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Industry 4.0: a perspective based on bibliometric analysis

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Abstract

The main aim of this contribution is to develop a co-words analysis of the *Industry 4.0* research field in order to highlight the themes covered in the last five years (2013–2017). The software tool SciMAT is employed using an approach that allows us to uncover the main research themes and analyze them according to their performance and impact measures. An amount of 333 documents were retrieved from the Web of Science. Our key findings are that the most important research themes were *Cyber-Physical-Systems* and *Cloud-Computing*.

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Keywords: Bibliometric Analysis; Science Mapping Analysis; Co-words analysis; Industry 4.0

1. Introduction

Nowadays, universities, research centres and companies are focusing their efforts in the *Industry 4.0* [1], which could be defined as the integration of different techniques such as, Big Data, cloud computing, 3D printing, cyber-security, autonomous robot, Internet of Things, augmented reality, simulation, etc. Thus, the *Industry 4.0* is currently transforming the business and manufacturing processes of companies and organizations.

Due to the fast development of the fourth industrial revolution [2], and the technologies that enable it, we need special tools and techniques that allow us to analyze and visualize in what topics the researchers are focusing on, and

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therefore, to detect the gaps that must be explored in order to develop and advance in this industrial revolution. Thus, universities, and scientific policy makers could detect the main players, and allocate funding where needed.

So, the main aim of this contribution is to carry out a conceptual science mapping analysis [3, 4, 5] of the research conducted by the *Industry 4.0* research field, from 2013 to 2017 (the last five years). The analysis is developed using SciMAT [6] software tool and partially based in the approach presented in [7].

This article is organized as follows: Section 2 introduces the methodology employed in the analysis. In Section 3, the dataset is described. In Section 4, the main results of the analysis developed are presented. Finally, some conclusions are drawn in Section 5.

2. Methodology

Science mapping or bibliometric mapping is a spatial representation of how disciplines, fields, specialties, and documents or authors are related to one another [8]. It has been widely used to show and uncover the hidden key elements (documents, authors, institutions, topics, etc.) in different research fields [9, 10, 11, 12, 13, 14].

Science mapping analysis can be carried out with different software tools [5]. Particularly, SciMAT was presented in [6] as a powerful tool that integrates the majority of the advantages of available science mapping software tools [5]. It is an open source software tool that present the following key features:

SciMAT was designed according to the science mapping analysis approach presented in [7], combining both performance analysis tools and science mapping tools to analyze a research field and detect and visualize its conceptual subdomains (particular topics/themes or general thematic areas) and its thematic evolution.

Therefore, in this contribution, SciMAT was employed to develop a longitudinal conceptual science mapping analysis [3, 5] based on co-words bibliographic networks [4, 15]. Thus, the analysis was carried out in three stages:

1. *Detection of the research themes*. In each period of time studied the corresponding research themes are detected by applying a co-word analysis [4] to raw data for all the published documents in the research field, followed by a clustering of keywords to topics/themes [16], which locates keyword networks that are strongly linked to each other and that correspond to centres of interest or to research problems that are the subject of significant interest among researchers. The similarity between the keywords is assessed using the equivalence index [17].
2. *Visualizing research themes and thematic network*. In this phase, the detected themes are visualized by means of two different visualization instruments: strategic diagram [18] and thematic network [7]. Each theme can be characterized by two measures [17]: *centrality* and *density*. Centrality measures the degree of interaction of a network with other networks. On the other hand, density measures the internal strength of the network. Given both measures, a research field can be visualized as a set of research themes, mapped in a two-dimensional strategic diagram (Figure 3) and classified into four groups:

    (a) Themes in the upper-right quadrant are both well developed and important for the structure of the research field. They are known as the *motor-themes* of the specialty, given that they present strong centrality and high density.
    (b) Themes in the upper-left quadrant have well-developed internal ties but unimportant external ties and so, they are of only marginal importance for the field. These themes are very *specialized and peripheral*.
    (c) Themes in the lower-left quadrant are both weakly developed and marginal. The themes in this quadrant have low density and low centrality and mainly represent either *emerging or disappearing* themes.
    (d) Themes in the lower-right quadrant are important for a research field but are not developed. This quadrant contains *transversal and general*, basic themes.

3. *Performance analysis*. In this phase, the relative contribution of the research themes to the whole research field is measured (quantitatively and qualitatively) and used to establish the most prominent, most productive and highest-impact subfields. Some of the bibliometric indicators to use are: number of published documents, number of citations, and different types of h-index [19, 20, 21]. For each theme, the performance measure are computed taking into account the documents associated with it. Thus, for instance, the h-index is computed using the citations of the theme's documents.

