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Application of a Bibliometric Tool for Studying Space Technology Trends

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ABSTRACT: The statistical analysis of academic literature, also known as "bibliometrics", is being increasingly applied to analyse research trends, to identify emerging areas of science and to find out where and how often specific articles are cited. The aim of this study was to identify technological innovation trend patterns in the aerospace sector applying bibliometric analysis over the period 2008 – 2015. In this study the keywords space technology, satellite, space launch vehicle, spacecraft, rocket and space station were used to scrutinize the database Web of Science (ISI). The obtained records were analysed using the Patent Insight Pro software (2015). It was observed that the researches related to aerospace technological development has been focused in satellites, giving also some directions for satellite launch vehicles. Bibliometric analysis revealed concern on new low-cost technologies development, and the applied logistic fit suggests that over the next five years the continuity on new space technologies development will be mostly related to small satellites, with also contributions associated with high-resolution imagery in order to improve Earth observation in low orbit.

KEYWORDS: Aerospace, Logistic curve, Technological monitoring, Unstructured data.

INTRODUCTION

In recent decades, the production of knowledge and technological innovation have been dictated by the countries' development policies, making innovation the vehicle of transformation and enrichment of knowledge, thus contributing to improve the quality of society's life (MCTI 2014).

The development of technological monitoring, as a technological forecasting tool, trying to anticipate future events, has become of great value to the consolidation of the knowledge-based economy.

One of the existing technological monitoring challenges is the search for patterns and explanations for unstructured behaviours. The use of tools developed by bibliometrics for measure and interpret the scientific and technological advances, depending on the examined sources, allows the monitoring methodology to produce useful information about the research, development and innovation activities (Watts and Porter 1997).

Bibliometrics is the statistical analysis of bibliographic data including books, articles or other publications, measuring the scientific activity in a subject category, journal, country or other area of interest (Thomson Reuters 2008). Additionally, it helps researchers to understand the developments in a field within the scope of the worldwide research community.

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Bibliometric analysis was developed through the elaboration of empirical laws on literature behavior, as Lotka's Law in 1926, known as the productivity law for authors in the realm of scientific papers, Bradford's Law in 1934, used for expressing the article productivity of journals, and Zipf's Law in 1949, used for investigating the frequency of the occurrences of words in a text.

In consonance with Mueller (1994), bibliometrics has aimed to analyse and to map authorship and co-authorship, collaboration and network; evaluation and description of literature, impact and indicators; production and productivity; visibility of authors and institutions; and citation and co-citation studies, allowing trends identification and the knowledge growth in an area, as well as predicting productivity and identifying the influence of individual authors, organizations or countries; measuring the emergence of new topics and the analysis of citation and co-citation processes (Giusti *et al.* 2011).

The research progress and the technological development has been investigated by many authors through the bibliometrics (Porter 2005, 2007; Losiewicz *et al.* 2000; Martino 1993). Some studies address the inter-relationships between research topics (Porter 2005; Small 2006), identification of important researchers or research groups (Kostoff 2001; Losiewicz *et al.* 2000), the study of research performance by country (De Miranda Santo *et al.* 2006; Kim 2007), the study of collaboration patterns (Anuradha and Urs 2007; Chiu and Ho 2007; Braun *et al.* 2000) and the forecast of future trends and developments (Smalheiser 2001; Daim *et al.* 2005, 2006; Small 2006).

Technological forecasting may be performed using a single bibliometric method (Gonzalez-Albo *et al.* 2010) or by the combination of methods, according to Kajikawa and Takeda (2009) in a study using citation network analysis.

Therefore, one can perceive that the bibliometric techniques for studying technological development consists in a well-established tool, and conforming to Godin and Gingras (2000), it is very useful for evaluating the role of universities in the knowledge production system; these authors point out that universities have become more important due to their increasing collaboration with the private sector.

Bibliometrics is used to analyse research trends, allowing identify emerging areas of science, finding out where and how often specific articles are cited. It investigates academic information through the use of different indicators (publications, cited references, occurrences of words, phrases, citations, co-citations, authorship) and related characteristics that may extract hidden patterns from many data structures (Daim *et al.* 2005).

Thus, the goal of this study was to identify technological innovation trend patterns in the aerospace sector, using bibliometric analysis of the scientific production over the period 2008 – 2015. It was also aimed to contribute for the technological monitoring literature of the space sector, using a structured approach in the data analysis in order to identify the innovation trend patterns.

