Bibliometric analysis of scientific production on aerospace technology Terrain Following Radar (1966-2024)

https://doi.org/10.56238/levv15n39-098

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ABSTRACT

Objective: To carry out a bibliometric study of the scientific production on the aerospace technology Terrain Following Radar, in the Web of Science database, from 1966 to 2024, using the RStudio® and VOSviewer® software.

Theoretical framework: It is based on the literature on the evolution of aerospace technologies, with emphasis on Terrain Following Radar and its context in the military sphere.

Method: This research is classified as descriptive and quantitative. Data were collected from the Web of Science database, accessed through the Portal de Periódicos da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, covering the period from 1966 to 2024. For data analysis, the RStudio® and VOSviewer® software were used, as well as the bibliometric packages Bibliometrix and Biblioshiny.

Results and conclusion: A total of 433 documents were identified, with the largest scientific productions on the subject coming from the United States, China, Italy, Germany and France. The year with the most publications was 2021, followed by 2022 and 2023. The most cited sources are IEEE Transactions on Geoscience and Remote Sensing, followed by Remote Sensing. The main keyword co-occurrences include SAR (Synthetic Aperture Radar), remote sensing, radar, InSAR (Interferometric Synthetic Aperture Radar), and interferometry. Regarding co-The authors. between countries, the United States, China and Germany stand out. The most relevant authors on the subject are Liu Y., Li Y. and Li Z. In terms of co-citation between authors, Lee J. S., Ferretti A. and Head J. W. The most cited studies globally in the last ten years are by Xue M. (2000), De Zan F. (2006) and Zhang Z. (2017). It is concluded that this study aims to enhance the knowledge base about the Terrain Following Radar aerospace technology and related fields of study.

Research implications: The main limitation of this research is its restriction to the Web of Science database, where most of the documents were articles. Thus, it would be interesting to adopt a broader approach, which includes other databases, such as Scopus or Google Scholar, in addition to considering different types of publications, such as books and conference proceedings.

Originality/value: This study aims to improve knowledge about aerospace technology Terrain Following Radar and the related fields of study.

Keywords: Terrain Following Radar, Bibliometric Analysis, RStudio®, VOSviewer®.

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INTRODUCTION

Military aerospace technologies are constantly evolving, driven by advancements in a variety of areas that aim to increase the effectiveness, safety, and responsiveness of armed forces. Additive manufacturing technology is transforming the aerospace industry by enabling the production of complex parts with less material waste and reduced costs, and is widely used by companies such as Boeing and Airbus to manufacture metallic and non-metallic components (Najmon, Raeisi, and Tovar, 2019).

In this context, *Terrain Following Radar* (TFR) is a technology used in military applications, mainly improving the operational capabilities and survivability of aircraft in hostile environments. TFR systems allow aircraft to maintain low-altitude flight paths, which are essential for avoiding detection by enemy radar and reducing the risk of being targeted by surface-to-air missiles (Kim *et al.*, 2015).

The ability to fly close to the ground while avoiding obstacles is facilitated by advanced angular super-resolution techniques, which improve the angular accuracy of radar systems, ensuring accurate navigation and obstacle avoidance (Jiang *et al.*, 2015). In addition, TFR systems are integrated with other technologies, such as ground collision avoidance systems (GCAS) and digital terrain databases, which provide real-time terrain mapping and enhance pilot situational awareness (Kim *et al.*, 2015).

The use of Synthetic Aperture Radar (SAR) in TFR systems further enhances their capabilities by providing high-resolution terrain imagery, even in harsh conditions such as fog, smoke, or night, where traditional optical systems fail. This is particularly important for missions that require stealth and precision. In addition, the integration of radar detection range calculations that consider terrain protection ensures that radar effectiveness is not compromised by natural obstacles, thus providing a more accurate detection range (Kaniewski *et al.*, 2015).

The development of modular radar scattering models that consider terrain topography and vegetation further increases the accuracy of radar systems in complex environments (Burgin *et al.*, 2014; 2016). The use of artificial neural networks for terrain classification also plays a significant role in assessing terrain passability, which is crucial for mission planning and execution (Pokonieczny, 2018). Overall, TFR systems are indispensable in modern military operations, offering advantages in terms of stealth, navigation accuracy, and situational awareness, significantly increasing mission success rates and aircraft survivability (Qiuyan *et al.*, 2018; Noh *et al.*, 2021; Jiang *et al.*, 2022).

Considering these reflections, the research question that guided the elaboration of this study was: Why is it necessary to identify research on the Terrain *Following Radar* aerospace technology? To answer this question, this work aims to carry out a bibliometric study of the scientific production related to the aerospace technology in question, using the *Web of Science database*, in the period from 1966 (first publication on the subject) to 2024, through the *RStudio®* and *VOSviewer® software*.

From this perspective, conducting a bibliometric study on the Terrain *Following Radar* aerospace technology is essential to understand the evolution and impact of this technology over time. Such analysis allows the identification of research trends, key scientific contributions, and knowledge gaps, providing a solid basis for future studies and innovations. In addition, by mapping the development and application of this technology from 1966 to 2024, it is possible to assess its relevance and influence in the aerospace field, helping researchers and professionals to direct their efforts more effectively and strategically.

Therefore, it is essential to analyze the scientific production on the subject to identify the main trends and advances in the area. The use of computational tools such as *RStudio®* and *VOSviewer®* makes the analysis more accurate and automated, making it easier to identify patterns and trends in scientific production. In this way, the study contributes to the understanding of the research already carried out on the Terrain *Following Radar aerospace technology* and to the improvement of new research.

The article is organized into sections that sequentially cover this introduction, a brief contextualization of the *Terrain Following Radar technology* and its evolution, the materials and methods adopted in the study, the analysis and discussion of the data, and, finally, the final considerations, where the limitations and suggestions for future research are presented.

