- ORIGINAL ARTICLE -

IIoT/IoT and Artificial Intelligence/Machine Learning as a Process Optimization Driver under Industry 4.0 Model

IIoT/IoT e Inteligencia Artificial/Aprendizaje Automático como Motor de Optimización de Procesos en el Modelo de Industria 4.0

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Abstract

The advance of digitalization in industry is making possible that connected products and processes help people, industrial plants and equipment to be more productive and efficient, and the results for operative processes should impact throughout the economy and the environment.

Connected products and processes generate data that is being seen as a key source of competitive advantage, and the management and processing of that data is generating new challenges in the industrial environment.

The article to be presented looks into the framework of the adoption of Artificial Intelligence and Machine Learning and its integration with IIoT (industrial Internet of Things) or IoT (Internet of Things) under industry 4.0, or smart manufacturing framework. This work is focused on the discussion around Artificial Intelligence/Machine Learning and IIoT/IoT as driver for Industrial Process optimization.

The paper explore some related articles that were find relevant to start the discussion, and includes a bibliometric analysis of the key topics around Artificial Intelligence/Machine Learning as a value added solution for process optimization under Industry 4.0 or Smart Manufacturing paradigm.

The main findings are related to the importance that the subject has acquired since 2013 in terms of published articles, and the complexity of the approach of the issue proposed by this work in the industrial environment.

Keywords: Artificial Intelligence, IIoT, IoT, machine learning, Industry 4.0.

Resumen

El avance de la digitalización en la industria está haciendo posible que los productos y procesos conectados colaboren con las personas, las plantas industriales y los equipos a ser más productivos y eficientes, y los resultados de los procesos operativos deberían impactar en toda la economía y el medio ambiente.

Los productos y procesos conectados generan datos que se ven como una fuente clave de ventaja competitiva, la gestión y procesamiento de esos datos está generando nuevos desafíos en el entorno industrial.

El artículo que se presentará analiza el marco de la adopción de la Inteligencia Artificial, y el Aprendizaje Automático, y su integración con IIoT o IoT bajo la industria 4.0, o el marco de fabricación inteligente. Este trabajo se centra en la discusión en torno a la Inteligencia Artificial/Aprendizaje Automático e IIoT/IoT como impulsor de la optimización de Procesos Industriales.

Este trabajo explora algunos artículos relacionados que se consideraron relevantes para iniciar la discusión, e incluye un análisis bibliométrico de los temas clave en torno a la Inteligencia Artificial/Aprendizaje Automático como una solución de valor agregado para la optimización de procesos bajo el paradigma de Industria 4.0 o Manufactura Inteligente.

Los principales hallazgos se relacionan con la importancia que ha adquirido el tema desde 2013 en cuanto a artículos publicados, y la complejidad del abordaje del tema propuesto por este trabajo en el ámbito industrial.

Palabras claves: Inteligencia artificial, IIoT, IoT, aprendizaje automático, Industria 4.0.

1. Introduction

This work consists in a bibliometric analysis looking for a deeper knowledge of constraints, opportunities and advantages of IIoT (Industrial Internet of Things), or IoT (Internet of Things) to have a wider view, and its integration with Artificial Intelligence to facilitate the Optimization of Industrial Processes. The paper is structured starting with a preliminary exploration work regarding IIoT/IoT and Artificial Intelligence under Industry 4.0 framework, and then the article is completed with a bibliometric analysis.

In a previous paper, [6] found some core concepts about Industry 4.0 model. The authors highlight that in this model machines will redefine themselves in how they communicate and perform individual functions, and that the new model is a fusion of Industrial Production and Information and Communication Technologies (ICT). This paradigm is making possible to connect information, objects and people due to the convergence of the physical and the virtual (cyberspace) worlds in the form of Cyber-Physical Systems (CPS). Therefore, it is enabling the transformation of workshops into smart sites.