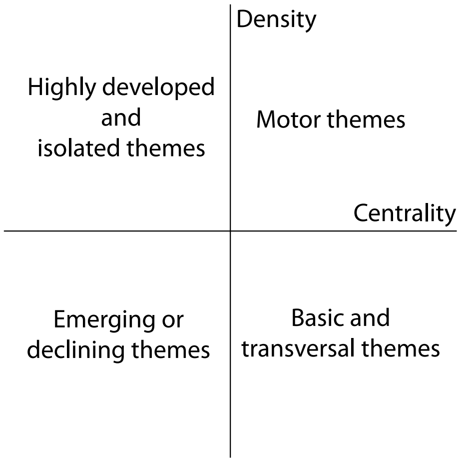


Fig. 1. The strategic diagram.

3. Dataset

In order to carry out the performance and science mapping analysis, the research documents related with the research field of *Industry 4.0* during the last five years (2013–2017) must be collected and also, preprocessed.

Since Web of Science is the most important bibliographic database, the research documents related with the research field were downloaded from it, using the query "TS=Industry 4.0". The query retrieved a total of 333 documents from 2013 to 2017 (Figure 2). The corpus was further restricted to articles and reviews. Citations of these documents are also used in this study; they were counted up to 14th March 2018.

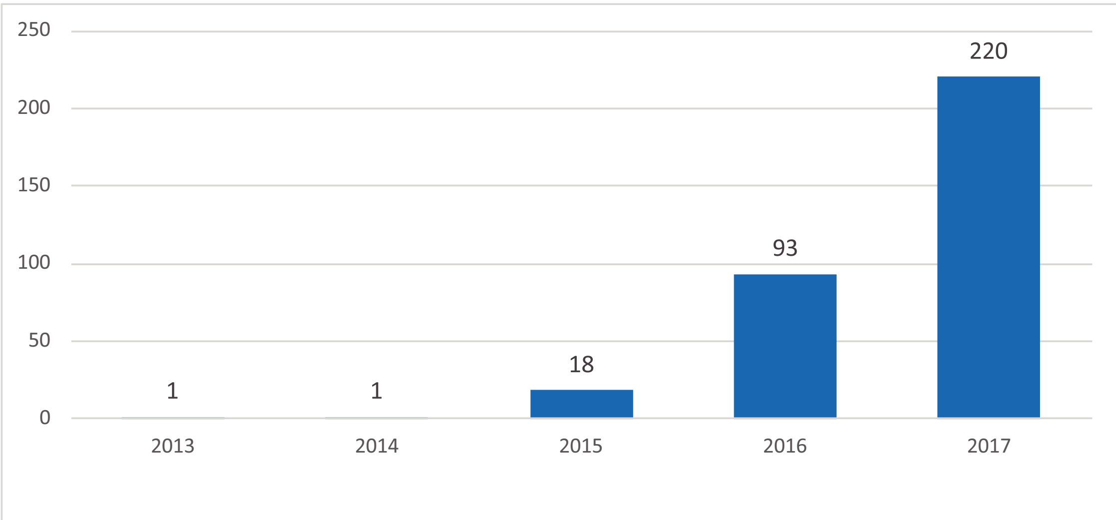


Fig. 2. Distribution of documents retrieved by years.

The raw data was downloaded from Web of Science as plain text and entered into SciMAT to build the knowledge base for the science mapping analysis. Thus, it contains the bibliographic information stored by Web of Science for each research document. To improve the data quality, a de-duplicating process was applied (the authors keywords and the Keywords Plus were used as unit of analysis). Words representing the same concept were grouped. Furthermore, some meaningless keywords in this context, such as stop-words or words with a very broad and general meaning, e.g. “SYSTEM” or “ALGORITHM”, were removed.

4. Conceptual Analysis

In order to analyze the most highlighting themes of the *Industry 4.0* research field, a strategic diagram is shown for the whole period (2013-2017). In addition, the volume of the spheres is proportional to the number of published documents associated with each research theme.

According to the strategic diagram shown in Figure 3, during this period the research pivoted on seven themes: *Cyber-Physical-Systems*, *Cloud-Computing*, *Smart-grid*, *Innovation*, *Decisional-DNA*, *Industry-Wireless-Sensor-Networks* and *Supply-Chain*. Furthermore, the thematic networks of each theme is shown in Figures 4 and 5.

