Operator 4.0 in manufacturing: trends, potential technologies and future perspectives

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Abstract. While Industry 4.0 is characterized by greater automation, manual assembly systems continue to play an important role. A search was conducted in INSPEC and Compendex databases to uncover trends in research focused on human/worker in an Industry 4.0 context. In total 1469 relevant bibliographic references where obtained. The bibliographic dataset was analyzed using VOSviewer to create a map of terms. Results from this dataset show a significant change in the rate of scientific production in 2019 (23% Vs. 200%+). Three major communities of terms where identified and mean term occurrence calculated: technological infrastructure (148.7), worker performance (94.4), adoption and integration (72.8). Augmented reality and human-robot collaboration were the most studied technologies associated with workers in an Industry 4.0 context.

Keywords: database search, network map, Industry 4.0, worker, technology

1. Introduction

Despite the increasing level of automation that has characterized manufacturing during the last decades, manual assembly systems still play an important role, particularly in some domains: automotive, domestic appliances, internal combustion engine and aerospace manufacturing, among others (Swift and Booker 2013). The level of automation continues to increase with the introduction of several digital technologies within Industry 4.0. In this new context, manufacturing will be characterized by a high degree of individualization of products which in turn will increase the number of variants while reducing batch size (mass customization). According to *Thoben et. al* (2017) this highly customized mass production will have an impact on the complexity of production (Falck et al. 2016) and the level of complexity of manual assembly is expected to increase (Mattsson et al. 2018; Kong 2019). Several technologies are promising to support humans in the execution of their tasks without substituting them completely. According to *Romero et al.* (2016) this support can be provided to assist workers in both the physical and cognitive aspects of work. Some examples of these technologies are collaborative robots, augmented reality, exoskeletons, and biometric tracking systems, among others. All of this has resulted in the introduction of the concept of Operator 4.0 (Romero et al. 2016; Mattsson et al. 2018; Peruzzini et al. 2018; Romero et al. 2018). Operator 4.0 is ''*understood as a smart and skilled operator who performs not only cooperative work with robots but also work aided by machines as and if needed by means of human cyber-physical systems (…)*''. Almost ten years after the introduction of the concept of Industry 4.0, it seems appropriate to carry out a preliminary assessment of how the subject of worker/human, in an Industry 4.0 context, has been dealt with in the scientific literature. More precisely, what is the main focuses of attention, their relative importance and some trends in the evolution of the body of knowledge.

2. Methods

2.1 Database search process

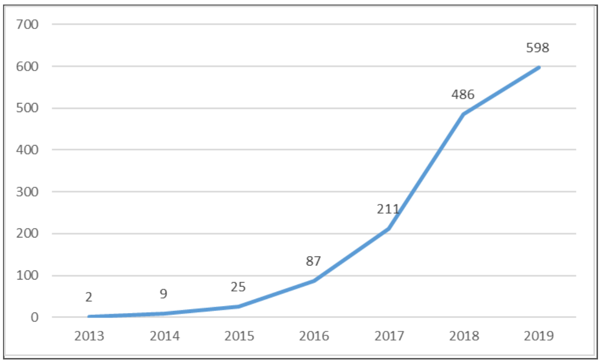
Searches were conducted in two databases in the field of engineering and technology. These databases were Compendex and INSPEC, searched through Engineering Village. Keywords sets were used to identify studies that were 1) associated to worker/operator in the context of Industry 4.0 and were 2) associated to manual assembly in manufacturing. The search was conducted for the last ten years which coincides, approximately, with the beginning of the use of the term Industry 4.0. We included journal and conference papers written in English (Elsevier 2015). The search was conducted using keywords: worker, operator, manual assembly, manufacturing and Industry 4.0. Booleans operators AND/OR were used as needed.

2.2 Analysis Process

Using advanced tools in Engineering Village search engine trends in research production by year and by country was uncovered. In a second step, an analysis of relevant bibliographic references found in the database search was performed using VOSviewer. This software tool can be used for constructing and visualizing networks of scientific publications, scientific journals, researchers, or terms, among others. A network of terms was constructed from the dataset of bibliographic references. This allows to group terms in clusters also referred as a community or a family of terms (Jan and Waltman 2019). Each term in the map is represented with a frequency of occurrence, a number of links (connection between two terms) and a total link strength of the term. We used for the analysis the Occurrence (O) of the term and the total link Strength (S). This allows to identify the most influencing terms in each cluster and the relative importance of each community of terms by calculating mean values.

3. Results

From the first database search a total of 1469 relevant bibliographic references were obtained. Figure 1 shows the frequency of records by year while Figure 2 shows the frequency of records by country. The bibliographic reference dataset was introduced in VOSviewer to analyze links and occurrence of terms as well as the presence of clusters. Results from VOSviewer shows that the relevant terms provided by the bibliographic references could be grouped in three main clusters. Clusters are identified in Figure 3 by different colors: cluster 1 (red), cluster 2 (green) and cluster 3 (blue).