THEORETICAL FRAMEWORK

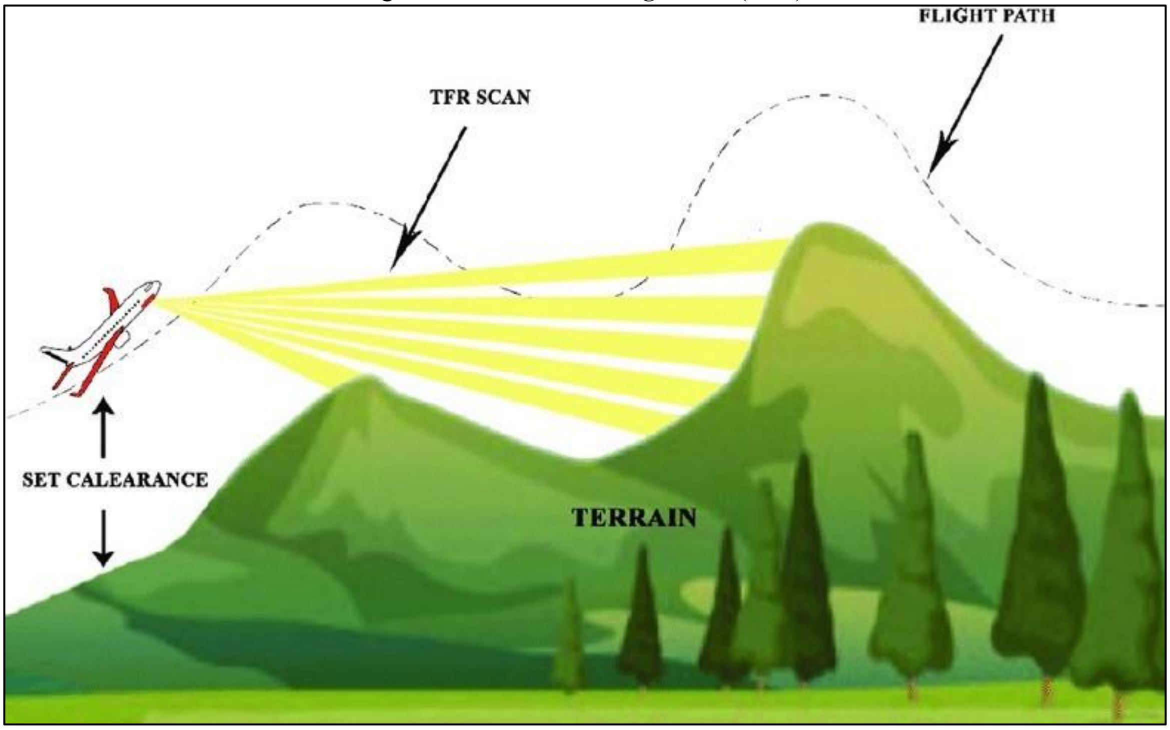
Next, a brief contextualization of the main advances and applications of *Terrain Following Radar* (TFR) is presented, highlighting its importance in the context of military aviation and the technological evolution that has sustained its development. Initially, the fundamental aspects of the TFR, its origin and the operational benefits provided are discussed. Then, the evolution of the TFR is presented, highlighting technological innovations and the integration of new capabilities that improve its functionality and accuracy. In this way, it seeks to offer an insight into the functionalities of the TFR in military operations and its future perspectives.

TERRAIN FOLLOWING RADAR

The development of Terrain *Following Radar* (TFR) has been instrumental in enhancing the operational capabilities of military aircraft, particularly in low-altitude flight missions. The TFR concept began to gain traction in the 1960s, with its application in advanced fighter and bomber aircraft, such as the B-1, F-111, F-16 E/F, and F-15, significantly improving its ability to fly safely close to the ground, avoiding detection by enemy radar systems (Burgin *et al.*, 2016).

TFR systems use radar technology to help pilots maintain close proximity to the ground while avoiding obstacles (see Figure 1), which is crucial for avoiding detection and improving survivability in hostile environments (Noh *et al.*, 2021). The integration of digital databases and advanced radar altimeters has further refined these systems, allowing for accurate terrain mapping and obstacle avoidance (Kim *et al.*, 2015).

Figure 1. *Terrain Following Radar* (TFR).



Source: Nalusamy A. Balaji (2019).

Modern advancements include the use of millimeter-wave radar modules, which offer high accuracy and environmental suitability, making them cost-effective and efficient for unmanned aerial vehicles (UAVs) in plant protection and other applications (Pundir and Garg, 2020).

In addition, the development of angular super-resolution techniques has improved the angular accuracy of TFR, addressing the limitations imposed by antenna beam width and enhancing obstacle detection capabilities (Faris and Sasongko, 2018).

The application of TFR goes beyond manned aircraft to UAVs, where real-time terrain data is used to generate safe flight paths, ensuring moderate maneuvers and effective terrain tracking (Qiuyan *et al.*, 2018).

The importance of terrain analysis in military operations is underscored by its impact on vehicle mobility and strategic planning, with terrain trafficability assessments being crucial for *off-road operations* (Kim *et al.*, 2015). In addition, the role of terrain in military engagements, particularly in guerrilla warfare, highlights the need for accurate terrain assessment to exploit defensive advantages (Jiang *et al.*, 2015).

Overall, the evolution of TFR technology has been instrumental in the advancement of military aviation, providing essential capabilities for both manned and unmanned systems in various operational environments

EVOLUTION OF THE TFR

According to Choi *et al.* (2023), Terrain *Following Radar* (TFR) has evolved significantly over the years, incorporating advanced technologies to enhance its functionality and accuracy. Initially, TFR systems were designed to help pilots maintain a safe altitude above the terrain, primarily using forward-looking radars to detect obstacles and terrain features.

Over time, the integration of digital maps has increased TFR capabilities, enabling functions such as *Terrain Referenced Navigation* (TRN) and *Terrain and Threat Avoidance* (Ta/THA), which further improve security and operational efficiency (Hong *et al.*, 2023).

The development of algorithms to generate phased array radar terrain scan data has also contributed to a more accurate terrain profile, which is essential for accurate terrain tracking (TF) (Jiang *et al.*, 2015).

In addition, advances in radar technology, such as the use of millimeter-wave radar modules, have improved measurement accuracy and environmental adaptability, making TFR systems more effective and cost-effective (Jiang *et al.*, 2022).

The introduction of angular super-resolution techniques has addressed the limitations of angular resolution, increasing the accuracy of TFR in detecting obstacles in the vertical plane. Synthetic Aperture Radar (SAR) and interferometric SAR (InSAR) have further revolutionized terrain observation by providing high-resolution imagery and angle estimation, crucial for all-day, all-weather operations (Burgin *et al.*, 2014; Qiuyan *et al.*, 2018).

In addition, the application of radar scattering models that consider terrain topography and vegetation has improved the accuracy of radar wave interactions, particularly in areas with vegetation and slope (García *et al.*, 2018). The use of ultra-wideband (UWB) radar in specific applications, such as sugarcane harvesting, demonstrates the adaptability of TFR systems to various terrains and operational requirements (Hua *et al.*, 2017).

Overall, the evolution of TFR has been marked by continuous technological advancements, leading to more robust, accurate, and versatile systems that are able to operate in a variety of environments and conditions.

METHOD

The procedures and techniques used to conduct the research are detailed below, including the bibliometric analysis and the data source employed. The methodological steps were carefully planned to ensure the accuracy and relevance of the results, ranging from data collection to analysis and presentation of the findings. The combination of quantitative methods and robust analysis tools enabled an in-depth exploration of the literature on Terrain *Following Radar*.

BIBLIOMETRIC ANALYSIS

According to Ribeiro and Corrêa (2013), scientific production has evolved in recent years, consolidated by researchers and evidenced in academic journals. In this context, bibliometric analysis is a quantitative methodology that allows the identification of the volume and growth pattern of literature in an emerging area. This analysis offers a retrospective view of the published literature, evaluating academic contributions in a specific field (Guleria; Kaur, 2021).