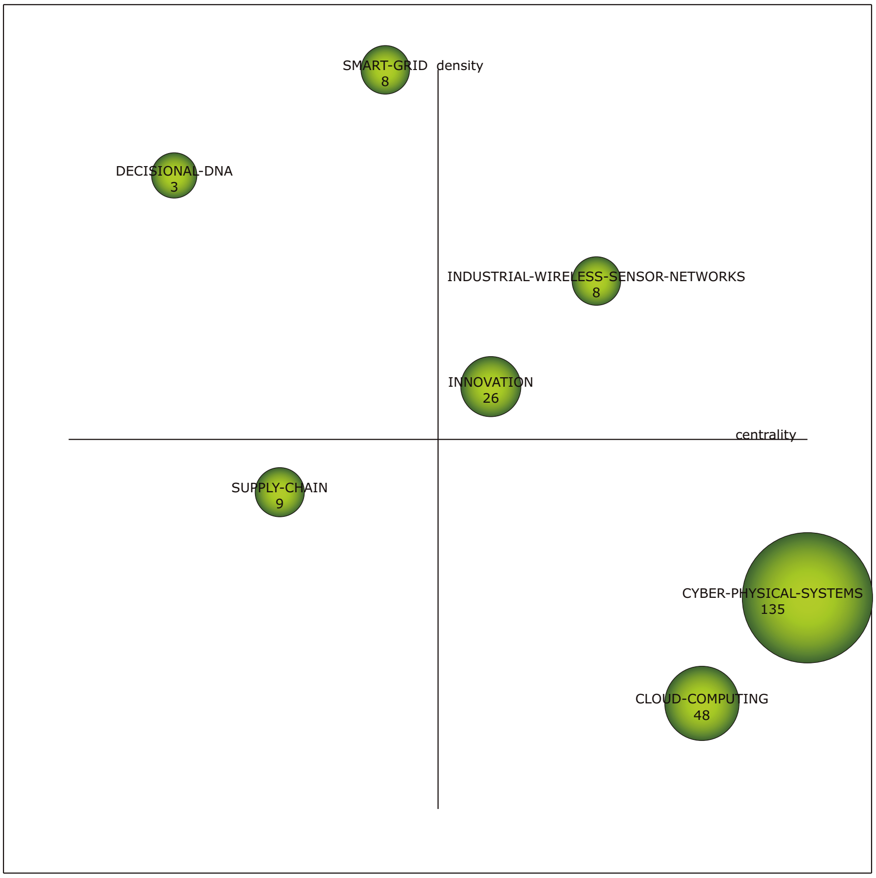


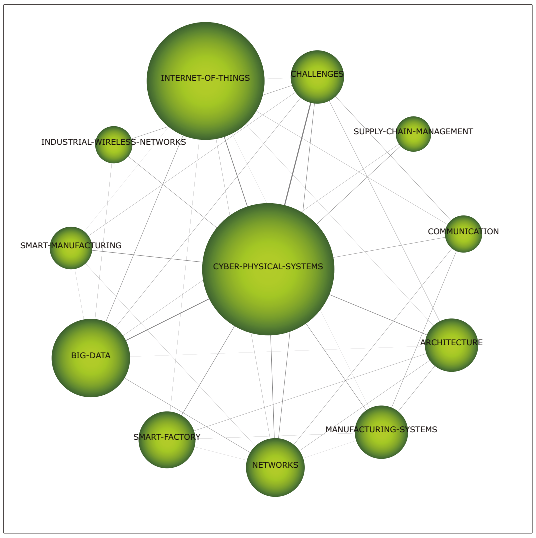
Fig. 3. Strategic diagram for the whole period (2013–2017).

The performance measures of the themes are given in Table 1, showing the number of documents, numbers of citations and h–index per theme. According to these performance measures, the following themes stand out (more than 100 citations): *Cyber-Physical-Systems* and *Cloud-Computing*. We should remark that both themes got great impact measures (citations and h–index), taking into account the small citation window.

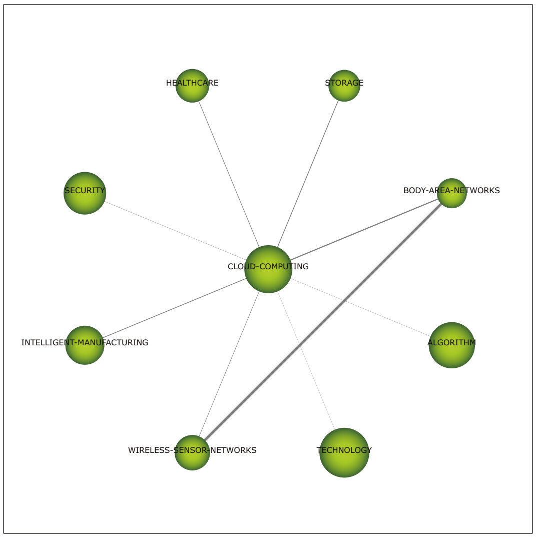
According with our results, the most important theme of the Industry 4.0 research field is *Cyber-Physical-Systems* (Figure 4.a), which is related mainly with Internet of Things, manufacturing systems and smart factories, and how this technologies use techniques related with Big data to accomplish their objectives [22, 23, 24]. Taking into account the citations achieved, it get two times more citations than the second theme in the impact rank.