The article [1] makes a very clear description and justify the role of Artificial Intelligence (AI) in the construction of sustainable business models (SBMs). It provides a quantitative overview of the academic literature that constitutes the field. The paper discusses the relationships between AI and rapid developments in machine learning and shows that for private organizations, the use of AI is for identifying solutions to improve the competitiveness of business. Therefore there is no doubt about benefits of AI to optimize industrial processes as long as it is properly integrated with a data source such as the IoT or IIoT infrastructure.

[2] Identify seven central elements in the model suggested by Industry 4.0. Smart factories, cyber-physical systems, self-organization, new distribution and purchasing systems, new product and service development systems, adaptation to people's needs, and corporate social responsibility.

This article pretends to explore some of the elements of Industry 4.0 paradigm mentioned in the previous paragraphs, and its relationship with IIoT, Artificial Intelligence and process optimization. Besides the paper presents some results from works related to the subject of interest, then stablish the methodology to perform a bibliometric analysis around the idea of IIoT or IoT and its integration with Artificial Intelligence/Machine Learning tools to facilitate industrial process optimization under the framework of Industry 4.0.

The bibliometric analysis had been done on Scopus indexed database, whose results was analyzed using bibliometric indicators. Through these indicators, information was obtained about the main authors, evolution of the relevance of the concept, and main key words of the issue considered in this work. The research was completed through the use of the VOSviewer® 1.6.11 software tool (http://www.vosviewer.com/), to analyze results and make easier to reach the conclusions and lines of research raised in this work.

2. Some preliminary findings

A previous bibliographic research was made regarding the issues in which this paper is focused. To start the development of this work, nine articles with some interesting insights were considered. This evidence seems a good starting point to complete the work with bibliometric research.

The first paper considered in this section is [7] that studies Industry 4.0 in the semiconductor industry, where high reliability and low operating costs are critical for a business' success. In this context, this article proposes an Industry 4.0 Pilot as a compilation of lessons learned during an end-to-end development of a reference design applied to a semiconductor packaging and test company. It is explored the requirements of clean rooms and information related to sensors and data acquisition boards, in addition to performance details and configurations pertaining to visualization tools and warning notifications from AI tools.

[8] Observes that smart manufacturing (SM) is a new paradigm that allows manufacturing to enter its fourth revolution by exploiting state-of-the art sensing, communication and computation as the IIoT. Through the use of high-performance computing and advanced modeling, SM aims to improve the flexibility and adaptability of manufacturing. This paper addresses this trend by reviewing the combined use of data-driven and knowledge-enabled hybrid models (HM), and discusses how such techniques seamlessly fit in the SM platform. Furthermore, a discussion of the new paradigms of HM enabled by the SM platform is given, highlighting their importance in future large-scale applications of the SM platform.

[9] Consider that with the rise of trends such as IIoT and cloud manufacturing that seek convergence of IT (Information Technologies) tools in OT (Operational Technologies) networks, OT and IT analysis are highly sought after in today's industries striving for real-time analysis of data. To analyze the data in the OT and IT domain it is necessary to use models, which not only focus on describing both domains but can also show the relationship between them. In this paper, it is presented a technique that uses the operational data, produced in an organization

from IIoT solutions, in order to model OT, with the purpose of applying analysis methods.

[10] Present a comprehensive survey and investigation of how widespread AI and IoT are among manufacturing SMEs, and discusses the current limitations and opportunities towards enabling predictive analytics. Firstly, an overview of the enablers for AI and IoT is provided along with the four analytics capabilities. Hereafter a comprehensive literature review is conducted and its findings showcased. Finally, emerging topics of research and development, making AI and IoT accessible technologies to SMEs, and the associated future trends and challenges are summarized.

[11] Points that Smart Manufacturing Systems can connect raw materials, production systems, logistic companies, and maintenance schedules using the capabilities of industrial, IoT. These connections are creating CPPS and linking functions across the entire product lifecycle. These connections are possible today because of the advances in DM technologies that can facilitate factory design, redesign, and analysis in CPPS and help to continuously and efficiently manage factory performance optimization. However, the paper concludes that implementing DM, especially in SMEs, is difficult because the required interface standards and data schema do not exist.