METHODOLOGY

The basic goal of this study was to investigate patterns and trends relevant for textual information in the Space Technology area, seeking to measure the level of research activities and interest in such area. Figure 1 illustrates the procedures used in this study.

From Fig. 1, it is possible to see that in this study the keywords space technology, satellite, space launch vehicle, spacecraft, rocket and space station (chosen from the sector natural language) were submitted to the Web of Science database, using the available search operators. The criterion for searching the terms in Web of Science was to select records in which the terms were present in the titles, abstracts or keywords. This database was chosen due to its multidisciplinary nature and coverage in addition to its recurrent use, internationally. Science Technology and Social Sciences areas were selected, using meetings, articles, reviews and editorials documents for the years 2008 – 2015, totalizing 625 records. In the evaluation of the recent trend on the number of scientific publications related to space technologies, it was observed an expressive number of publications from 2008. Thus, it was chosen to analyse all the records obtained from the Web of Science database between 2008 and 2015. The records were analysed using the Patent Insight Pro software (2015), since such software allows to analyse both the patent and the scientific production data. The cleaning tool was used, aiming to eliminate records with incorrect names and duplicates. Furthermore, the dashboard tool was used to find main clusters related to Space Technology, which in this study was named as research fronts, as well as the main keywords related to the theme.

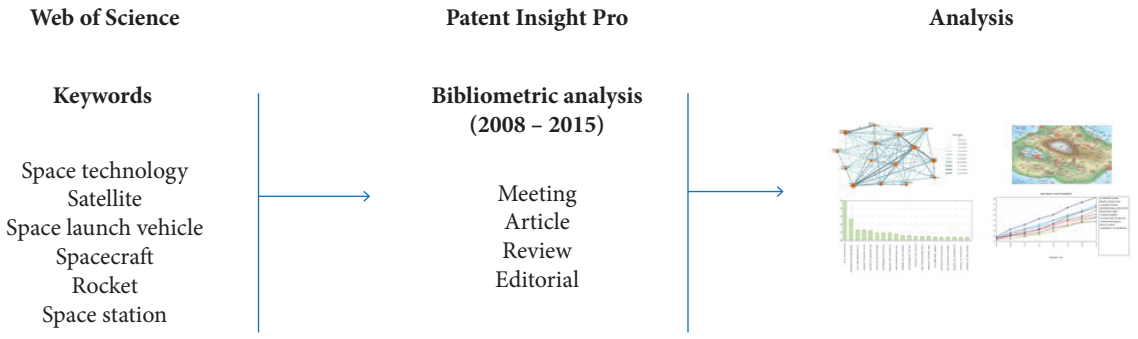

Figure 1. Employed framework.

A *research front* is a group of highly cited papers, referred to as core papers, in a specialized topic defined by a cluster analysis. A measure of association between highly cited papers is used to build the clusters. That measure is the number of times pairs of papers have been co-cited, that is, the number of later papers that have cited both of them. Clusters are created by selecting all papers that can be linked together by a specified co-citation threshold. *Research fronts* can reveal emerging areas of science through citation patterns.

RESULTS AND DISCUSSION

By employing the Patent Insight Pro software it was possible to identify 15 main research fronts: Rocket and Space Technology, Science and Technology, Earth Observation, Space Agency, Small Satellites, Low Earth Orbit, Remote Sensing, Simulation Results, Ground Station, University of Technology, International Space, Computer System, Space Launch Vehicle, Low Cost and High Resolution, and 15 main keywords: Low Earth Orbit, Satellite Communication, Satellite Data, Sounding Rocket, Satellite Mission, Satellite Operators, Satellite Remote, Satellite Technology, Development Process, Solar Panel, Wide Range, Station ISS, Technology Demonstration, Technology RST and Key Technology.

Figures 2 and 3 show the association map for the main *research fronts* and for *keywords*, respectively. The lines in the association maps, Figs. 2 and 3, represent shared records between the linked nodes; the colour and thickness of the lines are relative to each other and to nodes which have maximum shared records, connected via a thicker and darker line; the red number next to each line represents the number of shared records, and the highly associated items are automatically placed closer to each other.

In Fig. 2 it is possible to observe that the *research fronts* highly cited in the literature were Rocket and Space Technology, Space Launch Vehicle, Science and Technology, Earth Observation, Small Satellites, Low Earth Orbit, Remote Sensing, with strong association between them. It is also possible to infer a possible formation of a cluster of *research fronts* comprehending Science and Technology, Earth Observation, Small Satellites, Low Earth Orbit, and Remote Sensing. The same was observed for Rocket and Space Technology, and Space Launch Vehicle.

