Computing</td>
<td>42</td>
<td>ELSEVIER</td>
</tr>
<tr>
<td>4</td>
<td>Expert Systems with Applications</td>
<td>24</td>
<td>ELSEVIER</td>
</tr>
<tr>
<td>5</td>
<td>Soft Computing</td>
<td>22</td>
<td>SPRINGER</td>
</tr>
<tr>
<td>6</td>
<td>Neuro computing</td>
<td>18</td>
<td>ELSEVIER</td>
</tr>
<tr>
<td>7</td>
<td>Engineering Applications of Artificial Intelligence</td>
<td>16</td>
<td>ELSEVIER</td>
</tr>
<tr>
<td>8</td>
<td>Journal of Intelligent Fuzzy Systems</td>
<td>14</td>
<td>IOS PRESS</td>
</tr>
<tr>
<td>10</td>
<td>International Journal of Innovative Computing Information And Control, International Journal of Uncertainty Fuzziness and Knowledge Based Systems</td>
<td>9</td>
<td>KYUSHU TOKAI UNIVERSITY, WORLD SCIENTIFIC</td>
</tr>
</tbody>
</table>
**d) Category wise growth:**

Several categories are defined in the WOS Core, which help in determining the domain of the research papers. As far as the study is being concerned for type-2 fuzzy logic, it can be easily observed from Figure 5 and Table 5 that the topmost category i.e. the one having number of research papers is computer science artificial intelligence. It is well justified too since fuzzy logic itself is a part of artificial intelligence which is a branch of computer science.

**Table 5. WOS category wise research paper count**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>WOS Category</th>
<th>Record Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer Science Artificial Intelligence</td>
<td>326</td>
</tr>
<tr>
<td>2</td>
<td>Engineering Electrical Electronic</td>
<td>190</td>
</tr>
<tr>
<td>3</td>
<td>Computer Science Interdisciplinary Applications</td>
<td>88</td>
</tr>
<tr>
<td>4</td>
<td>Automation Control Systems</td>
<td>88</td>
</tr>
<tr>
<td>5</td>
<td>Computer Science Information Systems</td>
<td>78</td>
</tr>
<tr>
<td>6</td>
<td>Engineering Multidisciplinary</td>
<td>46</td>
</tr>
<tr>
<td>7</td>
<td>Operations Research Management Science</td>
<td>38</td>
</tr>
<tr>
<td>8</td>
<td>Mathematics Applied</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>Computer Science Theory Methods</td>
<td>26</td>
</tr>
<tr>
<td>10</td>
<td>Instruments Instrumentation</td>
<td>19</td>
</tr>
<tr>
<td>11</td>
<td>Computer Science Cybernetics</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>Mathematics Interdisciplinary Applications</td>
<td>17</td>
</tr>
<tr>
<td>13</td>
<td>Mechanics</td>
<td>14</td>
</tr>
<tr>
<td>14</td>
<td>Engineering Mechanical</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>Engineering Chemical</td>
<td>10</td>
</tr>
<tr>
<td>16</td>
<td>Computer Science Software Engineering</td>
<td>10</td>
</tr>
<tr>
<td>17</td>
<td>Engineering Manufacturing</td>
<td>9</td>
</tr>
<tr>
<td>18</td>
<td>Others</td>
<td>115</td>
</tr>
</tbody>
</table>

**e) Research Domain:**

All the 600 research papers that are under consideration for this study were analyzed to find in which research domain they lie. Table 6 presents the data for the same which is also visualized in Figure 6.

**Table 6. Research area wise record count**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Research Area</th>
<th>Record Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer Science</td>
<td>439</td>
</tr>
<tr>
<td>2</td>
<td>Engineering</td>
<td>260</td>
</tr>
<tr>
<td>3</td>
<td>Automation Control Systems</td>
<td>88</td>
</tr>
<tr>
<td>4</td>
<td>Mathematics</td>
<td>42</td>
</tr>
<tr>
<td>5</td>
<td>Operations Research Management Science</td>
<td>38</td>
</tr>
<tr>
<td>6</td>
<td>Instruments Instrumentation</td>
<td>19</td>
</tr>
<tr>
<td>7</td>
<td>Mechanics</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>Environmental Sciences Ecology, Science Technology Other Topics</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Energy Fuels</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>Physics, Robotics</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>Business Economics, Metallurgy Metallurgical Engineering</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Education Educational Research, Materials Science, Telecommunications</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>Medical Informatics</td>
<td>2</td>
</tr>
</tbody>
</table>

**f) Type of access:**

The papers under concern fall under two categories regarding the type of access: Open access and Paid access. Figure 7 helps in comprehending that 578 publications i.e. 96.3% of these research papers are having paid access while the rest 22 which constitute about 3.6% of the lot have open access.

