International Journal of Production Management and Engineering

Special Issue: Advances in Engineering Networks
https://doi.org/10.4995/ijpme.2019.10789
Received: 2018-10-09 Accepted: 2019-01-24

Patentometric: monitoring the scientific and technological trends of Additive Manufacturing in Medical Applications

Alvarez-Meaza, I.[a1*], **Zarrabeitia-Bilbao, E.**[a2], **Rio-Belver, R.M.**[b1], **Martinez de Alegria, I.**[a3], **and Bildosola, I.**[a4]

[a]University of the Basque Country, Industrial Organization and Management Engineering Department. Faculty of Engineering in Bilbao. Spain.

[b]University of the Basque Country, Industrial Organization and Management Engineering Department. Faculty of Engineering in Vitoria -Gasteiz. Spain

[a1] *izaskun.alvarez@ehu.eus,* [a2] *enara.zarrabeitia@ehu.eus,* [a3] *itziar.martinezdealegria@ehu.eus,* [a4] *inaki.bildosola@ehu.eus*
[b1] *rosamaria.rio@ehu.eus*

Abstract: Patents are a means of protecting inventions developed by firms, institutions or individuals, and they may be interpreted as indicators of invention. Patents indicators convey information on the processes of inventive activities. Therefore, patent statistics will assess science and technology (S&T) activities. Besides, additive manufacturing (AM) has become a revolutionary technology that is changing medical science. For this reason, the patent statistics will allow us to monitor what is the state of the inventive activity of AM in medical applications. The database used in order to retrieve patent information is Patseer and the data have been analyzed through the analytics package called Quick Stats. From the data obtained, it can be concluded that, additive manufacturing in medical applications is an emerging technology with huge market potential. Undoubtedly, the core of invention is located in United States, followed by Germany, United Kingdom and China somewhat behind. Firms are the main holders of legal rights, and the firm's market value and the knowledge diffusion of technology are ensured by the technological diversity and the number of forward citations presented by patents.

Key words: Additive Manufacturing, Medical Applications, Patents, IPC, Forward citations.

1. Introduction

Additive Manufacturing (AM) is defined as "the process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies" (ASTM, 2015). This approach has revolutionised the manufacturing process, because it offers the possibility of manufacturing parts of any geometric complexity without using additional tools or machines (Atzeni & Salmi, 2012; Galati & Iuliano, 2018; Gibson *et al.,* 2010; Hopkinson & Dickens, 2006). Synonyms found in the literature include additive processes, additive techniques, additive fabrication, rapid manufacturing, three-dimensional (3D) printing, rapid prototyping, layer manufacturing, additive layer manufacturing, direct digital manufacturing, freeform fabrication and so on (Jin *et al.,* 2017; Mellor, *et al.,* 2014).

Therefore, it is not surprising that the main advantages of additive manufacturing that Jin *et al.* (2017) have synthesized from previous research works are: parts can be made easily on-demand for

To cite this article: Alvarez-Meaza, I., Zarrabeitia-Bilbao, E., Rio-Belver, R.M., Martinez de Alegria, I., and Bildosola, I. (2019). Patentometric: monitoring the scientific and technological trends of Additive Manufacturing in Medical Applications. *International Journal of Production Management and Engineering,* 7(Special Issue), 65-72. https://doi.org/10.4995/ijpme.2019.10789

customization and personalization, fast and free manufacturing can be realized with no time limits in 3-dimensional structure, the cost of manufacturing can be reduced significantly and AM enables the environmental friendly product design. Therefore, additive manufacturing has become a revolutionary technology that has managed to change both the production management systems and the research strategies in developing countries.

Applications for AM are found in many fields including aerospace, architecture, medical devices or healthcare, consumer products, automotive, jewellery and defence applications (Mellor *et al.,* 2014; Petrovic *et al.,* 2011). If we highlight the applications in health sector, AM enables the production or the creation of prostheses, pre-surgery planning tools, alignment jigs and surgical cutting templates. However, it is particularly necessary to emphasize the importance of 3D bioprinting technology that can be used in organ production and also creating live tissues that retain biological functions (Rodriguez-Salvador *et al.,* 2017).