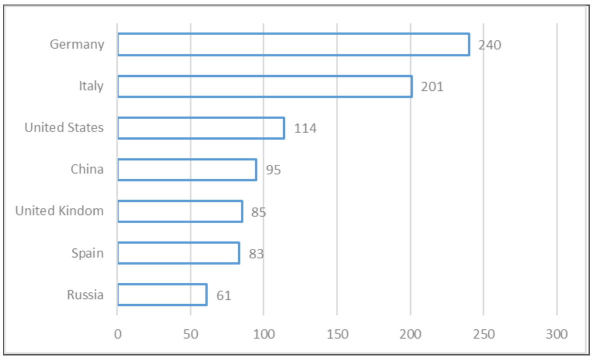


Figure 1 and 2. *Number of bibliographic records by year and country as provided by Engineering Village search advanced tool.*

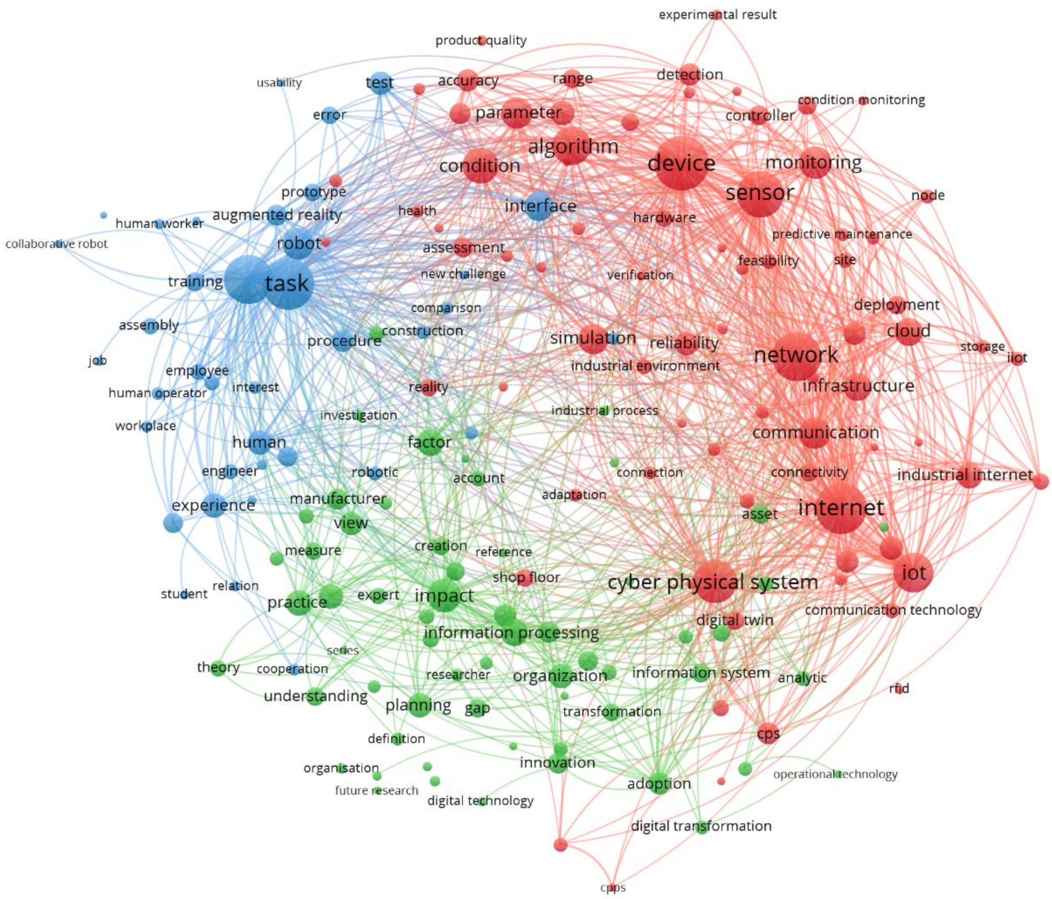


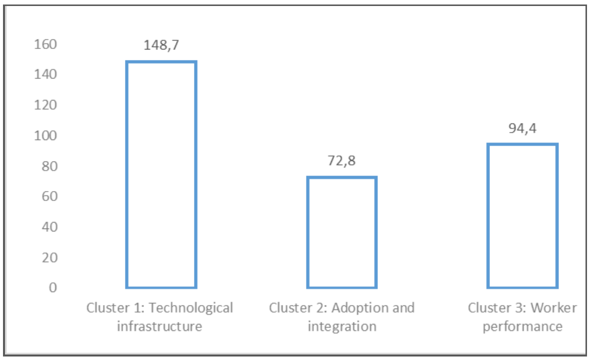
Figure 3. *Network visualization of terms contained in the 1469 bibliographic reference from Engineering Village and processed using VosViewer.*

In Table 1 the ten most important terms in each cluster are presented considering variables Occurrence and total link Strength. For each term these variables are presented as: (Occurrence; total link Strength) and they are listed in descending order by Occurrence.