Table 1. Performance of the themes in the whole period

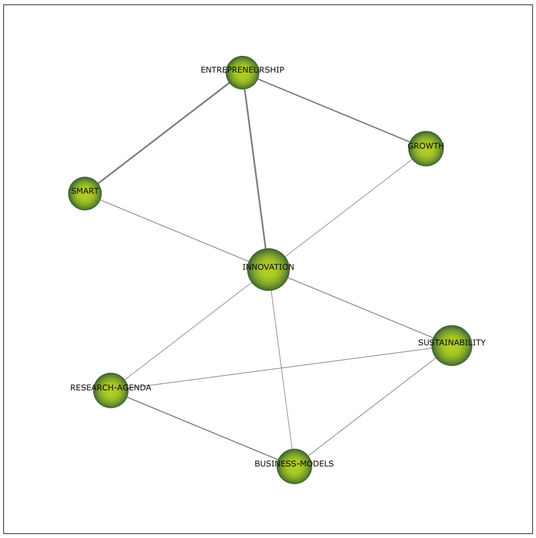
Name	Number of documents	Number of citations	h-index
CYBER-PHYSICAL-SYSTEMS	135	483	11
CLOUD-COMPUTING	48	206	8
INNOVATION	26	39	3
SUPPLY-CHAIN	9	18	2
INDUSTRIAL-WIRELESS-SENSOR-NETWORKS	8	13	2
SMART-GRID	8	20	2
DECISIONAL-DNA	3	22	2



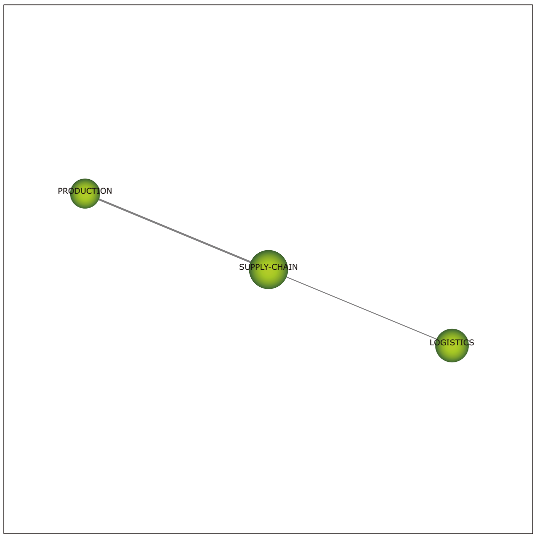
(a) Theme Cyber Physical Systems.