Taking into account the importance of AM in human health, the study of scientific production regarding to this technology becomes critical. Rodriguez *et al.* (Rodriguez-Salvador *et al.,* 2017) described that the number of this studies are still lacking. In addition, the study of patents in a specific technology such as laser additive manufacturing made by Zarrabeitia (Zarrabeitia *et al.,* 2017) concluded that the International Patent Classification (IPC) of patents with the highest number of patents is the A61, medical applications.

In order to determine general trends of AM technology following a qualitative process, the study of patents is a very appropriate method. The patent statistics have been used to define the path of the science assessing scientific and technology activities for a long time. Patents provide a uniquely detailed source of information of inventive activity (OECD, 2009). Therefore, this research work focuses on analyzing patents statistics of Additive Manufacturing Technologies, which are classified as Medical Science.

2. Objective

The main objective of this research work is to achieve an overall perspective of the technological trends of additive manufacturing technologies applied in medical applications such as, prostheses and orthopaedic devices, among others. Specifically, a worldwide patent study has carried out, in order to analyse the invention performance, the technological fields and the patent value.

3. Methods

The process to accomplish the main objective of the work starts in the planning stage, which stablished the identification of information sources, such as patent database sources. The database used in the study has been *PatSeer*, which is a complete online global patent database and research platform containing the world's most comprehensive full-text Patent collection (Sinha & Pandurangi, 2016). After that, the specific queries for database are defined to collect information (see Table 1). The definition of the appropriate query is very important due to the fact that the additive manufacturing technologies collect many synonyms terms and the medical applications cover a very large area of action that must be shortened. Thus, the query of AM were tested by collecting information from a technical report about AM done by experts (GridLogics, 2014), and the medical applications has been focused through the International Patent Classification (IPC), that constitutes a first reference for identifying patent in a specific technical domain (OECD, 2009).

IPC provides us the classification of patents and utility models according to the different areas of technology to which they pertain. Thus, the interest of the research work has defined A61F2 IPC, related to Filters implantable into blood vessels; Prostheses, i.e. artificial substitutes or replacements for parts of the body; Appliances for connecting them with the body; Devices providing patency to, or preventing collapsing of, tubular structures of the body.

The patents have been studied by families, because patent families are a way of working out patent indicators that are comparable across countries. A patent family comprises all patents protecting the same invention (OECD, 2009). The data have been analyzed through the analytics package of *PatSeer* called Quick Stats. Besides, in order to identified what the main knowledge areas about additive manufacturing technologies applied in medical applications are, a clusterization analysis has been carried out using *VOSviewe*r software.

Table 1. Main information of patent search.

Information	Data
Query	TAC:((3D OR 3 D OR 3-D OR 3-DIMENSION* OR 3 DIMENSION* OR (three* w2 dimension) OR desktop* OR additive) wd2 (print* OR fabricat* OR manufactur*)) AND (ICGR:(A61F2*) OR IC:(A61F2*) OR CPC:(A61F2*)) AND NOT (TACD:(stereoscopic* OR oxidation product* OR streaming interactive OR nanoweb OR nano web OR nanofiber* OR nanofibre* OR nano fiber* OR nano fibre* OR nanometer fiber* OR nanometer fibre* OR nanometre fiber* OR nanometre fibre* OR non halogen OR non-halogen OR media access control OR multi-wafer 3D CAM cell OR ((foof* OR feed* OR liquid*)w2 additive*) OR seed culture OR antibacteria* OR 3-sigma OR three sigma OR rheolog* additive* OR vibration isolator*))
Database	Patseer
Timespan	From 1994 to 2017
Type	Single Family of Patents
Date of the search	February 23, 2018
Results	767

4. Results

4.1. Monitoring inventive performance of the patents

In order to reflect inventive performance, the earliest priority date of the patents is analysed because it can be considered the closest to the invention date. In the Figure 1, it is shown that the 2015 year is the most productive in inventions related to AM in medical services.

