A bibliometric investigation into the literature of semantic reasoning in internet of things

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Nowadays, semantic interoperability is a new keyword in the Internet of Things (IoT). The constant need for interaction and cooperation has resulted in the creation of the Semantic Web with the help of tools and reasoners which manage personal information. Given the significance of the IoT and the increasing use of semantic techniques in this field, the present bibliometric investigation was conducted in the domain of semantic reasoning in the IoT. In this study, through the analysis of 799 articles retrieved from the Web of Science database, distribution of topic categories, prolific and influential authors, the language of articles, publishers of articles and their geographical distribution, the most debated/researched and the most frequently cited articles, and keyword trends were studied. The results of this study shows that 10 countries produced 84% of the total documents, with China being in the lead. Other interesting findings have been reported in the paper.

KEYWORDS
bibliometrics, internet of things (IoT), ontology, semantic reasoning, semantic web

1 INTRODUCTION

Differences in the definitions of the Internet of Things (IoT) stem from the fact that it has various stakeholders including occupations and research studies. Everyone attempts to define and interpret the IoT according to their particular needs, concerns, and contexts. Noteworthy is also the fact that heterogeneous devices used in large IoT networks generate substantial amounts of real-time data which are transmitted to clouds through gateways for further processing. Device heterogeneity can be due to capacity, features, sellers, and specific needs of the application. Although the Web is regarded as a suitable platform for integrating objects, the Semantic Web can enhance its capacity to understand object data and facilitate interoperability. In addition to the heterogeneity of devices, technologies, protocols, data formats, semantics, hardware platforms, software packages, radio frequencies, and processing strategies are considered important aspects of the IoT physical environment. Therefore, data heterogeneity causes a lack of interoperability among applications and devices.

Semantics in the IoT refers to the ability to intelligently extract information employing different machines to provide necessary services. Semantic technologies can help realize such features as interoperability and reasoning in the IoT. However, because of the dynamic and heterogeneous nature of IoT data, limited sources, and real-time needs, using this technology is faced with a number of challenges. Applying semantic technologies to the IoT enhances interaction and cooperation between IoT devices and facilitates data access, data integration, discovery of sources, semantic reasoning, and knowledge extraction.
The science of classifying and answering queries is at the core of Semantic Web reasoning services. Employing reasoners is one of the methods of reasoning knowledge in the Semantic Web. A semantic reasoner is a program which can deduce logical conclusions from a set of obvious facts or terms. A bibliometric study, this research centers on the existing articles in the Semantic Web.

Bibliometrics involves analyzing bibliographic data of scientific sources, and it can be used to reach an analysis of the status quo in a scientific field. These analyses include, among others, the identification of the most debated and/or researched topics in a certain field of science. Illustrating studies in a particular field, these analyses tend to be of immense interest to researchers, so their results are generally published as independent articles in international scientific journals. Drawing upon the Web of Science database, the present study is a bibliometric investigation into the domain of semantic reasoning in the IoT.

This bibliometric study, aimed at obtaining more accurate information in the above-mentioned domain, retrieved and analyzed the results of research done in scientific fields. The following are Sections 2, 3, and 4 which respectively present the method, results, and conclusions of this research.

2 | METHOD

The Web of Science (WoS) is one of the most commonly used scientific databases in bibliometric studies. The only scientific database employed in this study was the WoS. To retrieve relevant articles in the field of semantics, as well as semantic reasoning, in the IoT, the researcher used the following as search terms: “Internet of Things” and “reasoning”.

As stated above, the study began by searching for articles on the WoS, a well-known index of scientific and bibliographic documents. In this search, the results were filtered by “article” document type. Studies show that searching in the title of a paper does not always lead to the retrieval of all relevant publications. As such, abstracts or entire texts of articles should also be taken into account. The present study, therefore, considered searching for related titles, keywords and abstracts.