Table 1. *The ten most important terms in each of the three identified cluster*

Cluster 1: Technological infrastructure	Cluster 2: Adoption and integration	Cluster 3: Worker performance
Device (206; 1364)	Impact (112; 734)	Task (193; 1280)
Internet (191; 1460)	Factor (81; 530)	Worker (181; 1175)
Network (179; 1246)	Information Processing (79; 486)	Robot (100; 622)
Sensor (168; 1177)	Practice (75; 475)	Interface (91; 675)
Cyber Physical System (150; 1080)	Planning (73, 437)	Human (71; 527)
IoT (135; 1042)	Organization (71; 448)	Experience (70; 424)
Algorithm (129; 752)	Engineering (64: 415)	Test (67; 409)
Condition (121; 753)	Adoption (63; 517)	Procedure (64; 446)
Monitoring (106; 739)	Innovation (60; 391)	Augmented Reality (57; 417)
Communication (102; 748)	Transformation (47; 341)	Training (50; 371)

In Figure 4 and 5 the relative importance of each cluster is shown. The first graph corresponds to the calculation of mean values for terms Occurrence and total link Strength.



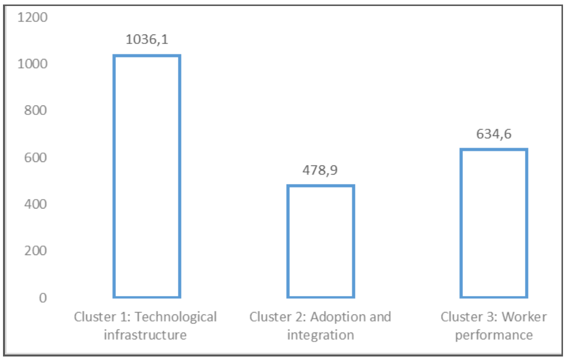


Figure 4 and 5. *Mean values of terms Occurrence and mean values of total links Strength (left and right respectively). Analysis is done by cluster to compare relative importance.*

4. Discussion

Results from de database search shows an exponential increasing in the number of publications in relation to human/worker in the Industry 4.0 context. The number of publications matching selected keywords was 2 in 2013, 87 in 2019 and 598 in 2019. Interestingly, *Fatisson et al.* (2013) found a similar pattern in the number of publications when searching about factors associated with nanoparticles after ten years of research in the field: 5 in 2001, 246 in 2006 and 1516 in 2011. In both cases these were emerging fields of research and could show the focus on novelty. In the case discussed in this paper, the concept of Industry 4.0 was introduced in 2011 as an initiative of the German government (European Commission 2017; GTAI 2018). From the explored 1469 reference dataset, the increase rate of publication has been of more than 200%

annually since 2013 but this changes in 2019 when this rate was about 23% in comparison with the previous years (598 Vs.486). It seems difficult to establish what exactly seems to be the cause or causes associated with this abrupt change. As research starts to focus on the deployment of these technologies, maybe more confidential issues arise which could limit open publication. The implementation of these technologies to support humans in manufacturing is considered a major competitive advantage as mentioned by *Nadeau and Landau* (2018) in their review of digital technologies in manufacturing. Another possible origin could be a stabilization of academic production, where researchers and institutions have defined their position in this new subject area. Geopolitical context and countries strategies could contribute to this apparent slowdown. Without any surprise, Germany is a research leader in this sector with 240 references published, while Italy shows a significant 201 references (only 16% less than Germany). United States and China are following in the list with 114 (52% less) and 95 (60% less) references respectively. These results are not surprising as, according to the World Bank, these countries are four of the seven countries that add the most value to their economies through the manufacturing sector (The World Bank 2019).

The analysis of terms using VOSviewer shows the presence of three major community of terms (clusters). The first major community of terms identified is related to the technological infrastructure within Industry 4.0 and is associated with the development of networks, devices, sensors and algorithm, among others, as part of the Internet of Things (IoT) and Cyber Physical Systems (CPS). The second community of terms identified relates to the adoption and integration of these new technologies and covers the factors and impacts of these technologies in the organization including innovation and deployment in practice. The third cluster is more human centric and focused on the performance of workers considering tasks, procedures and training but also human experience and interfaces. In terms of importance, technological infrastructure is still the main research focus with term Occurrence of 148.7 followed by worker performance (94.4), adoption and integration (72.8). *Romero et al.* (2016) make reference to eight possible technologies for the conceptualization of Operator 4.0 (exoskeletons, wearable trackers, virtual reality, augmented reality, intelligent assistants and collaborative robots, among others). At the same time *Nadeau and Landau* (2018) also describe, from documented results, an important number of digital technologies deployed or in deployment in manufacturing. According to our recent results two technologies stand out as research interests: augmented reality and human-robot collaborations. It is important to notice that our results focused on manual assembly and human/worker in manufacturing context.

5. Conclusions

According to our results, most of the research done related to human and manual assembly systems in an Industry 4.0 is focused on technological platforms and infrastructures. Two specific technologies related to human performance attract an increased amount of research attention: augmented reality and human-robot collaborations. Literature also shows less studies related to the adoption and integration of these new technologies in real environments. As these technologies become more mature one could expect the trend to change although confidentiality could limit the dissemination of these studies. A similar analysis in the future could clarify these elements.

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