The article from [12] identifies that blockchain's in combination with IoT elements in logistics and transportation, contributes to business process optimization, supply chain traceability and transparency, and significant financial savings. However it can be noticed that there are limitations as blockchain is at a relatively early stage of development with most projects.

[13] Consider that IIoT platform comprises four fundamental capabilities: connectivity, big data, advanced analytics and application development. IIoT has the potential to provide a high level of synergies between the 4 Ms of manufacturing, namely, man, machine, material and method. Practical implications: It is in the interest of service providers to collaborate and provide a universal solution to retain legacy systems to minimize the investment and reduce the security threat, which could boost IIoT adoption while ensuring that manufacturers are able to leverage this new technology efficiently.

In [14] it is affirmed that IoT, big data, data analytics and cloud computing, are changing the production into the next generation of industry. To address these challenges intelligent manufacturing in combination with data analytics plays an important role. In this sense, the integration of prescriptive analytics in manufacturing may help industry to increase productiveness. This paper highlights requirements for a prescriptive analytics based production control, so called prescriptive automation, and finally points out field of activities in this topic.

Finally, in this section, [15] refer to big data analytics as driver for effective manufacturing intelligence for yield management in semiconductor manufacturing that is one of the most complex manufacturing processes, as the authors observes, due to tightly constrained production processes, reentrant process flows, sophisticated equipment, volatile demands, and complicated product mix. Indeed, the increasing adoption of multimode sensors, intelligent equipment, and robotics have enabled the IoT and big data analytics for semiconductor manufacturing.

The study develop a framework based on Bayesian inference and Gibbs sampling to investigate the intricate semiconductor manufacturing data for fault detection to empower intelligent manufacturing. The proposed approach was validated through an empirical study and simulation. The results have shown the practical viability of the proposed approach.

3. Objective and Methodology of bibliometric research

Having collected enough evidence about the links of IIoT or IoT and data analytics in the productive environment, it is aimed to have a deeper understanding of the state of the art of the subject under study, and find some clues about opportunities and difficulties that arise from the use of IIoT or IoT, Artificial Intelligence and Machine Learning in the industrial environment to improve industrial processes.

Another observation that is object of this work is what [4] says about studies that have shown that digitization of products and services has become a necessity for a sound industrial ecosystem. However, these requirements and advanced technologies have made the systems more complex and led to many other challenges such as cybersecurity, reliability, integrity, etc. These are the major bottlenecks which needs to be overcome for the successful design and deployment of Industry 4.0.

Then the next step in the research is to develop a bibliometric analysis. [3] Highlights the bibliometric discipline, which is being facilitated by the easy access to articles compiled and indexed in enormous databases, making possible to have data about research facts, like number of authors, keywords, topic, citations, and institutional collaboration, among others.

This paper aims to take in consideration the issues in the above paragraphs, in the framework of the adoption of AI/ML in the industrial environment to add value to the data gathered by IIoT or IoT solutions.

The bibliometric analysis task began with the definition of the search criteria. In this case, these are the keywords, artificial intelligence, process optimization, industry 4.0, IIoT and the alternatives machine learning, IoT, industrie 4.0, smart manufacturing, and smart factory. Below is described the methodology used.

With the keywords were established, the Scopus database was searched. Scopus was selected considering that is one of the broadest scientific data base. On the other hand, to select the keywords within the search, the terms mentioned above were taken into account. The keywords included in the title, abstract and / or full text were combined using the Boolean operators "AND" and "OR".

The query string used for the search was the following:

ALL ("Artificial Intelligence" OR "Machine Learning" AND "process optimization" AND "industry 4.0" OR "Smart Manufacturing" OR "smart factory " OR "industrie 4.0" AND "IIoT" OR "IoT")

Once the results were obtained, an analysis of main authors, evolution of the number of publications on the subject, key words, and main countries of origin of the publications was carried out. Then the data found was exported in a CSV file, to analyze the results in detail. The export was carried out in two formats, the first with the information related to the complete bibliographic data, and then another file that contains only the keywords and the abstracts of the papers found.

