Beyond the Fingerprint: Exploring the Bibliometric Landscape of Emerging Synthetic Biometrics with a Focus on Synthetic Signatures

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ABSTRACT

Purpose: *This paper aims to conduct a comprehensive bibliometric analysis focusing on synthetic biometrics, particularly synthetic signatures, as an emerging alternative to traditional biometric methods such as fingerprints and iris scans. The study explores the research landscape to identify trends, influential studies, and emerging technologies in this innovative field.*
Methodology: *The research employs bibliometric analysis techniques to systematically map the academic discourse surrounding synthetic biometrics, with a specific emphasis on synthetic signatures. Bibliometric methods include citation analysis, co-citation analysis, and cluster analysis to uncover patterns, connections, and trends within the research literature. These methods provide a retrospective insight into the progression of synthetic signature research and its scholarly impact.*
Findings/Results:*The findings reveal several key insights:*
Emerging Trends: Synthetic signatures are increasingly recognized for their potential in enhancing security and identification systems beyond traditional biometrics.
Influential Studies: Specific studies and authors are identified as pivotal in shaping the discourse and development of synthetic signature technologies.
Technological Advancements: The analysis highlights advancements in synthetic biometrics, showcasing how these technologies are evolving to meet the challenges of robust and adaptable verification methods.
Challenges and Opportunities: The study identifies both potential and challenges associated with synthetic signatures, providing a nuanced understanding of their feasibility and application in real-world scenarios.
Originality/Value: *This paper contributes to the existing literature by offering a structured analysis of the bibliometric landscape of synthetic biometrics, particularly synthetic signatures. By mapping out the academic discourse and identifying key trends and technologies, it provides valuable insights into the potential and challenges of this innovative field. The findings are expected to guide future research directions and policy considerations in the development and adoption of synthetic biometric technologies.*
Paper Type: *Review Paper.*

Keywords: synthetic biometric, synthetic signature, biometric, signature verification

1. INTRODUCTION:

The realm of biometrics, the science of identifying individuals based on their unique biological characteristics, has undergone a significant transformation in recent years. While traditional methods like fingerprints and facial recognition have dominated for decades, a new frontier is emerging – synthetic biometrics [1]. This exciting yet challenging area explores the creation of artificial biometric data that mimics real human characteristics.
Within the synthetic biometric landscape, synthetic signatures [2] have emerged as a sub-category with significant potential and growing research interest. A traditional signature, a handwritten inscription

used for identification and verification, is being transformed by technology. Synthetic signatures are computer-generated imitations that replicate an individual's signing style[3,4].

This paper delves into the world of synthetic biometrics with a specific focus on synthetic signatures. We utilize a bibliometric analysis approach, a powerful tool for mapping research trends and knowledge production within a particular field. By analysing scholarly literature, we aim to:

- Unveil the Evolving Landscape: Bibliometrics allows us to identify the growth trends in research on synthetic biometrics, particularly focusing on synthetic signatures. This analysis will reveal how this field has matured over time, pinpointing key milestones and research bursts.
- Mapping the Scholarly Terrain: Through bibliometric techniques, we can identify prominent authors and institutions leading the charge in synthetic signature research. This information helps establish the intellectual landscape and identify potential research collaborations.
- Identifying Influential Works: Bibliometric analysis can highlight the most cited papers on synthetic signatures. These foundational works will provide a strong base for understanding the core concepts, methodologies, and challenges in this domain.
- Charting the Uncharted: By analyzing publication trends, we can uncover emerging areas of research within synthetic signatures. This exploration will shed light on unanswered questions and potential future directions for the field.

The exploration of synthetic biometrics holds immense potential, offering a range of possibilities beyond traditional fingerprint or facial recognition. Here are some key advantages of synthetic biometrics:

- Enhanced Security: Synthetic biometrics can be used to create multi-factor authentication systems, adding an extra layer of security compared to traditional single-factor methods[5,6].
- Accessibility Solutions: For individuals with physical limitations that hinder traditional signature use, synthetic signatures can offer an alternative verification method[7].
- Privacy Considerations: In certain scenarios, synthetic biometrics could provide a layer of privacy by using anonymized biometric data for identification purposes [8].