**g) Top authors according to record count:**

The top authors were identified according to the record count. It can be noted that J.M. Mendel is the top author with 47 research papers from the year 2000 to 2016. O. Castillo holds the second position with 34 research papers. This data is recorded in Table 7.
The year wise data for record count of the top 3 authors is recorded as in Table 8. Figure 9 visualizes this data, from which it can be concluded that J.M. Mendel published the maximum papers in 2007 while O. Castillo and P. Melin published their maximum papers in 2014.

### Table 7. Top authors according to record count

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Author</th>
<th>Record count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MENDEL JM</td>
<td>47</td>
</tr>
<tr>
<td>2</td>
<td>CASTILLO O</td>
<td>34</td>
</tr>
<tr>
<td>3</td>
<td>MELIN P</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>HAGRAS H</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>ZARANDI MHF</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>KAYNAK O</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>LAM HK</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>LI HY</td>
<td>13</td>
</tr>
<tr>
<td>9</td>
<td>CHEN SM</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>JOHN RI</td>
<td>11</td>
</tr>
<tr>
<td>11</td>
<td>LIN TC</td>
<td>11</td>
</tr>
<tr>
<td>12</td>
<td>TURKEN IB</td>
<td>11</td>
</tr>
<tr>
<td>13</td>
<td>KAYACAN E</td>
<td>10</td>
</tr>
<tr>
<td>14</td>
<td>ZHAO T</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table 8. Year wise record count of top 3 authors

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mendel</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>CASTILLO</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>MELIN</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

### h) Most cited research papers:

In this study, top 5 research publications have been identified according to the number of citations, as shown in Table 9. The research paper titled “Type-2 fuzzy sets made simple” is the most cited one (953 times). The average citation for this paper is 59.56. When analyzed, it was found that among all the papers that cited it, 355 belonged to the “Computer Science” research domain. Another research
domain catering to the citations of this research paper is "Engineering". This shows the popularity of this paper in various domains, as presented in Table 10. Tables 11–14 show the research areas corresponding to papers ranked 2–5. The data from these is used to map the research papers to various research domains as shown in Figure 10.

**Table 9. Citation and average citation count for top 5 research papers**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Research Paper</th>
<th>Total Citation</th>
<th>Average Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type-2 fuzzy sets made simple</td>
<td>953</td>
<td>59.56</td>
</tr>
<tr>
<td>2</td>
<td>Interval type-2 fuzzy logic systems: Theory and design</td>
<td>782</td>
<td>43.44</td>
</tr>
<tr>
<td>3</td>
<td>Interval type-2 fuzzy logic systems made simple</td>
<td>647</td>
<td>53.92</td>
</tr>
<tr>
<td>4</td>
<td>Centroid of a type-2 fuzzy set</td>
<td>496</td>
<td>29.18</td>
</tr>
<tr>
<td>5</td>
<td>A hierarchical type-2 fuzzy logic control architecture for autonomous mobile robots</td>
<td>456</td>
<td>32.57</td>
</tr>
</tbody>
</table>

**Table 10. Top 5 research areas corresponding to paper titled “Type-2 fuzzy sets made simple”**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Research area</th>
<th>Record count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer Science</td>
<td>355</td>
</tr>
<tr>
<td>2</td>
<td>Engineering</td>
<td>187</td>
</tr>
<tr>
<td>3</td>
<td>Automation Control Systems</td>
<td>54</td>
</tr>
<tr>
<td>4</td>
<td>Mathematics</td>
<td>42</td>
</tr>
<tr>
<td>5</td>
<td>Operations Research Management Science</td>
<td>23</td>
</tr>
</tbody>
</table>

**Table 11. Top 5 research areas corresponding to paper titled “Interval type-2 fuzzy logic systems: Theory and design”**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Research area</th>
<th>Record count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer Science</td>
<td>296</td>
</tr>
<tr>
<td>2</td>
<td>Engineering</td>
<td>185</td>
</tr>
<tr>
<td>3</td>
<td>Automation Control Systems</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>Mathematics</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>Instruments Instrumentation</td>
<td>18</td>
</tr>
</tbody>
</table>

**Table 12. Top 5 research areas corresponding to paper titled “Interval type-2 fuzzy logic systems made simple”**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Research area</th>
<th>Record count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer Science</td>
<td>277</td>
</tr>
<tr>
<td>2</td>
<td>Engineering</td>
<td>154</td>
</tr>
<tr>
<td>3</td>
<td>Automation Control Systems</td>
<td>49</td>
</tr>
<tr>
<td>4</td>
<td>Mathematics</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>Operations Research Management Science</td>
<td>33</td>
</tr>
</tbody>
</table>

**Table 13. Top 5 research areas corresponding to paper titled “Centroid of a type-2 fuzzy set”**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Research area</th>
<th>Record count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer Science</td>
<td>221</td>
</tr>
<tr>
<td>2</td>
<td>Engineering</td>
<td>122</td>
</tr>
<tr>
<td>3</td>
<td>Automation Control Systems</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>Mathematics</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>Operations Research Management Science</td>
<td>17</td>
</tr>
</tbody>
</table>

**Fig. 10. Top 5 research publications from 2000 to 2016 mapped to their research areas**
study, we evaluated the major research applications of type-2 fuzzy logic which are tabulated in Table 16. It can be inferred that control is the top most research application area, followed by clustering and classification.