Subsequently, the analysis was completed by incorporating the CSV file from SCOPUS database into the VOSviewer® 1.6.11 software tool to visualize the concentration of the most relevant authors and the clustering of keywords most relevant with the concepts of interest for this article. VOSviewer® is the most widely used information visualization software to select the topmost keywords used by the authors in their papers [4].

3.1 Limitations of the selected methodology

The authors are aware that the proposed bibliometric study poses some weaknesses and limitations.

The first one that can be considered is regarding the scientific repository used in the bibliometric research. Although Scopus indexed data base is one of the broadest scientific data base [17]; it does not cover all papers in the topic. The work can be continued and extended on other scientific databases like Web of Science (WoS), IEEE Xplore, among others.

The second issue to consider as limitation is the language considered in the query, just English-written papers were considered.

Finally the query string itself is a limitation, although it is proposed as broad as possible to try to give it the greatest reach, surely other combinations of keywords and logical structure could appear.

4. Bibliometric Analysis results

The search using the methodology described in the previous section was performed on 23rd June 2021, and yielded 101 results. The first parameter to be studied is the evolution of the number of documents per year, which, as shown in Figure 1, has been growing since 2013 when the first article appeared around the issue being analyzed. This indicator shows that the subject is a very novel one with much potential of scholarly research, and growing interest. Something to note is that it is assumed that the decline shown for the current year is a consequence of the fact that it has not yet ended.

Other parameter that was observed is that more than 50 % of the papers came from 3 countries, China with 23 articles, then United States with 17, and third Germany contributing with 13 publications, then India contributes with 7 works, below many countries of all continents generated less than 7 articles each. Regarding the production on the studied subject in Latin America, Brazil offers 3 papers, then Colombia with 2, and finally Mexico has 1 publication. This information can be seen with more detail in figure 2.
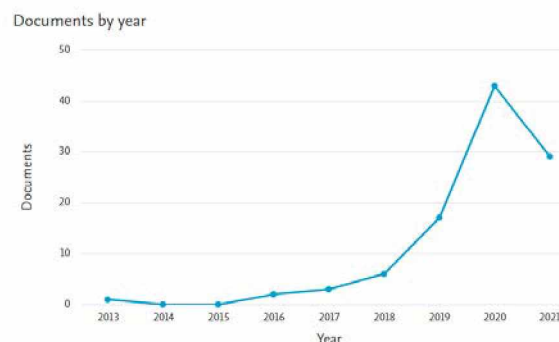

Figure. 1. Evolution in the number of publications about AI/ML and IIoT/IoT as process optimization in the Industry 4.0 model. Source: Scopus data base.
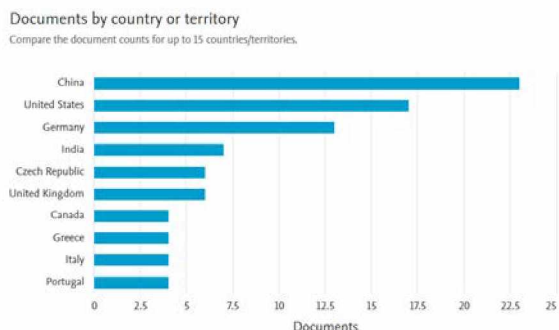

Figure. 2. Contribution in the number of publications about AI/ML and IIoT/IoT as process optimization in the Industry 4.0 model by country of origin. Source: Scopus data base.

The second item that was observed from the search at Scopus was the most prolific authors in the studied subject. Then to analyze the researchers with more papers and citations, in the subject of interest for this paper the tool VOSviewer® is going to be used. By this way it was possible to see the concentration of authors in a more graphical way. A full counting methodology was used. Below in figure 3, it is shown the concentration of authors, based on the number of publications and citations, and grouped in 5 clusters by the strength in the link among each name.