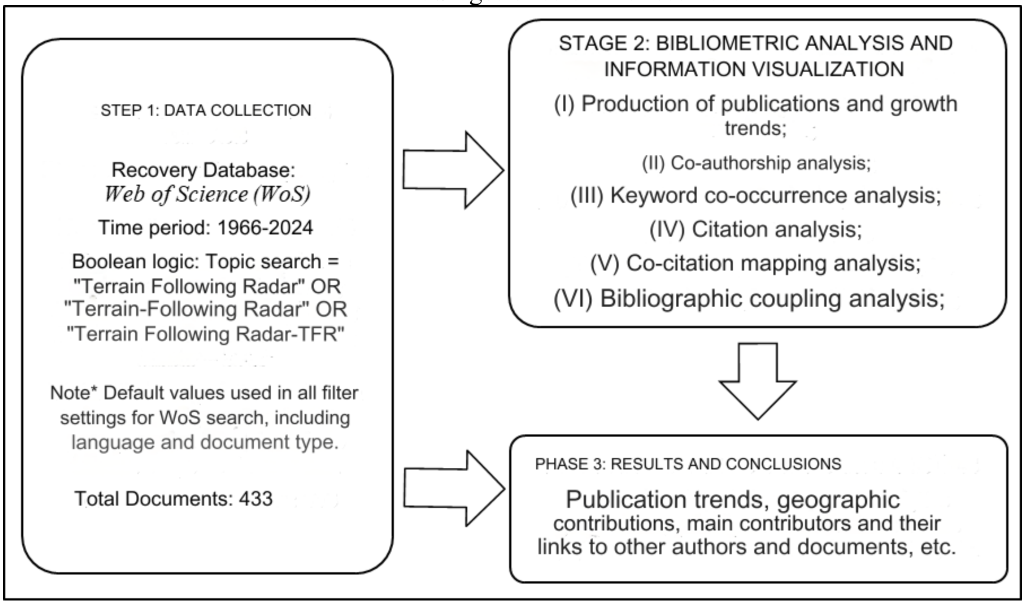
Moretti and Figueiredo (2007) point out that bibliometric analysis provides a comprehensive view of scientific publications on a given topic in a specific period. Similarly, Gutiérrez-Salcedo *et al.* (2018) emphasize that bibliometrics is a science that involves the quantitative and statistical study of the production, publication, use, and dissemination of scientific knowledge from bibliographic databases.

This study used two effective techniques: performance analysis and scientific mapping. The performance analysis evaluated the performance of publications considering production by countries, authors, affiliated institutions, and growth trends over the years. The other technique, relational bibliometric analysis or scientific mapping, identified relationships between publications and explored the structure and evolution of the research field. For this co-citation analysis, analyses of co-The authors., co-words and thematic evolution were performed. Co-citation analysis helps to identify the predominant publications and authors in a research area through citations. In addition, the analysis of evolution is carried out by researchers to understand the development of the research field over the years and predict its future trends (Ding; Yang, 2020).

DATA SOURCE

The data source considered for the study was the Web *of Science* (*WoS*) core collection, accessed on July 3, 2024. *WoS* is one of the most renowned scientific citation index databases in the world (Clarivate, 2023). From that date on, the term "*Terrain Following Radar*" was searched in English, considering this expression in the title and keywords. The period analyzed covered from 1966 to 2024, since the first publication on the subject took place in 1966. The steps of retrieving the articles and the subsequent analysis are shown in Flowchart 1.

Flow chart 1. Stages of scientific research.



Source: The authors. (2024).

In Stage 1, 433 documents were obtained, selected after searching for topics using Boolean logic. The logic used was "*Terrain Following Radar*" OR "*Terrain-Following Radar*" OR "*Terrain Following Radar – TFR*". Among the publications, the three main types of documents were: article (n=331, 76.27%), *paper* (n=101, 23.27%) and review articles (n=12, 2.76%). The records exported for all 433 documents contained complete information (authors, countries, year of publication, document types, journal of origin, title, subject categories, and references), including abstracts and cited references. This comprehensive data derived from Step 1 was used effectively to perform the bibliometric analysis and visualization of the information in Step 2.

In Stage 2, the *free bibliometric analysis* software *VOSviewer®* (version 1.6.18), widely used internationally, was used to analyze and visualize the relationships between authors, countries, journals, co-citations and terms. Due to the difficulty of identifying *clusters* in the mapping and deriving themes, *VOSviewer®* offers an attractive graphical user interface that facilitates quick analysis of these maps (Cobo *et al.*, 2011). For the execution of the bibliometric analysis, the *Bibliometrix* and *Biblioshiny* packages, *free software* developed by Massimo Aria and Corrado Cuccurullo (Aria & Cuccurullo, 2017), were installed in interface with *RStudio®* (version 4.2.1).

It is important to note that *Bibliometrix* for *RStudio®* has a built-in utility called *Biblioshiny*, which offers a graphical interface aimed at users who do not code. This feature allows you to perform a comprehensive analysis with improved graphical representation. *Bibliometrix* combines bibliometric techniques, such as co-word analysis, cocitation network analysis, generation of collaboration networks, and *Sankey graph*, to analyze the evolution of a field of research (Guleria; Kaur, 2021). VOSviewer, on the other hand,® is mainly used to analyze collaboration networks through co-The authors., co-occurrence, and keyword-based co-citation. In Stage 3 of this study, the use of the *aforementioned software* allowed obtaining the expected bibliometric results, according to the objective of the research.

For the arrangement and presentation of the results, the last stage of the bibliometric method, the use of the figures generated by the mentioned packages was chosen, according to the researchers' criteria. It is important to highlight that, as this was a study based on secondary data, made available free of charge in data repositories, there was no need to submit it to the Research Ethics Committee (REC).

RESULTS AND DISCUSSIONS

Through the *Web of Science database*, scientific productions on the Terrain Following Radar aerospace technology were identified in the period from 1966 to 2024. These data included review articles, early and free access, and enriched cited references. The dataset has 433 documents and 16,036 references. 22 documents of single The authors. and 1,615 multi-authored documents were found. In total, 1,637 authors researched this topic during the period analyzed. Table 1 details and summarizes this information.