It is worth to mention that the *research fronts* Simulation Results, Ground Station, University of Technology, International Space, Computer System, Space Agency, High Resolution and Low Cost were also significantly representative.

From Fig. 3 we can conclude that the *keywords* Low Earth Orbit, Station ISS and Technology Demonstration are strongly associated. Such strong association is also observed between Satellite Data and Satellite Remote. However, it was observed two other moderate associations. The first association is formed among Low Earth Orbit, Satellite Mission and Satellite Communication, and the second association among Satellite Data, Wide Range and Satellite Technology. This scenario suggests that the researches related to technological development have been focused in satellites, also giving some directions for satellite launch vehicles.

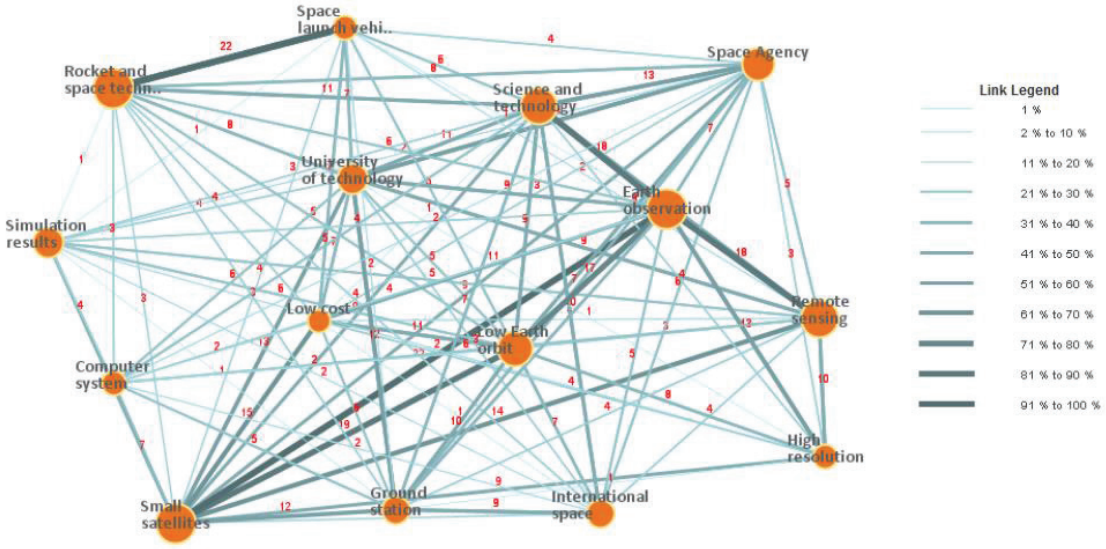

Figure 2. Association map for *research fronts*.

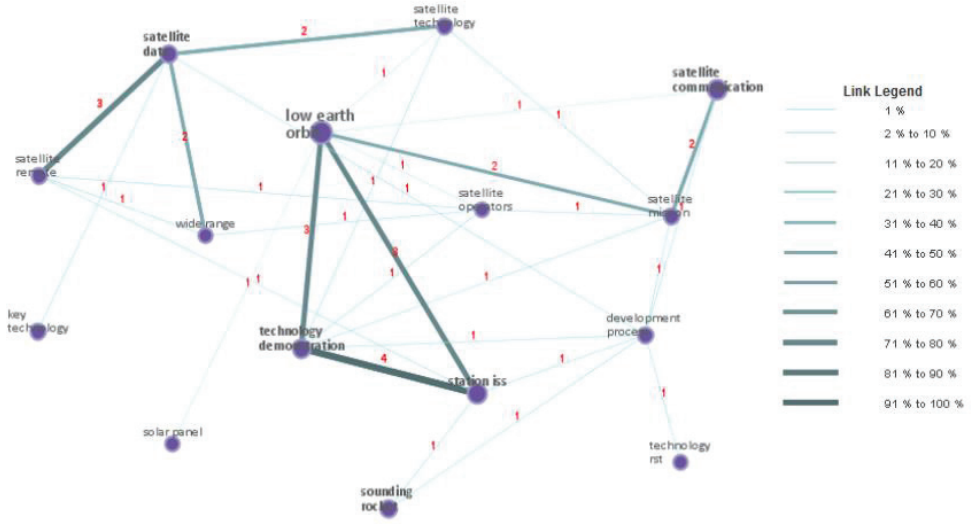

Figure 3. Association map for *keywords*.