The analysis was done considering the most prolific and cited authors, then 13 authors are shown. Each of them has 2 articles. Then the most cited is Wang, X. with 23 citations, then with 21 citations appear How, B.S., Lam, H.L., Leong, W.D., and Teng, S.Y., all of them grouped in a cluster. Finally the third most cited author is Chen, Y, who is alone in one of the clusters.

By analyzing the clusters, it is possible to see the one with Wang, X., and Wang, Y. These researchers are two of the four authors of the first publication on the subject that is being analyzed in this bibliometric study [16]. This paper explores the benefits of deploying a smart grid in an industrial environment, to make the factory optimize the use of energy under a smart factory paradigm by an IIoT architecture.
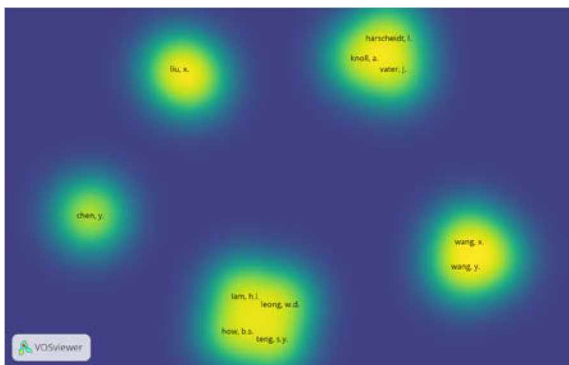

Figure 3. Concentration of relevant authors on Process Optimization, AI/ML and IIoT/IoT under Industry 4.0 framework at SCOPUS, generated with VOSviewer.

Regarding the areas of origin of the papers it can be observed that the areas of engineering, and computer science are the most populated with 24% and 22,5 % of the publications, respectively. In third place comes business, management and accounting with 9,3% and then rest with less percentage.

To complete the bibliometric analysis it can be observed that the type of papers reviewed are mostly articles, 58,3%, then conference papers, 21,4%, review, 19,4%, and finally editorial with 1%.

4.1 Topmost keywords in the studied field at Scopus

The keywords were analyzed with the clustering generated by the VOSviewer® 1.6.11 software tool, from the CSV file from Scopus database. The results are shown in figure 3, which allows to count the words which appear in the title, abstract and keywords to build all the relations which appear between different documents published in SCOPUS [5].

Fig. 4 represents the cloud map with relevant words of the articles. This map shows how many times the words appear in the articles and how related are between them using full counting method. It must be noted that in this case the words shown appeared more than 10 times.

The cloud shows four clusters of words coloured in yellow, green, blue and red. The first one is related to supply chain management, the yellow one. The green one is related to the data framework and the opportunities that this opens. The blue one, is related to OT (Operational Technologies) networks, the industrial framework of IoT, in this cluster of words appears the term efficiency. The fourth group coloured in red is related to data and simulation, with terms like IoT, cyber physical systems, simulation, big data and manufacturing.

At first sight, it could be observed that the term IIoT is not present into the relevant key words, but it appears the key word industrial Internet.

The yellow cluster is related to the number of articles related to the digital solutions about the supply chain processes optimization, the word Supply Chain is the most relevant one, with 21 occurrences. The red group of words, is the most populated with the word IoT in the middle of the graph, showing that this is a key element to integrate the issues studied in this work. The fact that the word IoT is in the middle of the graph.
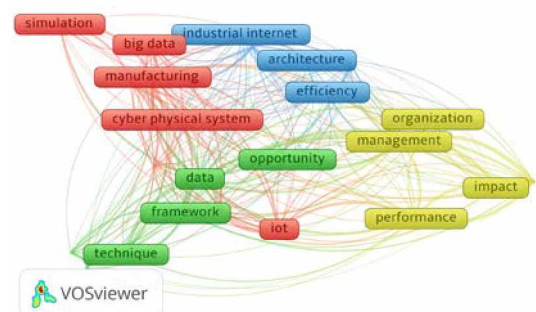

Figure 4. Cloud map of words in titles and abstracts (full counting), generated with VOSviewer. Source: Scopus Database.