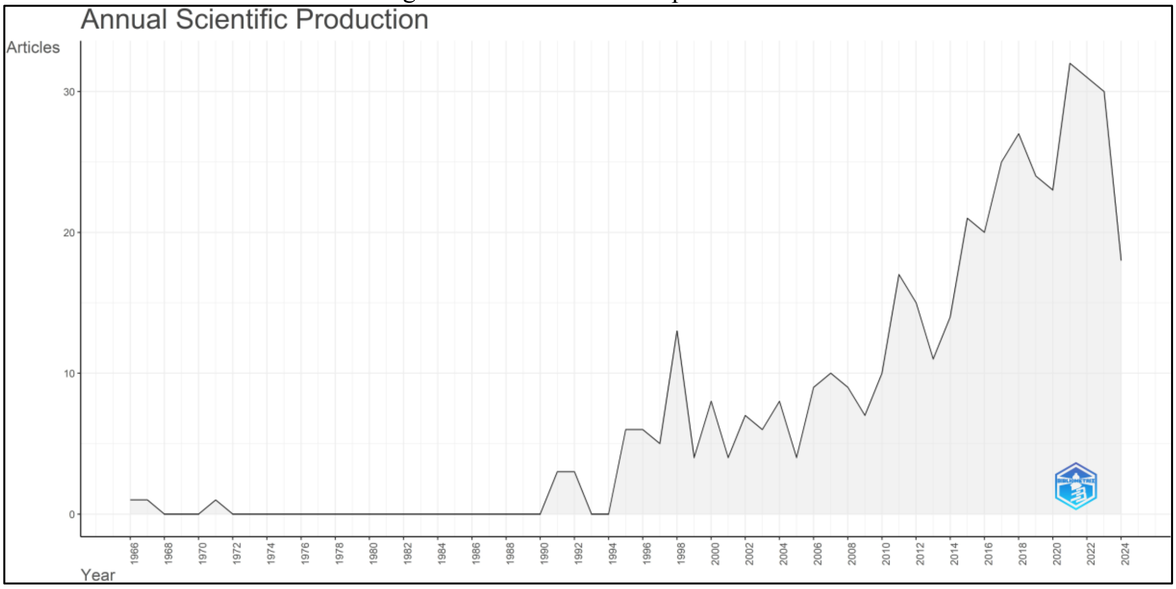
Table 1 – Main information about the data.

Description	Results
Time Period	1966-2024
Sources (magazines, books, etc.)	243
Documents	433
References	16.036
Authors	1.637
Authors of single-authored documents	22
Authors of multi-authored documents	1.615

Source: *Bibliometrix* (2024).

Figure 2 shows the annual scientific production on *Terrain Following Radar aerospace technology* in the period from 1966 to 2024. The year 2021 stood out with the highest number of publications, totaling 32. Then, the years 2022 and 2023 had 31 and 30 publications, respectively. On the other hand, the years 1966, 1967 and 1971 registered only one publication each.

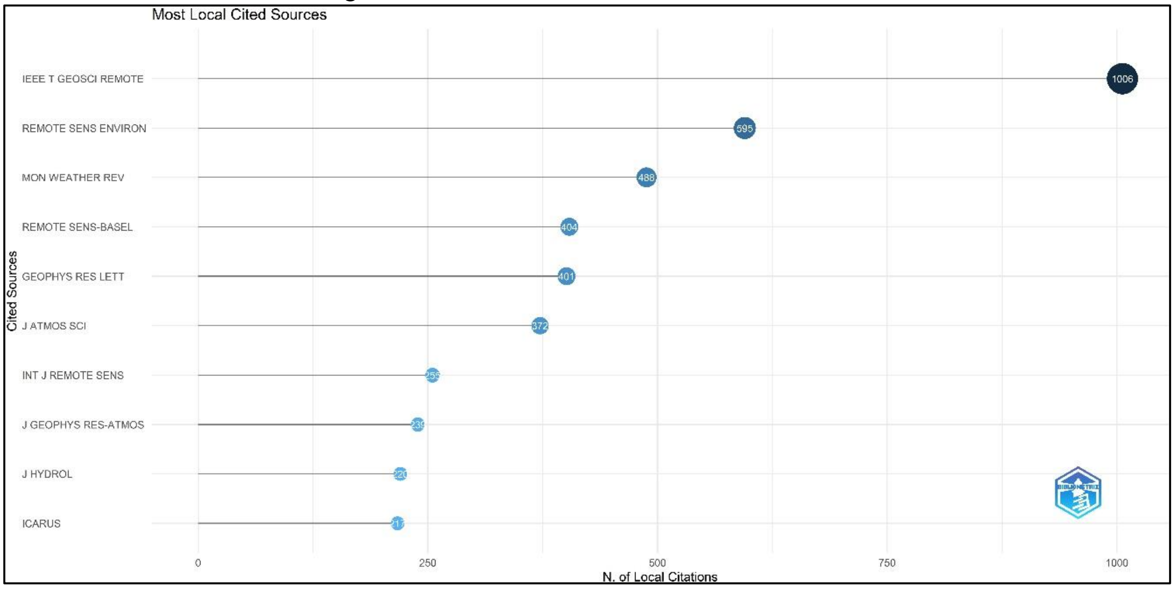
Figure 2. Annual scientific production.



Source: *Bibliometrix* (2024).

Figure 3 presents the ten most cited local sources in the reference lists of the 433 documents analyzed. Among them, the journal "*IEEE Transactions on Geoscience and Remote Sensing" stands out* with 1,006 citations. Among these ten sources, the least cited was "*Icarus*", with 217 citations.

Figure 3. Local sources cited from the references.



Source: *Bibliometrix* (2024).

A measure of how often an article is cited each year in a journal can be defined as the source impact factor. This index is used to evaluate the importance or classification of a journal, counting the number of times its articles are cited (Oyewola; Dada, 2022). In this study, we used three different measures of the common index (see Table 2). The journal "*IEEE Transactions on*

Geoscience and Remote Sensing" stood out with an h-index of 17 and a g-index of 24, followed by the journal "*Remote Sensing*", which obtained an h-index of 14 and a g-index of 24. Regarding the m-index, "*Remote Sensing*" presented an impact factor of 1.273, indicating that the articles published in this journal were cited more frequently than in other journals.