**k) Control terms and density plot:**

In order to gain better understanding of the research topics in the field of Type-2 fuzzy logic, some control terms need to be identified. These terms are the most frequently occurring author keywords that are extracted using both the title and the abstract of the research articles. In this paper, the 600 research articles from 2000 to 2016 have been analyzed and the density plot for the same has been created, as shown in Figure 12. It can be comprehended that China grants the maximum number of research grants in this aspect.

**j) Major Applications:**

Type-2 fuzzy logic has always been associated with research applications catering to domains like classification, clustering, image processing etc. In our study, we evaluated the major research applications of type-2 fuzzy logic which are tabulated in Table 16. It can be inferred that control is the top most research application area, followed by clustering and classification.

**Table 14. Top 5 research areas corresponding to paper titled “A hierarchical type-2 fuzzy logic control architecture for autonomous mobile robots”**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Research area</th>
<th>Record count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer Science</td>
<td>174</td>
</tr>
<tr>
<td>2</td>
<td>Engineering</td>
<td>110</td>
</tr>
<tr>
<td>3</td>
<td>Automation Control Systems</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>Mathematics</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>Instruments Instrumentation</td>
<td>11</td>
</tr>
</tbody>
</table>

**Table 15. Top 10 funding agencies**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Funding agencies</th>
<th>Record count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>National Natural Science Foundation of China</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>National Science Council Taiwan</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>Fundamental Research Funds for the Central Universities</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>National Science Council Republic Of China</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Program For New Century Excellent Talents In University</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Australian Research Council, Bogazici University, Conacy</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Program for Liaoning Excellent Talents In University</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>National Nature Science Foundation Of China, National Science Council Of Taiwan</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Centre for Intelligent Systems Research Cisr At Deakin University, Tubitak</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>973 Program of China, Rsk Ying Tung Education Foundation of China, Key Laboratory for Integrated Automation for The Process Industry Northeast University, Natural Science Foundation of Hebei Province of China, Program for Liaoning Innovative Research Team in University, Taiwan National Science Council, Zhujiang New Star</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 16. Major research applications of Type-2 fuzzy logic**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Application</th>
<th>Record count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control</td>
<td>138</td>
</tr>
<tr>
<td>2</td>
<td>Clustering</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>Classification</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>Filtering</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>Image Processing, Image Segmentation</td>
<td>9</td>
</tr>
</tbody>
</table>

**Fig. 11. World mapping of top 4 countries with maximum number of grants from funding agencies**
about the inter-country collaboration which is visualized as in Figure 13. The nodes of this graph represent the countries that participate in inter-country collaboration and the edges represent the number of publications for the same. The inter-country collaboration was found to be the maximum between UK and China, Turkey and Iran. It can be observed that Turkey and Canada have also participated actively in such collaborations. As an individual country, USA, UK, China, Turkey, Canada and Iran have been dynamically involved in such inter country collaborations for research publications.

Regarding this inter-country collaboration that is illustrated in Figure 13, it is our believe that it will grow a lot in future years, as the type-2 fuzzy community in growing in many more countries and also it is consolidating in countries that already have research on type 2. There are other publications too in 2017 (published and ongoing papers) where other collaborations are flourishing, but they could not be repre-

Fig. 12. Density plot for identifying the control terms in the field of Type-2 fuzzy logic

Fig. 13. Inter-Country collaboration pattern
sent here due to the limitation of the time interval of 2000-2016 and the year 2017 is not complete to the moment.

4. Conclusion

This paper charted and mapped the progress of research work in the field of Type-2 fuzzy logic from the year 2000-2016 on the basis of 600 research papers retrieved from web of science. The primary aim of this study was to analyze the research work in type-2 fuzzy logic so that the growth of this discipline through the years is tracked. The study performed in this paper helps in answering various significant research questions like the growth rate of type-2 fuzzy logic in terms of research publications, top journals, authors, research grant agencies etc. The inter-country collaboration was also visualized to map the authorship patterns among various countries. All this would help the researchers in understanding the discipline in a more elaborate manner. This kind of work in the field of type-2 fuzzy logic is the only one of its kind as it statistically highlights the various aspects related to it. As future work we envision updating this information about type-2 research in a few more years to verify the evolution and growth of the type-2 fuzzy area.

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