A last observation to consider is that the cloud map of words includes terms that appeared more than fifteen times in the title and abstract, then some important concepts like digital twin, integration and system, are not shown in the figure 4.

4.2 Results Analysis

A big doubt seems to appear regarding the knowledge of the concept and value that AI/ML can add in the shop floor for the process operator. In this line, the work [13] gives some light about the knowledge of the subject considering the manufacturing 4Ms and the potential synergy that the featured solution can provide.

An interesting finding from this work, is that terms approached by this work regarding IA/ML, IoT/IIoT and industrial processes optimization had a positive result in the bibliometric analysis at Scopus database, as it can be seen in the word cloud at figure 4, where key concepts like efficiency, manufacturing, industrial internet, big data, data, and performance are among the most relevant words of the papers considered.

From the work [12] and the analysis of the topmost keywords in the studied field at Scopus it can be concluded that the process optimization is not only in the plant shop floor, but along the supply chain as well. Then the impact of the adoption of IoT/IIoT and AI/ML in the industrial environment impact in the whole organization and alter traditional management practices.

The works [15] [7] seem to confirm the benefits of applying IIoT, IoT and Analytics in complex production environments like the semiconductor industry.

A last point to raise is in line with [9], regarding integration between IT and OT and the adoption of analytics models, the results shown in the bibliometric analysis is some way in line with the assumptions of the work cited in section 2 of this paper. It can be seen in the cloud of words shown in figure 4, where IoT is in the center of the graph with high interaction with other items.

5. Potential research lines

This work has been a good exercise to analyze the complexity that means involving IA/ML and IIoT or IoT in industrial processes to optimize them. It seems that a systemic approach is needed, this work left the idea that seems to be lack of works related to the role of people in the adoption of the solutions approached in this work.

For future work it should be researched about the implications for people in the process and IIoT or IoT for the success of AI/ML as process optimization driver under Industry 4.0 paradigm.

Some other issues to continue looking into the IIoT, IoT and AI/ML framework in industrial processes at first sight are concepts like cybersecurity, complexity of deployment, and return on investment (ROI).

The articles [10] and [11] give light to the issue in the SME sector, these works left some ideas to continue studying the issue more thoroughly to

stablish methodologies and tools that could ease the adoption of IIoT or IoT and analytics models in this kind of firms.

Finally, to continue with this work can be studied more precisely the implications to the whole productive organization, and needs of management changes or alterations that produce the adoption of IIoT, IoT, and AI/ML thorough the supply chain under the Industry 4.0 paradigm.

6. Conclusions

The first thing to mention as a conclusion is the vast amount of information and the potential the subject has in the future. On the other hand, it can see that the concept has a long road to walk to mature and adapt to capture the attention of the industrial world massively. It can be observed that more than 50% of the papers that were highlighted in the section 2, this means 6 out of 9 articles, were published in 2020.

From the origin of the papers, it can be observed the leadership in the subject that China, USA, and Germany with more than 50% of the works considered. Despite the limitation on the language, explained in section 3.1, Latin America is far behind in production about the studied issue.

The analysis from the bibliometric study gives a better understanding of the state of the art of IIoT or IoT, Artificial Intelligence and Machine Learning in the industrial environment to improve industrial processes. The optimization occurs not only at the production site, but along the whole value chain.

Regarding the hypothesis about complexity and challenges such as cybersecurity, reliability, integrity, among others, the bibliometric study gave few clues. On the other hand it must be highlighted the integration on IT and OT, traditionally dissociated, that IIoT/IoT provides.

Finally it must be observed that although the studied subject is quite novel in the manufacturing environment, there is a number of interesting adoption cases in different kind of industries including the SMEs sector.

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