However, the emergence of synthetic biometrics, particularly synthetic signatures, also raises concerns:

- Deepfakes and Forgery: The ability to create realistic synthetic signatures could be misused for forgeries and identity theft, posing a significant security risk.
- Ethical Dilemmas: The potential for manipulating biometric data raises ethical questions about user consent, data ownership, and potential biases within the technology itself.

By employing a bibliometric analysis focused on synthetic signatures, this study aims to provide a comprehensive understanding of this rapidly evolving field. We will not only map the existing research landscape but also identify potential research gaps and future directions. This exploration will contribute valuable insights to the ongoing conversation surrounding synthetic biometrics and their societal implications.

Within the broader field of synthetic biometrics, this study focuses on synthetic signatures due to their unique characteristics and potential for real-world applications. The analysis will not only shed light on the specific challenges and advancements in synthetic signatures but will also serve as a springboard for understanding the wider implications of synthetic biometrics in our evolving technological landscape.[9,10]

Research Questions-

- To Identify the trends in research productivity within the field.
- Who are the most contributing authors and what are the most relevant documents?
- How has thematic development progressed in synthetic signature research?
- To find the key collaborative networks among researchers.
- What are the emerging trends and future directions in synthetic biometrics, with a focus on synthetic signatures?

2. METHODOLOGY :

The bibliometric technique suggested by [11] is used in this paper. To assess a research field, identify and visualize its conceptual subdomains (specific topics/themes or general thematic areas), and track its thematic evolution, this bibliometric technique blends performance analysis tools with scientific mapping tools. The bibliometric approach suggested in [12,13] is used to analyze the database. The methodology has been divided into three phases- Data retrieval, data cleansing, and data analysis. Data has been retrieved from the scopus database using the search string given below.

Search String used: TITLE-ABS-KEY (synthetic AND (biometric* OR signature)) AND (LIMIT TO (LANGUAGE , "English")) AND (LIMIT TO (SUBJAREA , "COMP")) AND (LIMIT TO (SRCTYPE , "j"))

In data cleaning phase all the duplicates and irrelevant studies have been discarded. In the last phase of data analysis, biblioshiny has been used to analyse the corpus and present the results. All the results have been discussed thoroughly in section 3.

Inclusion Criteria:

Keywords: Articles must include keywords related to synthetic biometrics or synthetic signatures in their title, abstract, or keywords.
Keywords: "synthetic", "biometric*", "signature".
Language: Only articles published in English.
Subject Area: Articles must belong to the subject-area of Computer Science.
Source Type: Only journal articles will be considered.
Relevance: Studies must focus on synthetic biometrics or synthetic signatures, including development, application, analysis, or evaluation.

Exclusion Criteria:

Non-English Articles: Articles published in languages other than English.
Non-Computer Science Subjects: Articles that are not categorized under the subject domain of Computer Science.
Non-Journal Sources: Conference papers, chapters, reviews, editorials, and other non-journal publications.
Irrelevant Focus: Articles that do not specifically address synthetic biometrics or synthetic signatures, even if the keywords are mentioned.
Duplicates: Duplicate studies or multiple publications of the same research.
Incomplete Studies: Articles without complete data or full text available for review.