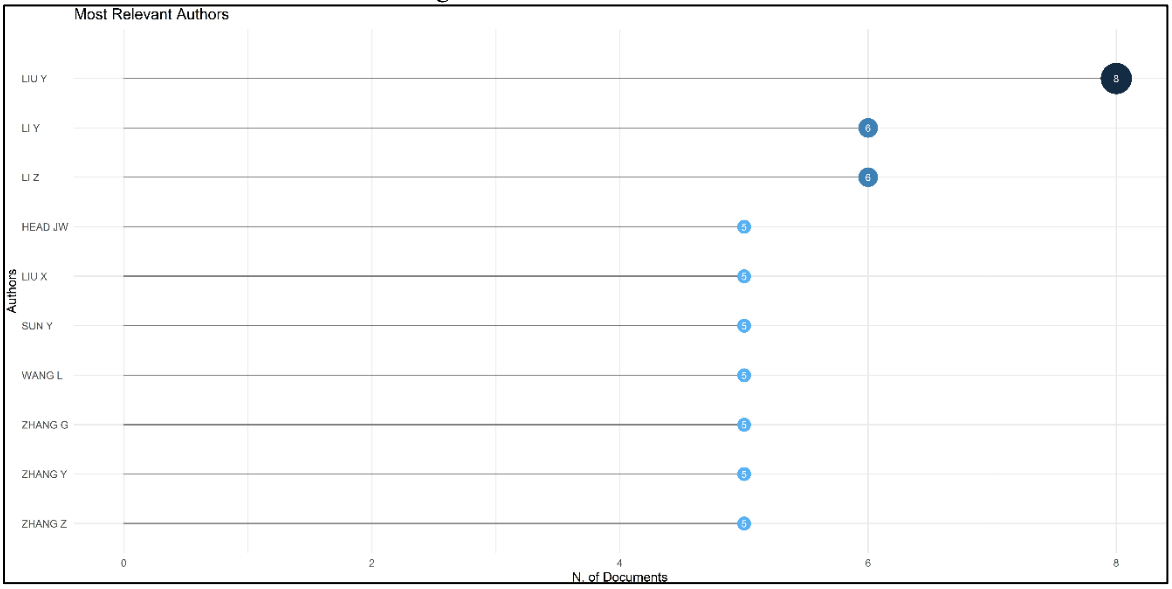
Table 2 – Impact factor of the source

Source	h-index	g-index	m-index	TC*	PY**
IEEE Transactions on Geoscience and Remote Sensing	17	24	0.567	1929	1995
Remote Sensing	14	24	1.273	596	2014
Monthly Weather Review	11	12	0.324	412	1991
Remote Sensing of Environment	11	12	0.367	901	1995
IEEE Journal of Selected Topics in Applied Earth	7	7	0.700	239	2015
IEEE Geoscience and Remote Sensing Letters	6	8	0.222	213	2004
International Journal of Remote Sensing	6	8	0.185	157	1998
Hydrology and Earth System Sciences	5	5	0.185	442	1998
Icarus	5	9	0.300	274	1998
Journal Of Geophysical Research-Planets	5	5	0.152	446	1992

*Total citations; **Year of publication.
Source: *Bibliometrix* (2024).

Figure 4 shows the ten most influential authors in research on Terrain *Following Radar aerospace technology*, in the period from 1966 to 2024. Liu Y. stands out in first place with 8 publications, followed by Li Y. and Li Z., both with 6 publications. Among the ten authors, Head J. W., Liu X., Sun Y., Wang L., Zhang G., Zhang Y., and Zhang Z. have five publications each.

Figure 4. Most relevant authors.



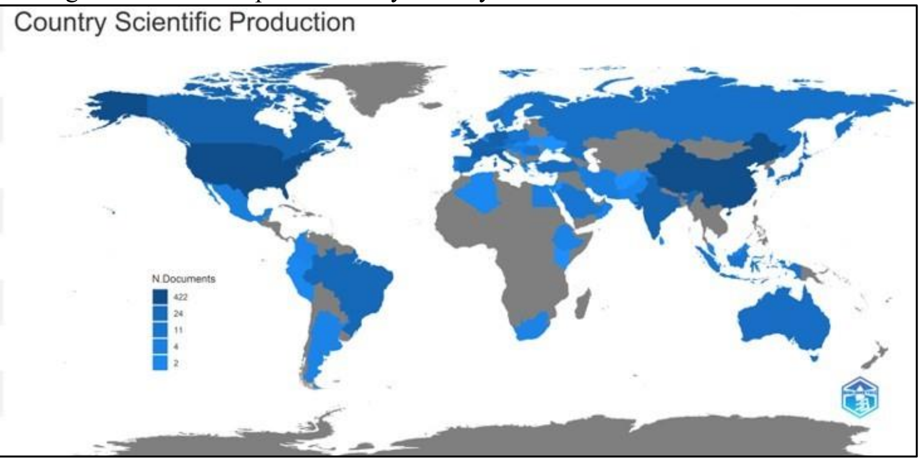
Source: *Bibliometrix* (2024).

Figure 5 illustrates the scientific production by country in the theme addressed, based on the number of publications. The geographical distribution of articles, considering the affiliations of all authors, reveals a concentration in the United States of America, with 422 affiliations, ranking first.

It is followed by China (398 affiliations), Italy (73), Germany (70) and France (58). Brazil occupies the ninth position, with 37 affiliations, along with other countries.

Figure 5. Scientific production by country.

USA	422
CHINA	398
ITALY	73
GERMANY	70
FRANCE	58
CANADA	54
INDIA	50
UK	48
BRAZIL	37
SWITZERLAND	34



Source: *Bibliometrix* (2024).

Table 3 presents the ten most cited documents globally, containing four columns: *Paper*, DOI, Total Citation (TC), Frequency of Total Citation (NTC) and Country. The author Xue

M. (2000), from the journal "*Meteorology and Atmospheric Physics*", leads the list with 693 total citations, followed by De Zan F. (2006), from the journal "*IEEE Transactions on Geoscience and Remote Sensing*", with 534 total citations. Among the ten most cited documents, the journal "*IEEE Transactions on Geoscience and Remote Sensing*" appears with three *papers*. It is important to note that five of the ten most cited global documents are from the United States, followed by China, with three articles.

Table 3 – Most cited documents at the international level on the subject.

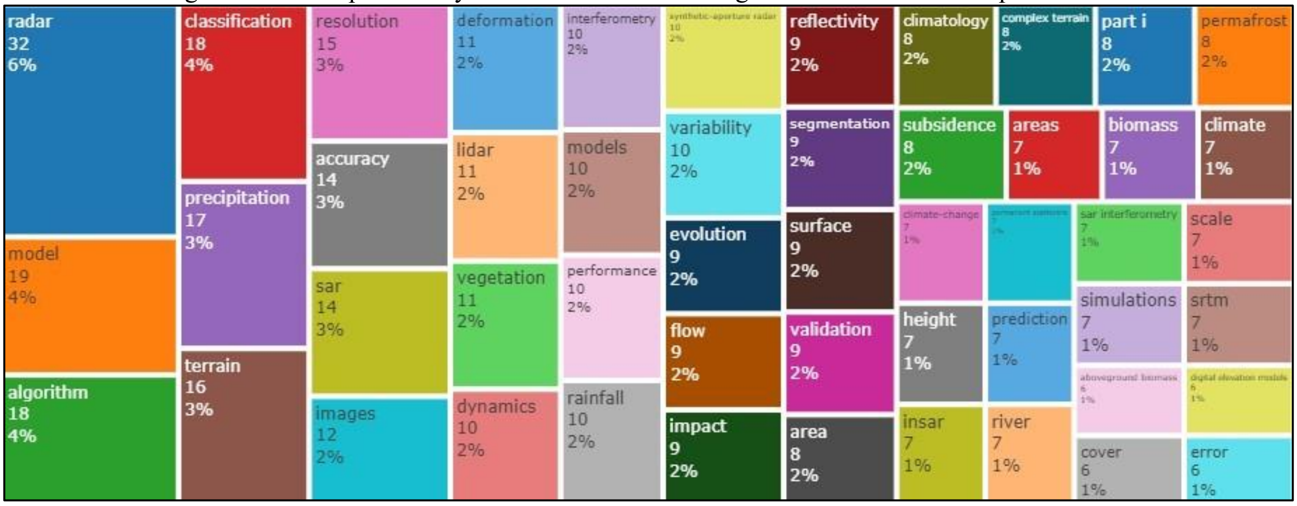
Paper	TWO	TC*	NTC**	Country
(1) XUE M, 2000, METEOROL ATMOS	10.1007/s007030070003	693	6.76	China
(2) DE ZAN F, 2006, IEEE TRANS	10.1109/TGRS.2006.873853	534	6.32	Italy
(3) ZHANG Z, 2017, IEEE TRANS	10.1109/TGRS.2017.2743222	405	10.69	China
(4) BECK HE, 2019, HYDROL EARTH	10.5194/hess-23-207-2019	307	8.40	USA
(5) SOLOMON SC, 1992, J GEOPHYS	10.1029/92JE01418	260	2.44	USA
(6) FARLEY KA, 2020, SPACE SCI REV	10.1007/s11214-020-00762-y	226	6.81	USA
(7) CARBONE RE, 2008, J CLIM	10.1175/2008JCLI2275.1	208	6.86	USA
(8) XU W, 1999, IEEE TRANS GEOSCI	10.1109/36.739143	206	3.66	China
(9) QUEGAN S, 2019, REMOTE SENS	10.1016/j.rse.2019.03.032	160	4.38	United Kingdom
(10) MASTERS D, 2004, REMOTE SENS	10.1016/j.rse.2004.05.016	150	3.35	USA

*Total citations; ** Total Citation Frequency.
Source: *Bibliometrix* (2024).