It is useful the inventor's country of residence to compile patent statistics aimed at reflecting inventive activity. It allow us analysing the market allocation strategy of companies. The main country is United State of America with 197 number of records, followed by Germany (37), United Kingdom (26) and China (26) somewhat behind (See Figure 2).

The holder of the legal rights and obligations on a patent application is the applicant; in the United States, that it is called the assignee. It can be an individual, a company, a university, a hospital or a government entity. Regarding AM technologies in medical applications, the holders with the most number of records are companies from Europe, China and USA, followed by universities from China (See Figure 3).

4.2. The identification of technological fields

The information provided by the International Patent Classification (IPC) constitutes a first reference for

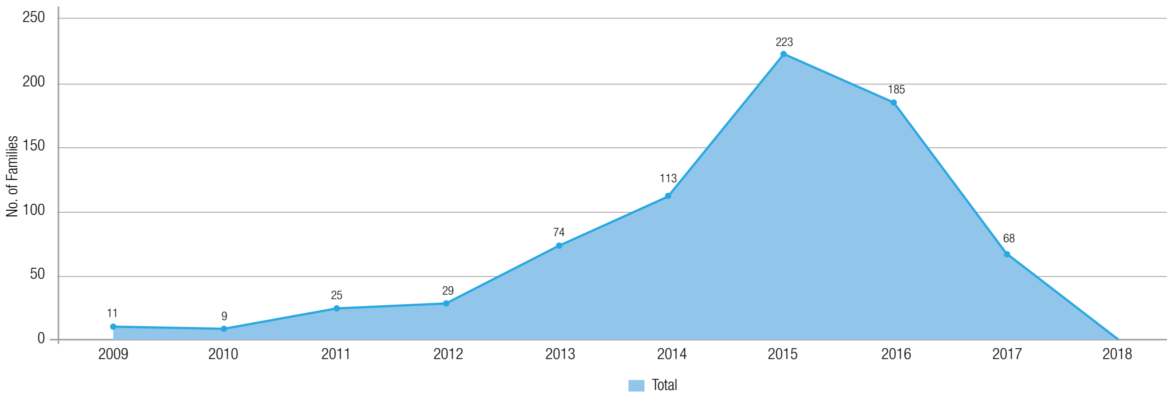

Figure 1. Earliest priority date.