However, other *research fronts* as Low Cost have demonstrated significant growth, suggesting that low-cost is a trend on implementation and operation of science and technology, under those previously practiced, such as developing "smart structures", which combine composite panels, piezoelectric materials, and next generation sensors, potentially improving the cost and development time for more accurate future sensor platforms (Rockberger and Abramovich 2014), or building a low-cost long-wave infrared spectral sensor (Crites *et al.* 2012). Furthermore, it was verified the important role of the Technology Universities in different countries (Dudas *et al.* 2014; Cilliers, 2013; Nisantzi *et al.* 2013; Okninski *et al.* 2015) on the development of space technologies, for example, the Warsaw University of Technology with the Amelia Small Rocket Program, aiming to develop rockets that are fully recoverable and reusable, thereby reducing operational costs (Okninski *et al.* 2015).

Table 1 shows the number of publications related to Space Technology from 2008 to 2015, standing out publications related to Low Earth Orbit, Earth Observation, and Small Satellites. It is possible to observe a significant growth on the number of publications related to Space Technology from 2012 to 2014, and a decrease in 2015.

Table 1. Number of publications between 2008 and 2015, related to Low Earth Orbit (LEO), Earth Observation (EO) and Small Satellites (SSAT).

Year of Publication	Number of Publications	LEO	EO	SSAT
2008	64	14	9	10
2009	80	11	14	13
2010	70	4	9	10
2011	55	7	11	10
2012	86	15	8	21
2013	100	21	13	16
2014	100	16	10	13
2015	70	15	10	10

Concerning the *research fronts*, Low Earth Orbit and Small Satellites showed accentuated increase in the number of publications in 2012, in opposition to Earth Observation, which evidenced some reduction in the number of publications. Probably, the researches related to technological development have been concentrated on small satellites, designated to Low Earth Orbit.

Figure 4 shows the top 20 journals publishing papers related to Space Technology, with *Acta Astronautica* followed by *Cosmonautics and Rocket Engineering* standing out as the most used journals for publications in this area.

Based on the strong association observed among the *research fronts* Earth Observation (EO), Low Earth Orbit (LEO) and Small Satellites (SSAT), as shown in Fig. 2, logistic curves were used for fitting the cumulated number of publications as a function of time (years), aiming to identify the stabilization trend for each *research front.* The logistical fits were created using the Microsoft Excel software. The results are exhibited in Fig. 5 and, as can be observed, the number of publications related to LEO will still continue to grow until at least 2022, while publications related to EO and SSAT are reaching the ceiling, probably saturating around 2020.

Such results suggest some potential for growth of new space technologies related to small satellites within the next five years, resulting in significant contributions for high-resolution and improvement on obtaining images and data from Earth surface (remote sensing) in low orbit.