Figure 6 shows a *TreeMap* with the fifty most frequent words in scientific publications on the Terrain *Following Radar aerospace technology*. The word "radar" is the most prevalent, appearing

32 times (6%), followed by "model" with 19 occurrences (4%), "algorithm" and "classification" with 18 occurrences each (4%), "precipitation" with 17 (3%) and "terrain" with 16 (3%). This hierarchical view highlights the relevance of these words in publications.

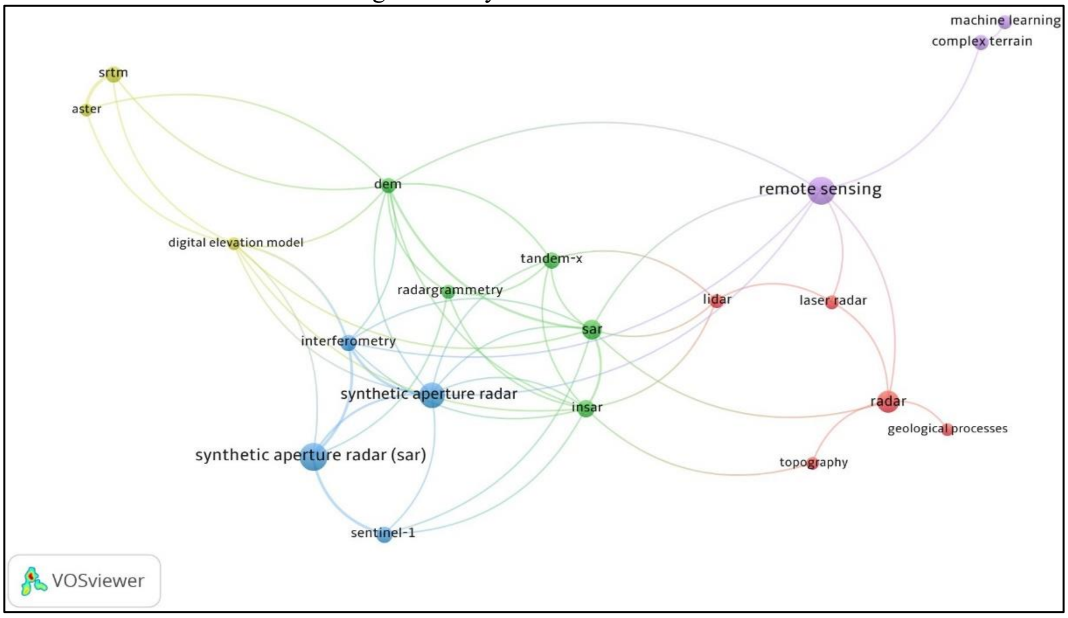
Figure 6. TreeMap summary of the words with the highest occurrences in the publications.



Source: *Bibliometrix* (2024).

Figure 7 illustrates the network of keyword co-occurrence. In this context, the analysis of this network helps researchers to identify the main topics discussed in a specific research area. According to Zupic and Čater (2015), keyword co-occurrence is an effective scientometric technique that allows visualizing and displaying the similarities between keywords or topics that often occur in the literature. Based on this, of the 1,336 keywords found, a co-occurrence limit of at least five was established in *VOSviewer*, resulting in 20 keywords. From these, five *clusters* emerged, with 65 nodes in the network. Each node in the visualization represents a keyword, and the size of the node is proportional to the occurrence of that keyword in the literature reviewed. In other words, larger nodes indicate a higher frequency of keyword co-occurrence. The top five co-occurrences are: SAR (*Synthetic Aperture Radar*) (21); remote sensing (21); radar (14); InSAR (*Interferometric Synthetic Aperture Radar*) (9); and interferometry (8).

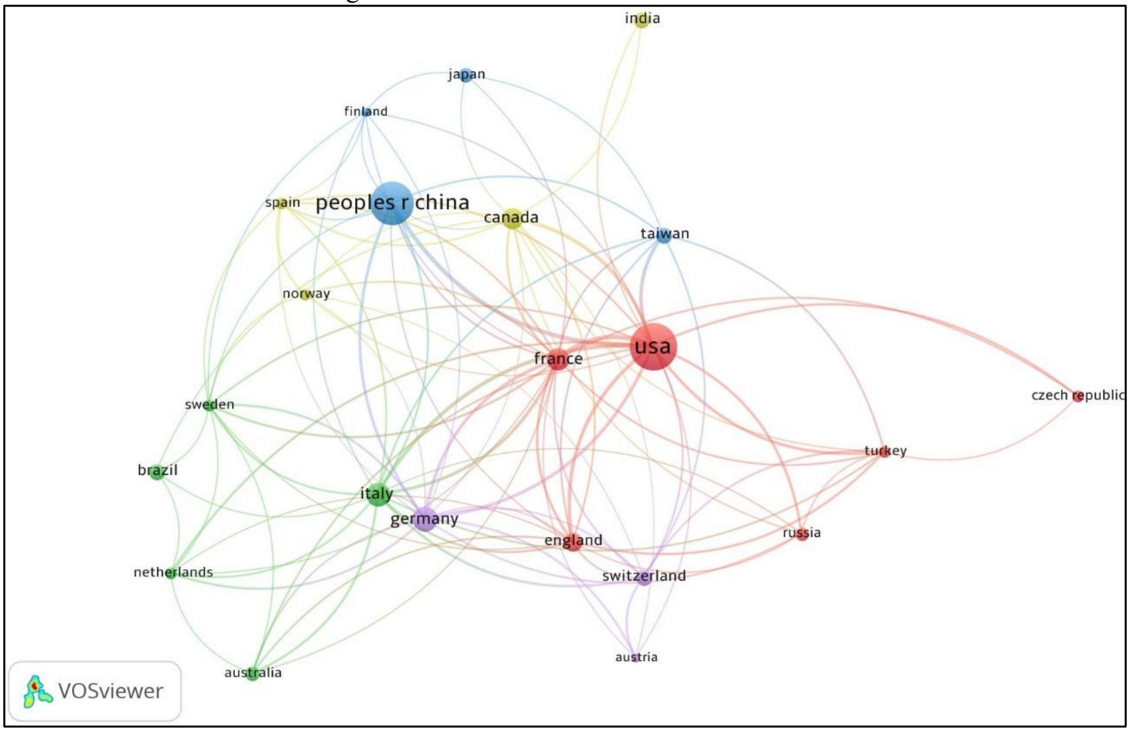
Figure 7. Keyword co-occurrence.