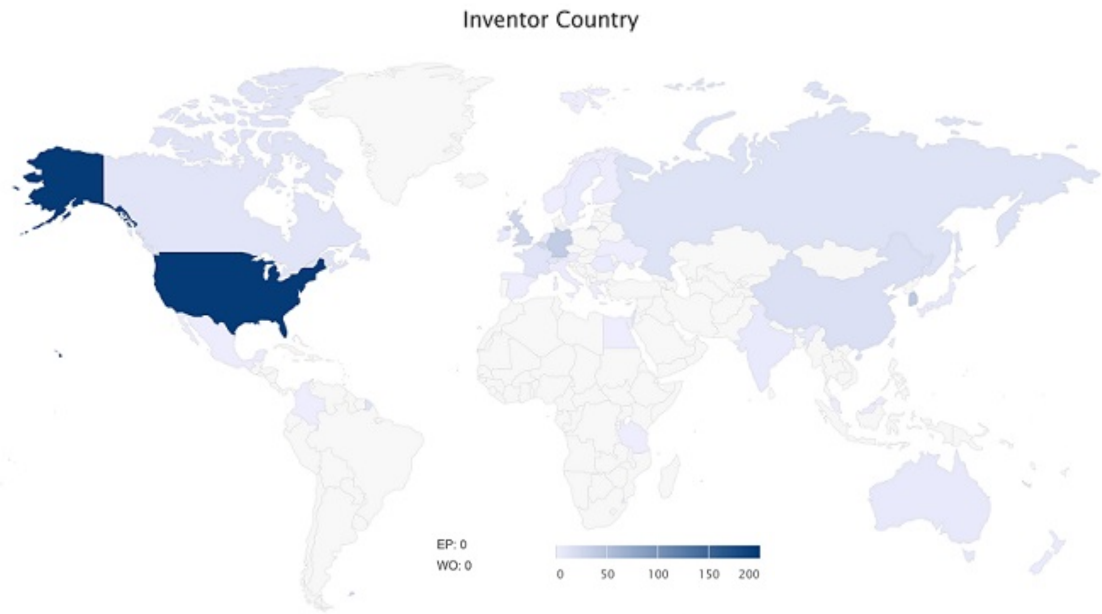

Figure 2. Investor's country.

identifying patents in a specific technical domain (OECD, 2009). The main result of the analysis is related to the core IPC that the research study takes in account, A61F. But it is an interesting results that other technological fields are also linked to the additive manufacturing technology patents based on medical applications, such as, B33 additive manufacturing, B29 working of plastics, G06 computing (image data processing and electric digital data processing) and G05 control of regulating systems in general, among others (see Figure 4). The number of technical classes attributed to a patent application has been used as an indicator for the scope, and hence for the value of the patent (OECD, 2009). Lerner (Lerner, 1994) finds a positive correlation between the firm's market value and the average scope of its patents.

4.3. The Patent Value

In this research, the patent value is analysed by forwards citations of the patent, the patent family size and the number of inventor in a patent.

The prior art of the invention cited in a patent documents provides useful information about the diffusion of technologies. The forward citation as indicator of a patent value show the technological importance of the invention and the impact on further developments (OECD, 2009). The analysis of the data shows that most have about eight number of forward citations, but two of them have an important difference with the rest. Specifically,

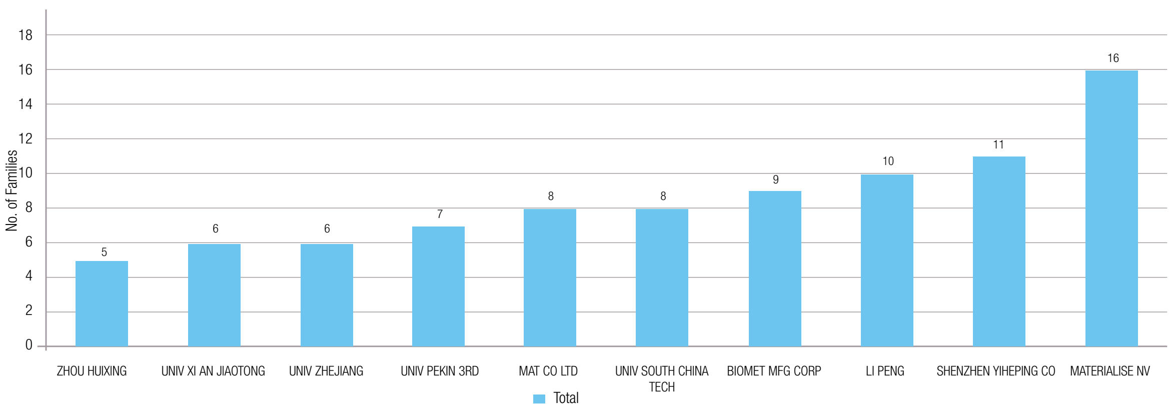

Figure 3. Current Assignee.