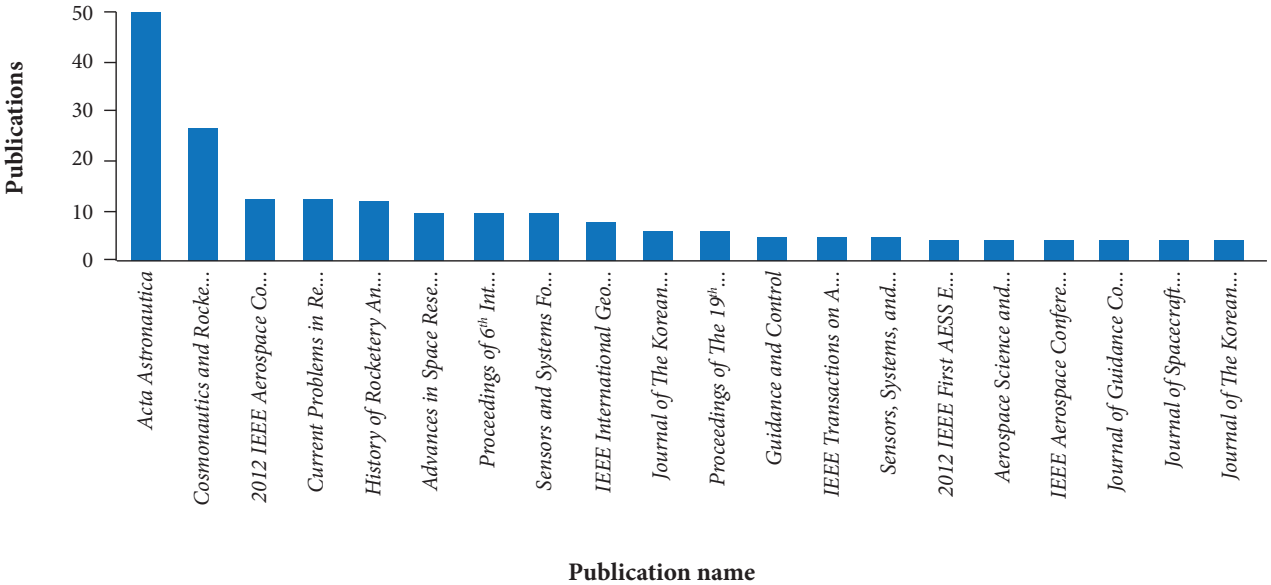

Figure 4. Top 20 journals used for publication of papers related to Space Technology.

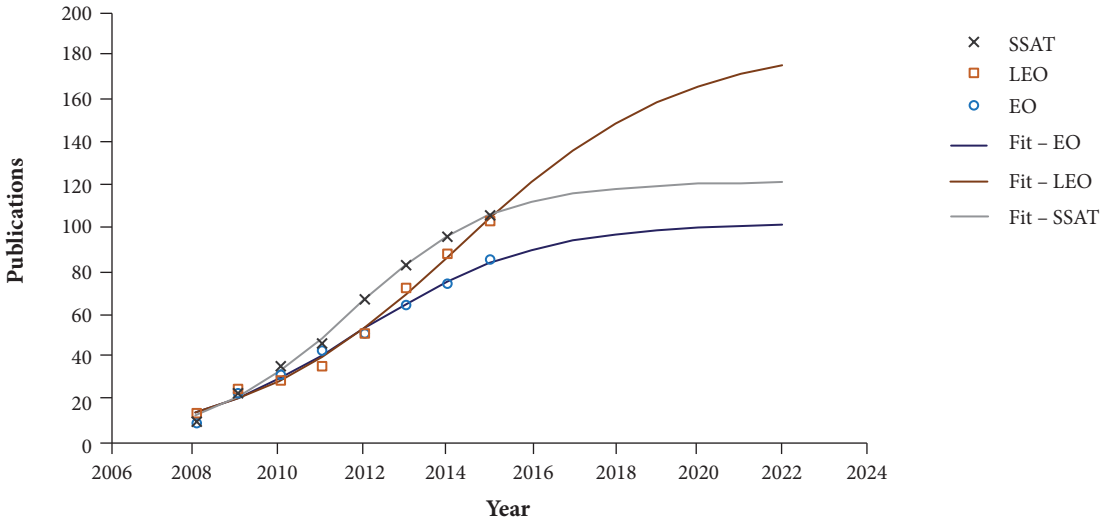

Figure 5. Accumulated number of publications and logistical fits for *research fronts* Earth Observation (EO), Low Earth Orbit (LEO) and Small Satellites (SSAT).

CONCLUSIONS

This study shows that bibliometric analysis is an appropriate tool for predicting trends in space technologies, allowing to identify the mostly used *keywords* and *research fronts* in scientific publications, contributing then for the technological monitoring of the space sector.

The present bibliometric study indicates a great interest on the development and utilization of small satellites in space applications, including remote sensing constellations and technology demonstrations, probably as a result of the improved functionality through the miniaturization of technology and alternative philosophies of conception, reducing costs and development time, and increasing space accessibility for scientific purposes, enabling new forms of space exploration.

Actually, despite the technological advances, the space remains a costly enterprise, which still needs to be further developed aiming to ensure its low-cost access. The results in this paper allow some optimism regarding the possibility of reaching such goal in the near future, with the continuing development of new space technologies related to low-cost access to space and small satellites within the next five years, with contributions associated with high-resolution imagery, improving Earth observation in low orbit.

AUTHOR'S CONTRIBUTION

Conceptualization, Pelicioni LC; Ribeiro JR and Devezas T; Methodology: Pelicioni LC; Ribeiro JR and Devezas T; Investigation, Pelicioni LC; Ribeiro JR; Devezas T; Belderrain MCN and Melo FCL; Writing – Original Draft, Pelicioni LC; Ribeiro JR; Devezas T; Belderrain MCN and Melo FCL; Writing – Review & Editing, Pelicioni LC; Funding Acquisition, Belderrain MCN; Resources, Belderrain MCN; Supervision, Devezas T

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