Through the searching step, which took place on February 18, 2021, a total of 799 articles in this domain were retrieved from the WoS citation database. In addition to using the information provided in these articles, to analyze them, the researcher employed some bibliometric tools such as VOSviewer and BibExcel as well. More specifically, the BibExcel software package was used to arrive at the trends of the articles. Moreover, Microsoft Excel 2010 was used to extract and tabulate statistics in different fields and calculate correlations between variables.

In the following section, statistical results representing prolific and influential authors in this domain, frequently cited articles, as well as keywords and other information about these articles, are provided and analyzed.

3 | RESULTS

Every article available in the WoS database can be ascribed to at least one field category. Of all these articles, according to the WoS field categories, 34% are related to Computer Science, 26% relate to Electrical or Electronic Engineering, 16% pertain to Telecommunications, and the remaining 24% center around Business Economics, Chemistry, Instruments Instrumentation, etc. The corresponding illustration diagram is presented in Figure 1. The frequency of articles in the domain of semantic reasoning in the IoT is displayed in Figure 2. Likewise, this information was obtained from the WoS citation database.
According to the diagram in Figure 3, it can be perceived that the frequency of articles published in 2020 has been the highest number since 2012. In general, the growing trend of publishing such articles reveals researchers’ tendencies towards this domain. These articles, in turn, received 9512 citations, as shown in Figure 3. It can be concluded from the information displayed in Figure 3 that the citing trend of articles in this domain has been increasing exponentially from 2011 to 2020 such that the year 2020 witnessed the maximum number of citations, that is, more than 2400 citations, and the same trend is expected to continue in 2021.

### 3.1 Prolific and influential authors

Through the analysis of the statistics with the Bibexcel statistical analysis software, the 10 most prolific and influential authors in the domain of semantic reasoning in the IoT were identified (see Table 1). These authors’ ranking was determined based on the H-index which is a bibliometric index essentially devised for evaluating authors. This evaluation is conducted through combining quantitative and impact-related data. Therefore, this study only used the H-index to analyze the citations to articles in this domain.

#### Table 1 10 most prolific and influential authors in the domain of semantic reasoning in IoT

| ID | Author         | All citations | All articles | h-index |
|----|----------------|---------------|--------------|---------|
| 1  | Blanco-F Y     | 334           | 17           | 10      |
| 2  | Gil-Solla A    | 298           | 15           | 10      |
| 3  | Lopez-N M      | 334           | 17           | 10      |
| 4  | Pazos-Arias J  | 309           | 14           | 10      |
| 5  | Ramos-C M      | 274           | 14           | 9       |
| 6  | Garcia-Duque J | 178           | 9            | 8       |
| 7  | Skarmeta AF    | 326           | 11           | 8       |
| 8  | Fernandez-V    | 150           | 8            | 8       |
| 9  | Diaz-R R       | 126           | 6            | 6       |
| 10 | Jara AJ        | 304           | 6            | 5       |
3.2 | Most prolific universities

Table 2 presents the most active universities in terms of publishing articles in this domain. With respect to Table 2, it can be concluded that the most prolific university in this domain has been the University of Vigo in Spain.

Nevertheless, although this university ranks first because of its considerable number of articles, the analysis of the 799 retrieved articles from the WoS database reveals that Chinese universities and organizations, in total, have been most prolific in the domain of IoT semantic reasoning (see Figure 4).

In regard to the statistics in Figure 4, one may compute that approximately 18.27% of these articles belong to China, 11.76% are attributed to the United States of America, and 11.63% have been written in Spain. In turn, it can be calculated that nearly 84.23% of the articles belong to the 10 most prolific countries in this domain.

3.3 | Most frequently cited articles

The 10 most frequently cited articles in the domain of IoT semantic reasoning are presented in Table 3, implying that studying these documents by all researchers intending to do investigations in this domain is probably essential. The number of citations to these articles exceeds 100. Among these, a survey article by C Perera (2013) referred to 1136 times has been the most frequently cited one.