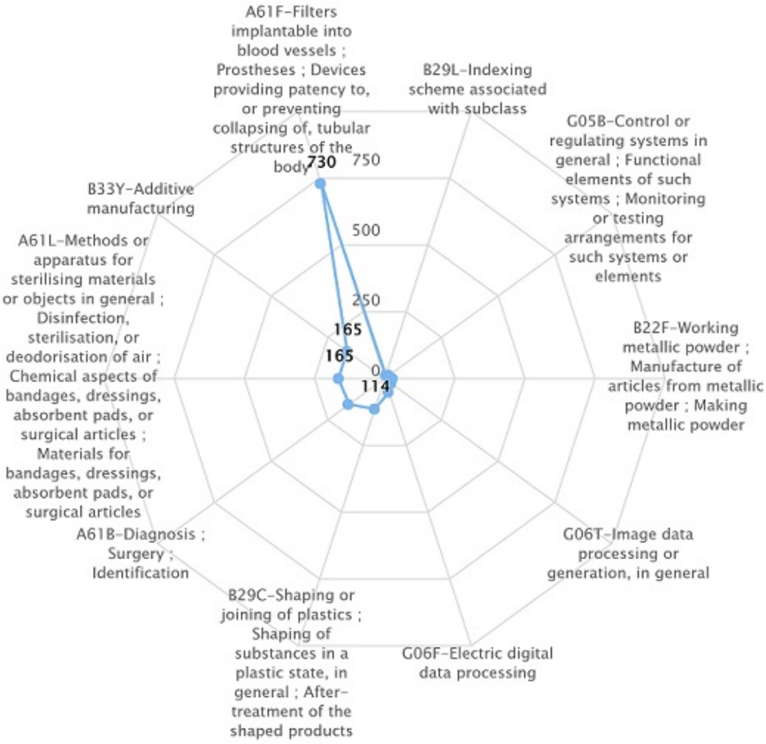

Figure 4. International Patent Classification (IPC).

the US2010291401A1 with 40 citations and the US2014107628A1 with 34 citations (see Figure 5).

The value of patens is also associated with the geographical scope of patent protection; that is, with the patent family size it can approximate the cost to have protection in different jurisdictions and the sign of market potential of an invention (OECD, 2009). The biggest family have 30 members (see Figure 6) the patent AU2010284197B9, followed by 22 and 18. But, in general, the number of members is in the range of 6 to 12.

The number of inventors may proxy the cost of the research behind the invention (OECD, 2009). In general, the average number of inventors is around 10, but the patent RU2612528C1 with 18 inventors stands out (see Figure 7).

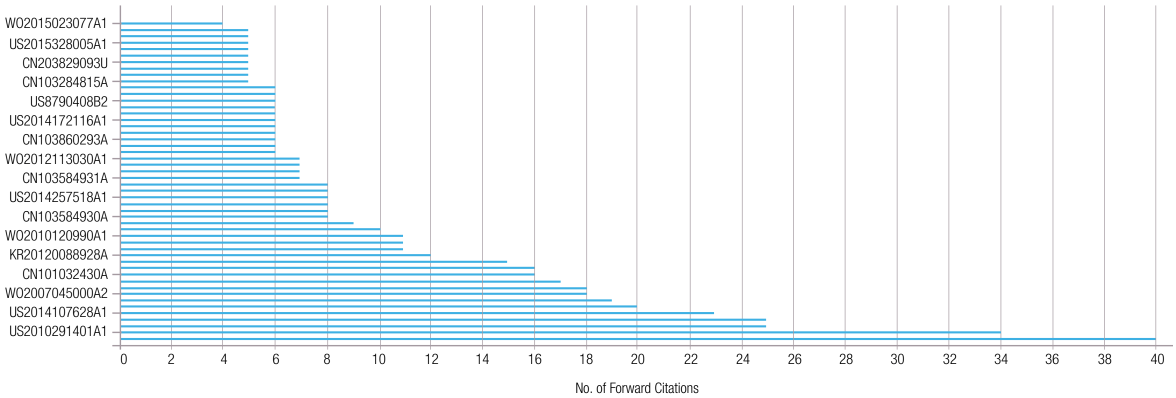

Figure 5. Most cited records.