(b) Theme Cloud-Computing



(c) Theme Innovation



(d) Theme Supply-Chain

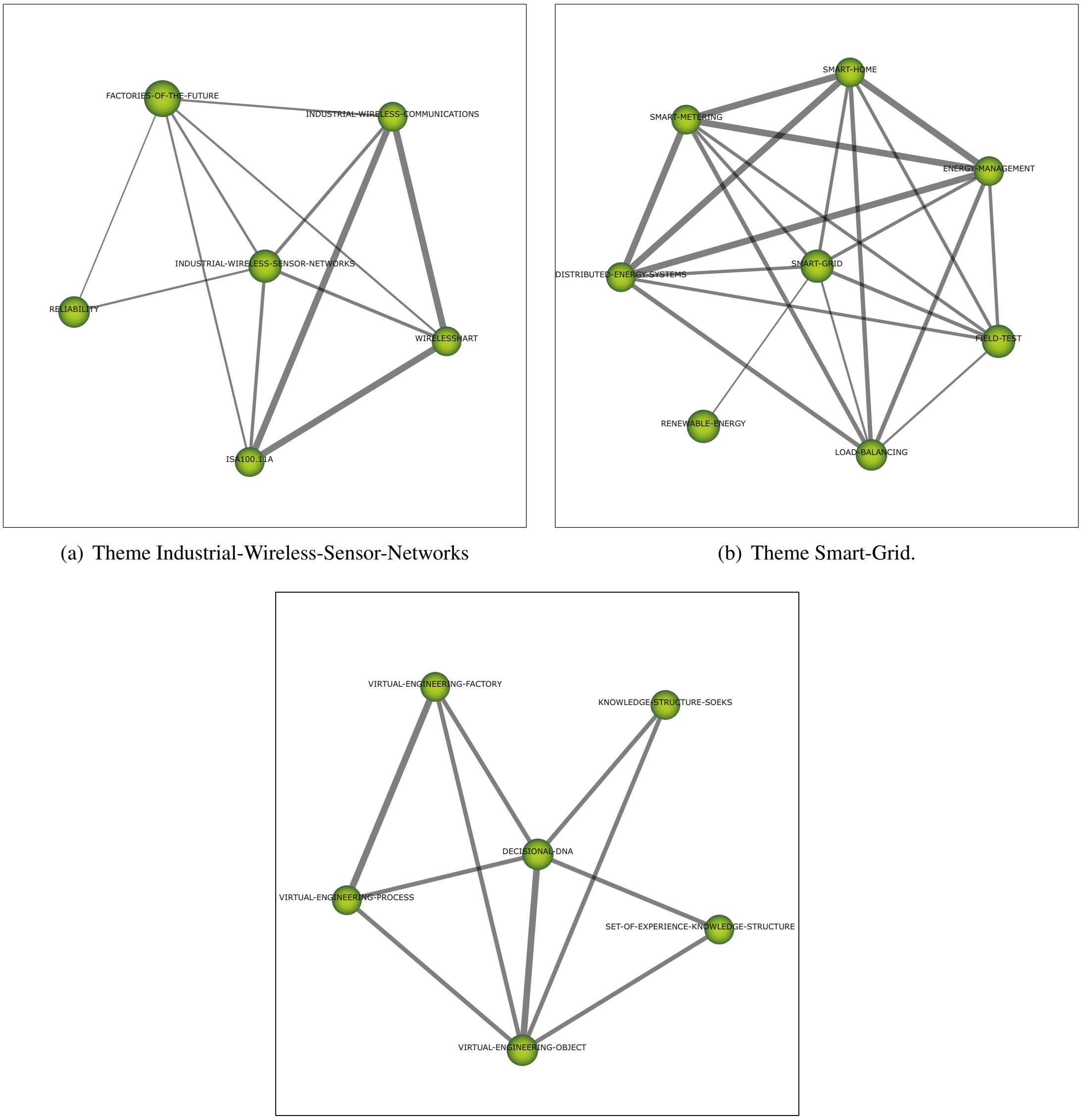
Fig. 4. Thematic networks (part I).

The theme *Could-Computing* (Figure 4.b) is the second ranked in number of documents and citations achieved. It is mainly focused on how the cloud computing could help to solve some problem of the industry 4.0 such as the storage, the security or the sensor networks.

The theme *Innovation* (Figure 4.c) is mainly focused on how the Industry 4.0 could enable new business model, suitable new companies and modify the current research agenda, and therefore, create new value in the current industry [25].

The theme *Supply-Chain* (Figure 4.d) is devoted to the logistic and production of the supply chain management by means of the enabling techniques of the Industry 4.0 [26].

The theme Industrial-Wireless-Sensor-Networks (Figure 5.a) is focused on the hardware needed to construct the factories of the future, by means of a interconnected set of sensor.



(a) Theme Industrial-Wireless-Sensor-Networks

(b) Theme Smart-Grid.

(c) Theme Decisional-DNA.

Fig. 5. Thematic networks (part II).

The theme *Smart-Grid* (Figure 5.b) deals with electrical grids in order to make them smart for enabling the Industry 4.0. So, the theme cover different related topics such as, meters, renewable energy, energy loading and balancing, etc.

Finally, the theme *Decisional-DNA* (Figure 5.c) is mainly devoted to the virtual engineering, covering aspects such as, the factories, processes, knowledge structures and virtual objects, among others.

5. Conclusions

In this contribution, a conceptual science mapping analysis of the articles published in the last five years (2013-2017) within the *Industry 4.0* research field has been performed. The analysis was carried out using SciMAT [6].

An amount of 333 documents (articles and reviews) related with the field were retrieved from Web of Science. The documents were retrieved by means of a query in which the search term was ”Industry 4.0”. Therefore, our corpus only contains document that explicitly contain this term in the abstract, title or keywords.

As results of the science mapping analysis carried out, we should remark that the theme *Cyber-Physical-Systems* is the one with highest number of document and impact measures. Moreover, the theme *Could-Computing* achieved also a great citations count.

Finally, we would like to address some future works. First, a global analysis could be carried out taking into account a wider time span and enriching the query with more search terms. Second, the evolution of the research themes could be studied across the consecutive time periods.

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