3.4 | Most important keywords

Authors tend to provide keywords as summaries of articles. Therefore, first, the most frequent keywords used in the domain of semantic reasoning in the IoT were analyzed. Following this, trends representing the keywords were examined. The keywords were studied in three periods. Figure 5 presents the most important keywords obtained by means of the VOSviewer. The size of nodes can reflect the frequency of keywords: the higher frequency of keyword, the larger size of the node. As shown in Figure 5, the Internet of Things node has the biggest size representing the Internet of Things has the highest frequency of keywords. Among the specialized keywords, Ontology also has a higher frequency. This means that many authors employed ontology in their research method. Apart from the frequency, this figure shows colors that represent groups (clusters) of terms that are relatively strongly related to each other. The thickness of the connecting line showed the strength of pairs of topic areas or keywords. The thinker link between two keywords such as ontology and semantic web represents a closer relationship. Since the Internet of Things is a different field from semantic topics,

| ID | University                                      | Country | Document |
|----|-------------------------------------------------|---------|----------|
| 1  | Universidade De Vigo                           | Spain   | 18       |
| 2  | University of Murcia                           | Spain   | 15       |
| 3  | Udice French Research Universities             | France  | 14       |
| 4  | Centre National de la Recherche Scientifique CNRS | France  | 13       |
| 5  | University of Catania                          | Italy   | 11       |
Table 3: Ten most frequently cited articles in the domain of IoT semantic reasoning

| Id | Document title                                                                 | Citations |
|----|--------------------------------------------------------------------------------|-----------|
| 1  | Context Aware Computing for The Internet of Things: A Survey \(^{11}\)               | 1136      |
| 2  | The ChEBI reference database and ontology for biologically relevant chemistry: enhancements for 2013 \(^{12}\) | 337       |
| 3  | Towards the Implementation of IoT for Environmental Condition Monitoring in Homes \(^{13}\) | 335       |
| 4  | A Knowledge-Driven Approach to Activity Recognition in Smart Homes \(^{14}\)        | 275       |
| 5  | Closed-loop PLM for intelligent products in the era of the Internet of Things \(^{15}\) | 233       |
| 6  | A Survey on Distributed Topology Control Techniques for Extending the Lifetime of Battery Powered Wireless Sensor Networks \(^{16}\) | 195       |
| 7  | An internet of things-based personal device for diabetes therapy management in ambient assisted living (AAL) \(^{17}\) | 143       |
| 8  | Interconnection Framework for mHealth and Remote Monitoring Based on the Internet of Things \(^{18}\) | 115       |
| 9  | BIM and ontology-based approach for building cost estimation \(^{19}\)               | 111       |
| 10 | Sensor Search Techniques for Sensing as a Service Architecture for the Internet of Things \(^{20}\) | 105       |

![Figure 5](image)

**Figure 5**: Schematic presentation of keywords in IoT semantic reasoning in VOSviewer

It can be seen that keywords related to semantics such as ontology were placed in a green cluster and words related to the Internet of Things were placed in a blue cluster.

## 4 CONCLUSIONS

The current research presented a bibliometric investigation in the domain of semantic reasoning in the Internet of Things. The analysis conducted in this study shows that the year 2020 observed the publishing of the highest number of documents (i.e., 191 articles) in the domain of semantic reasoning in the IoT. Additionally, of the documents analyzed, 10 countries produced approximately 84% of the total, with Chinese universities and organizations being the most prolific ones in the IoT semantic reasoning domain. The most articles published in this domain, however, belong to the University of Vigo in Spain. Furthermore, the analysis of keywords revealed that in addition to the term *Internet of Things*, the most widely used keywords are *fog computing*, *edge computing*, *Semantic Web*, and *wireless sensor network*, considered to be the most significant terms. More investigation showed a major part of research methods on semantic reasoning were performed by *ontology*. As well, *ontology* has highest average number of citations among the specialized keywords. This study was conducted on WoS citation database. However, according to related researches on WoS and Scopus, the results of bibliometric investigations into natural sciences and engineering conducted based on WoS and Scopus have noticeable overlap.
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