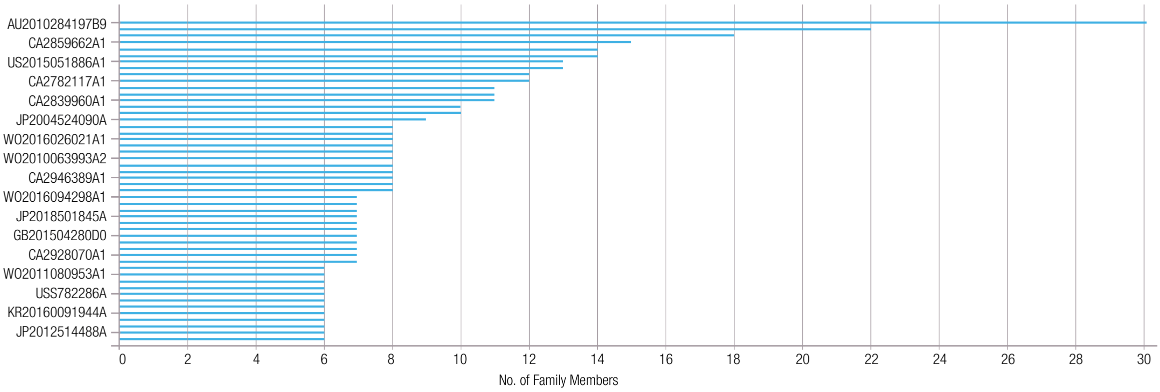

Figure 6. Largest Families.

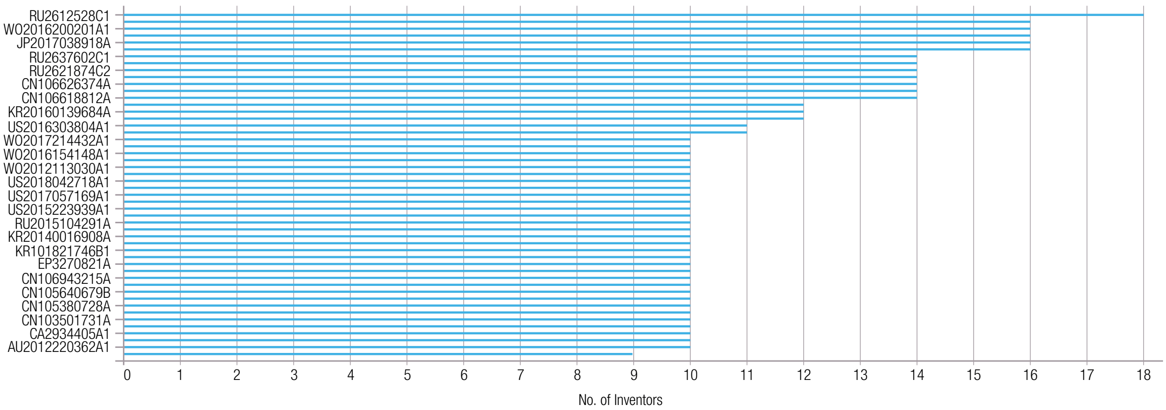

Figure 7. Max. No. of Inventors.

4.4. Visualization networks

The global research activity in additive manufacturing technologies applied in medical applications is identified through knowledge areas that have been determined depending on the occurrence of keywords. This clusterization is carried out when the terms have a high co-occurrence, and the created clusters represent a singular concept related to additive manufacturing technologies applied in medical applications.

Relating to patents, the clusters were created by extracting keywords from the title. The co-occurring network of additive manufacturing technologies applied in medical applications of the 100 most cited keywords of patents generated by VOSviewer is represented in Figure 8. The intellectual landscape shows that “Method”, “System”, “Manufacture”, “Implant” and “Same” are the top keywords.

Clustering terms allows us to know the affinity between the keywords, and thus to know which are the thematic fields of the different terms. For example, “Manufacture” is related to “AM process”, “prosthetic ear”, “bone implant” and “implantable medical device”.

In this process 27 clusters have been created, most of them small, and a total of 238 links, with the term “Method” having a total of 65 links associated with it. It is therefore a very common term in patents relating to additive manufacturing.