Source: *VOSviewer* (2024).

Figure 8 shows the 23 countries with the highest co-The authors.s distributed in 5 *clusters*. For this analysis, the minimum number of documents per country was set at 5, while the minimum number of citations was set at 3. Thus, the analysis of co-The authors. between countries reflects both the relationship of collaboration and the degree of collaboration in the thematic area. Larger nodes indicate greater collaborations between countries in research on Terrain *Following Radar aerospace technology*, with the thickness and length of the links between the nodes representing the intensity of cooperation. The countries with the highest number of co-The authors.s were: the United States, with 119 documents, 5,452 citations, and link strength of 83; China, with 101 documents, 1,781 citations and link strength of 27; and Germany, in third position, with 35 documents, 918 citations and total link strength of 39.

Figure 8. Co-The authors. between countries.



Source: *VOSviewer* (2024).

Figure 9 illustrates the authors' collection network. Article co-citation analysis allows researchers to understand the nature of the articles cited in a *cluster* and the interconnections between *clusters* (Chen; Ibekwe-Sanjuan; Hou, 2010). The findings of the cocitation network, extracted from *VOSviewer*, show that the pairs of highly cocited articles are those connected by thick arcs. A pair of co-cited papers occurs when two papers are cited together in a single paper. The thick arcs indicate a strong relationship between these papers, suggesting similarities in specific topics within the field of Terrain *Following Radar* aerospace technology. In contrast, thin arcs indicate a weak association of co-citation between articles, reflecting the lack of content similarities. In this way, it is possible to identify the frequency with which two or more authors are cited together in the same article (co-citation). This measure assumes that the more items are cited together, the more likely it is that their content is related. Thus, of the 10,801 authors identified, a minimum number of twenty co-citations was defined in VOSviewer, resulting in 25 authors. Thus, the five main authors cited are: Lee, J. S. (52); Ferretti, A. (43); Head, J. W. (39); Toutin, T. (36); and Cloude, S. R. (33).

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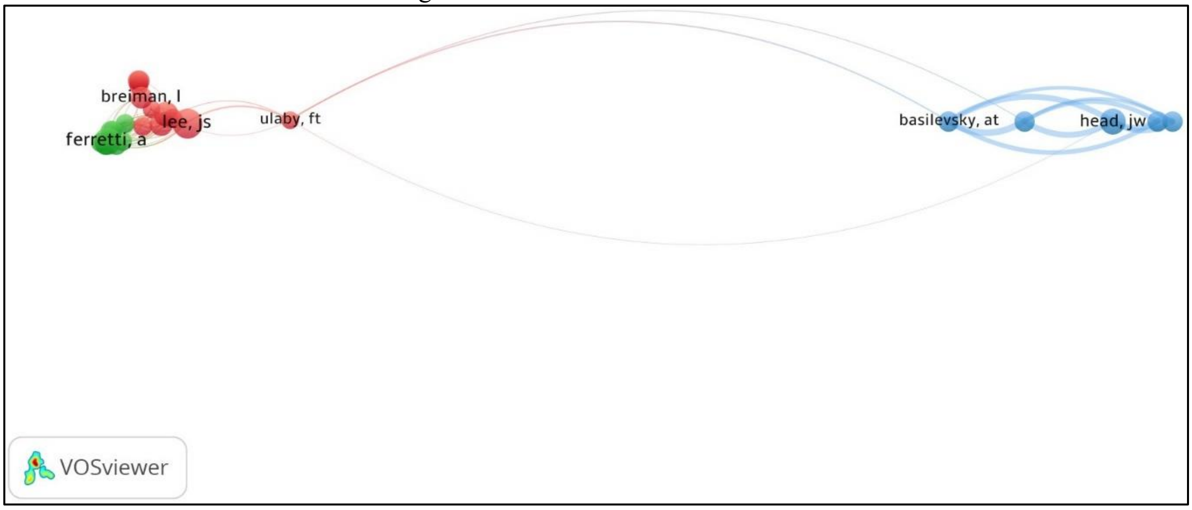
Figure 9. Author co-citation network.



Source: *VOSviewer* (2024).

Thus, by providing an overview of the scientific production on Terrain *Following Radar aerospace technology* in the period from 1966 to 2024, this study presents possible contributions related to the focus of research and the identification of existing gaps. In addition, the importance of international collaborations between countries on the subject is emphasized.

FINAL CONSIDERATIONS

This study sought to enhance the knowledge base on Terrain *Following Radar* aerospace technology and the field of related studies. For this, a bibliometric analysis was carried out using the *VOSviewer*® software and the *Bibliometrix package* in *RStudio*®. The relational technique for bibliometric studies involves the application of five main methods: co-The authors. analysis, citation analysis, co-citation mapping, keyword co-occurrence analysis, and bibliographic analysis. These methods were applied to 433 documents extracted from the *Web of Science database*.

During the researched period of almost 60 years, it is noticed that there was a significant growth in the number of publications about this technology. In addition, the United States and China stand out as the most cited countries in surveys on the subject, exerting great global influence. In addition to these, Germany, Italy and France are also leaders in publications on the subject. These five countries together represent 74.42% of all publications, indicating considerable investments in the area.

However, the results of this study indicate the absence of greater national and international cooperation to address the challenges associated with the theme. Therefore, it is essential to intensify collaboration and research at the international level.

The results also highlighted the five most relevant affiliations of the authors in studies on the subject, with emphasis on: *National Aeronautics and Space Administration – NASA* (USA); *Helmholtz Association* (Germany); *Chinese Academy of Sciences* (China); *NASA Jet Propulsion Laboratory* – JPL (USA); and *California Institute of Technology* (USA).

In order to identify the most relevant journals, this bibliometric research analyzed quantitative (volume of publications) and qualitative (number of citations) indicators. Therefore, based on the number of publications, H-index, and G-index, *IEEE Transactions on Geoscience and Remote Sensing* was considered the most influential journal on the subject, while *Remote Sensing* stood out for its highest impact factor, based on the m-index.

The keyword analysis also highlighted the main areas of research related to *Terrain Following Radar* technology, which include: Remote Sensing; Engineering; Image Science and Photographic Technology; Geology; and Meteorology and Atmospheric Sciences.

The main limitation of this research is its restriction to the *Web of Science* database, where most of the documents analyzed were articles. Thus, it would be necessary to expand the line of research to include other databases, such as *Scopus* and *Google Scholar*, in addition to considering other types of publications, such as books and conference proceedings.

REFERENCES

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959-975.

Burgin, M., Khankhoje, U. K., Duan, X., & Moghaddam, M. (2014). Generalized radar scattering model including terrain topography. In 2014 IEEE Geoscience and Remote Sensing Symposium (pp. 5037-5039). IEEE.