5. Conclusions

Additive manufacturing in medical applications are relatively recent technological developments that are in full growth. The enterprises are the main holders of the legal rights and the core invention activity is located in USA, which is way ahead of Germany, UK and China. Many patents cover different technological fields what strengthens the firm’s market value. The number of forward citations are clearly there to justify the diffusion of

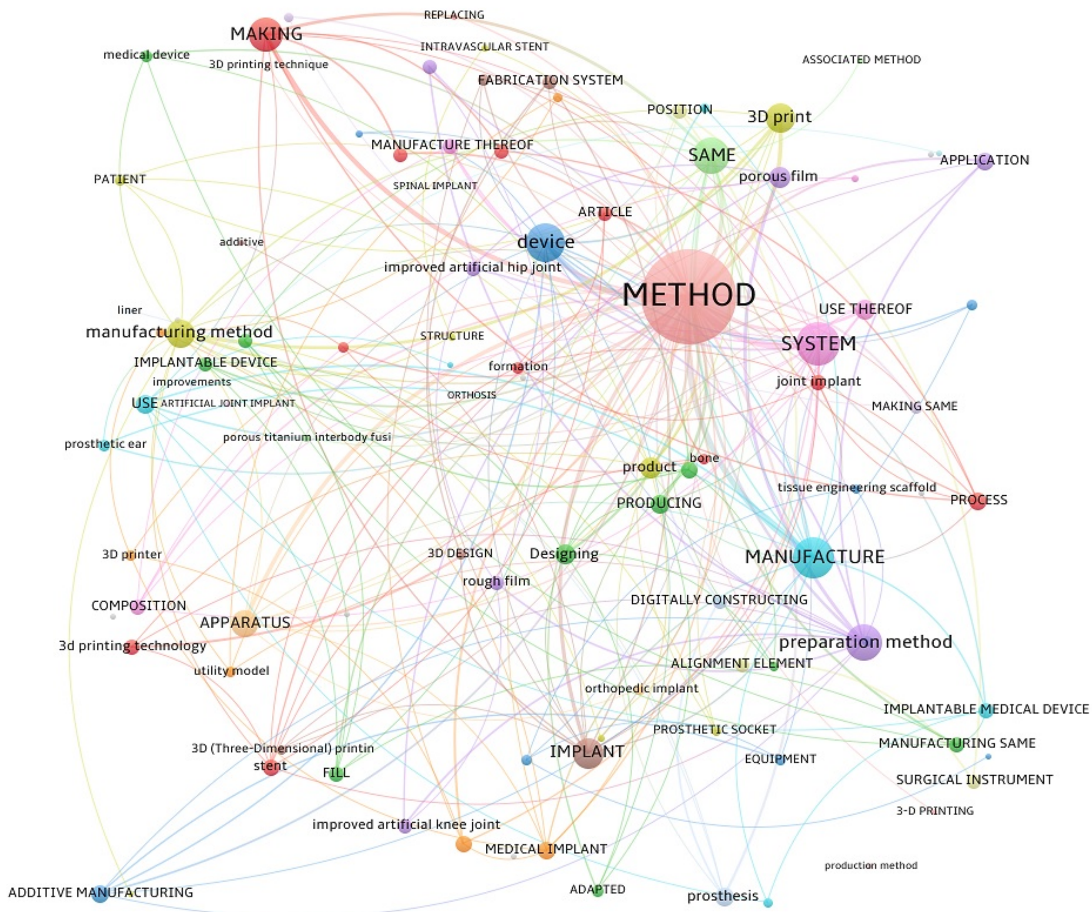

Figure 8. The visualization map of the co-occurring keywords of patents.

these technologies. In regards to the cost to have protection in different jurisdictions and the cost of the invention, it can be concluded that most of the patents, except for a couple of them, usually follow a very similar trend. So, the cost is not a differentiating milestone.

The keywords extracted from the title have allowed us to know which is the field of knowledge that the patents are working. The clustering process of the 100 most used keywords results in "Method", "System" and "Manufacture" being the most frequent terms and with the highest number of links to other terms.

Finally, future works related with this study could take other topics of investigation, such as, the analysis of knowledge diffusion and the dynamics of technical change, the economic value of the inventions and the role of university in technological development, among others.

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