Burgin, M. S., Khankhoje, U. K., Duan, X., & Moghaddam, M. (2016). Generalized terrain topography in radar scattering models. IEEE Transactions on Geoscience and Remote Sensing, 54(7), 3944-3952.

Chen, C., Ibekwe-SanJuan, F. and Hou, J. (2010), The structure and dynamics of cocitation clusters: A multiple-perspective cocitation analysis. J. Am. Soc. Inf. Sci., 61: 1386-1409. https://doi.org/10.1002/asi.21309.

Choi, DY. et al. (2023). Development of a Terrain Scan Data Generation Algorithm Using DTED. In: Lee, S., Han, C., Choi, JY., Kim, S., Kim, J.H. (eds) The Proceedings of the 2021 Asia-Pacific International Symposium on Aerospace Technology (APISAT 2021), Volume 2. APISAT 2021. Lecture Notes in Electrical Engineering, vol 913. Springer, Singapore. https://doi.org/10.1007/978- 981-19-2635-8_81.

Clarivate. (2023). Web of Science™ de dados de citação global independente mais confiável do mundo.

Cobo, M.J., López-Herrera, A.G., Herrera-Viedma, E. and Herrera, F. (2011), Science mapping software tools: Review, analysis, and cooperative study among tools. J. Am. Soc. Inf. Sci., 62: 1382-1402. https://doi.org/10.1002/asi.21525

Ding, X., & Yang, Z. (2020). Knowledge mapping of platform research: a visual analysis using VOS-viewer and Cite Space. Electronic Commerce Research. https://doi.org/10.1007/s10660- 020-09410-7.

Faris, A. and Sasongko, R. A. (2018). Terrain Following System Based on Online Detection Data, 2018 15th International Conference on Control, Automation, Robotics and Vision (ICARCV), Singapore, pp. 739-743, doi: 10.1109/ICARCV.2018.8581149.

García, A. J., Bakon, M., Martínez, R., & Marchamalo, M. (2018). Evolution of urban monitoring with radar interferometry in Madrid City: performance of ERS-1/ERS-2, ENVISAT, COSMO- SkyMed, and Sentinel-1 products. International journal of remote sensing, 39(9), 2969-2990.

Guleria D., Kaur G. (2021). Bibliometric analysis of ecopreneurship using VOSViewer and RStudio bibliometrix, 1989–2019. Library Hi Tech, 39(4), 1001–1024. https://doi.org/10.1108/LHT-09-

Gutiérrez-Salcedo, M; Martínez, M. A; Moral-Munoz, J. A; Herrera-Viedma, E; & Cobo, M. J. (2018). Some bibliometric procedures for analyzing and evaluating research fields. Applied Intelligence, 48, 1275-1287. https://doi.org/10.1007/s10489-017-1105-y.

Hua Z., Lixiang R., Jisheng, W., Ran L., Manlu L., Yulu F., Liang G. (2017). Terrain following system and realization method of sugarcane harvester based on UWB radar.

Hong, K., Kim, S., Bang, H., Seo, K., & Jeon, J. (2023). Accelerated Algorithm for Generating Measurements of Terrain Following Radar Based on Digital Elevation Models. Journal of the Korean Society for Aeronautical and Space Sciences, 51(6), 399-406.

Jiang, W., Huang, Y., Wu, J., Li, W., & Yang, J. (2015). A new approach for terrain following radar based on radar angular superresolution. In The proceedings of the third international conference on communications, signal processing, and systems (pp. 223-231). Springer International Publishing.

Jiang, M., Wei, H., Tang, C., Zhang, H., & Xu, G. (2022, November). Terrain observation using ground-based interferometric millimeter-wave sar imaging. In 2022 3rd China International SAR Symposium (CISS) (pp. 1-5). IEEE.

Kaniewski, P., Leśnik, C., Susek, W., & Serafin, P. (2015, June). Airborne radar terrain imaging system. In 2015 16th International Radar Symposium (IRS) (pp. 248-253). IEEE.

Kim, C. S., Cho, I. J., Lee, D. K., & Kang, I. J. (2015). Development of low altitude terrain following system based on TERain PROfile matching. Journal of institute of control, robotics and systems, 21(9), 888-897.

Moretti, S. L. A., Figueiredo, J. C. B. (2008). Análise bibliométrica da produção sobre Responsabilidade Social das Empresas no ENANPAD: evidências de um discurso monológico. Revista De Gestão Social E Ambiental, 1(3), 21–38. https://doi.org/10.24857/rgsa.v1i3.34.

Najmon, J. C., Raeisi, S., & Tovar, A. (2019). Review of additive manufacturing technologies and applications in the aerospace industry. Additive manufacturing for the aerospace industry, 7-31.

Nallusamy, T., & Balaji, P. (2019). Optimization of NOE Flights Sensors and Their Integration. Advances in Human and Machine Navigation Systems, IntechOpen, https://doi.org/10.5772/intechopen.86139.

Noh, J., Ahn, H., Lee, J., Bang, H. (2021). Terrain-Following Guidance Based on Model Predictive Control. In: Lee, S., Han, C., Choi, JY., Kim, S., Kim, J.H. (eds) The Proceedings of the 2021 Asia-Pacific International Symposium on Aerospace Technology (APISAT 2021), Volume 2. APISAT
2021. Lecture Notes in Electrical Engineering, vol 913. Springer, Singapore. https://doi.org/10.1007/978-981-19-2635-8_62.

Oyewola, D. O., & Dada, E. G. (2022). Exploring machine learning: a scientometrics approach using bibliometrix and VOSviewer. SN applied sciences, 4(5), 143. https://doi.org/10.1007/s42452- 022-05027-7.

Pokonieczny, K. (2018). Use of a multilayer perceptron to automate terrain assessment for the needs of the armed forces. ISPRS international journal of geo-information, 7(11), 430.

Pundir, S.K., Garg, R.D. Development of mapping techniques for off road trafficability to support military operation. Spat. Inf. Res. 28, 495–506 (2020). https://doi.org/10.1007/s41324-019-00310-z.

Qiuyan Z, Junjie T, Shixian L, Jia P. (2018). A radar sensor, terrain following system for plant protection unmanned aerial vehicle terrain following.

Ribeiro, H. C. M., Corrêa, R. (2013). Análise da produção científica da temática Gestão Socioambiental na perspectiva da revista RGSA. Revista De Gestão Social E Ambiental, 6(3), 86- 104. https://doi.org/10.5773/rgsa.v7i2.652.

Van Eck, N.J., Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84, 523–538 (2010). https://doi.org/10.1007/s11192-009-0146-3.

Zupic, I., & Čater, T. (2015). Bibliometric Methods in Management and Organization.Organizational Research Methods, 18(3), 429–472. https://doi.org/10.1177/1094428114562629.

Oyewola, David Opeoluwa; DADA, Emmanuel Gbenga. Exploring machine learning: a scientometrics approach using bibliometrix and VOSviewer. SN Applied Sciences, v. 4, n. 5, p. 143, 2022.