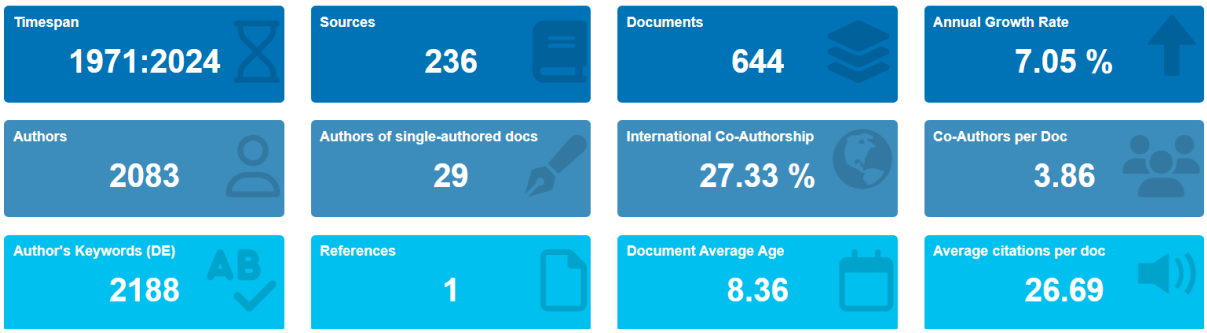

Figure 1: Main Information of extracted corpus

The bibliometric dataset on synthetic biometrics, with a particular focus on synthetic signatures, spans from 1971 to 2024, encompassing 236 sources such as journals and books, and includes overall 644 documents. The field has experienced an annual growth rate of 7.05%, indicating a steady increase in research activity. On average, documents in this dataset are 8.36 years old and receive 26.69 citations each, highlighting their relevance and impact within the academic community. The dataset references a vast array of keywords, with 5601 Keywords Plus (ID) and 2188 author's keywords (DE), showcasing the diverse and expansive nature of research topics covered. Contributions come from a broad and active

scholarly community comprising 2083 authors, reflecting the widespread interest and collaborative efforts in advancing synthetic biometrics, particularly synthetic signatures.

3. RESULTS AND DISCUSSION:

3.1 Article Production per year

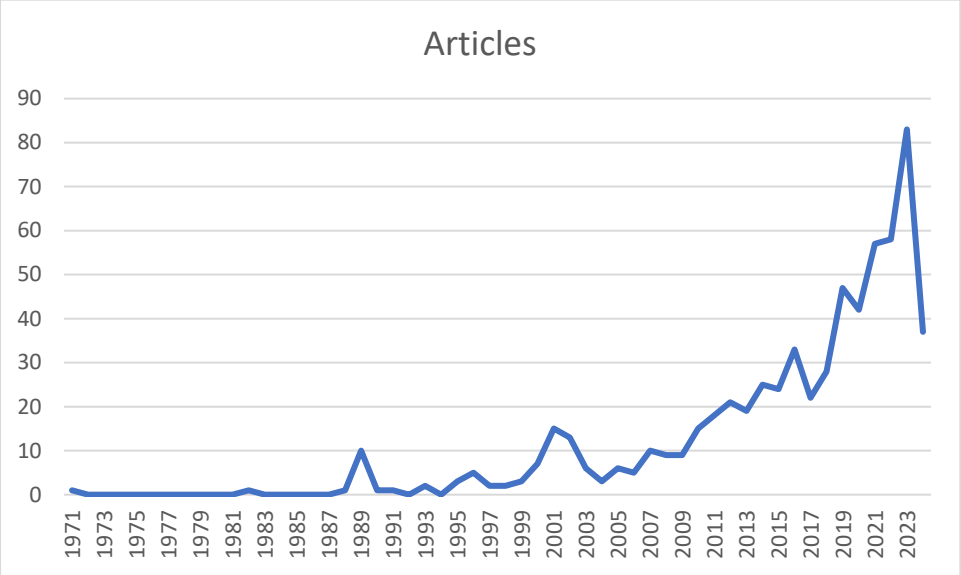

Figure 2: Article production per year

The dataset on synthetic biometrics, with an emphasis on synthetic signatures, illustrates the evolution of research publications from 1971 to 2024. Initial activity was sparse, with just one article in 1971 and sporadic publications through the 1980s. A significant increase began in the late 1990s, with notable spikes in 1989 (10 articles) and 2001 (15 articles). Research output continued to grow in the 2000s, with a marked increase from 2010 onwards. The number of articles published annually has surged in recent years, peaking at 83 in 2023. This upward trend reflects a growing interest and investment in synthetic biometrics, driven by advancements in technology and increasing applications. The dataset underscores a robust and accelerating field, with 2024 already showing significant contributions despite being an incomplete year.

3.2 Most influential Sources

The dataset on synthetic biometrics, particularly focusing on synthetic signatures, reveals that the research is disseminated across various prominent journals. Leading the list is IEEE Access with 34 articles, followed by IEEE Transactions on ImageProcessing with 27 articles. Pattern Recognition has contributed 22 articles, while IEEE Transactions on InformationForensics & Security and IEEE Transactions on Pattern Analysis and Machine Intelligence have published 19 and 15 articles, respectively. The International Journal of Molecular Sciences and Multimedia Tools and Applications each feature 14 articles. Sensors has 13 articles, and both ISPRS Journal of Photogrammetry and Remote Sensing and Pattern Recognition Letters have published 12 articles each. These journals represent key sources of high-impact research and development in the field of synthetic biometrics and synthetic signatures.

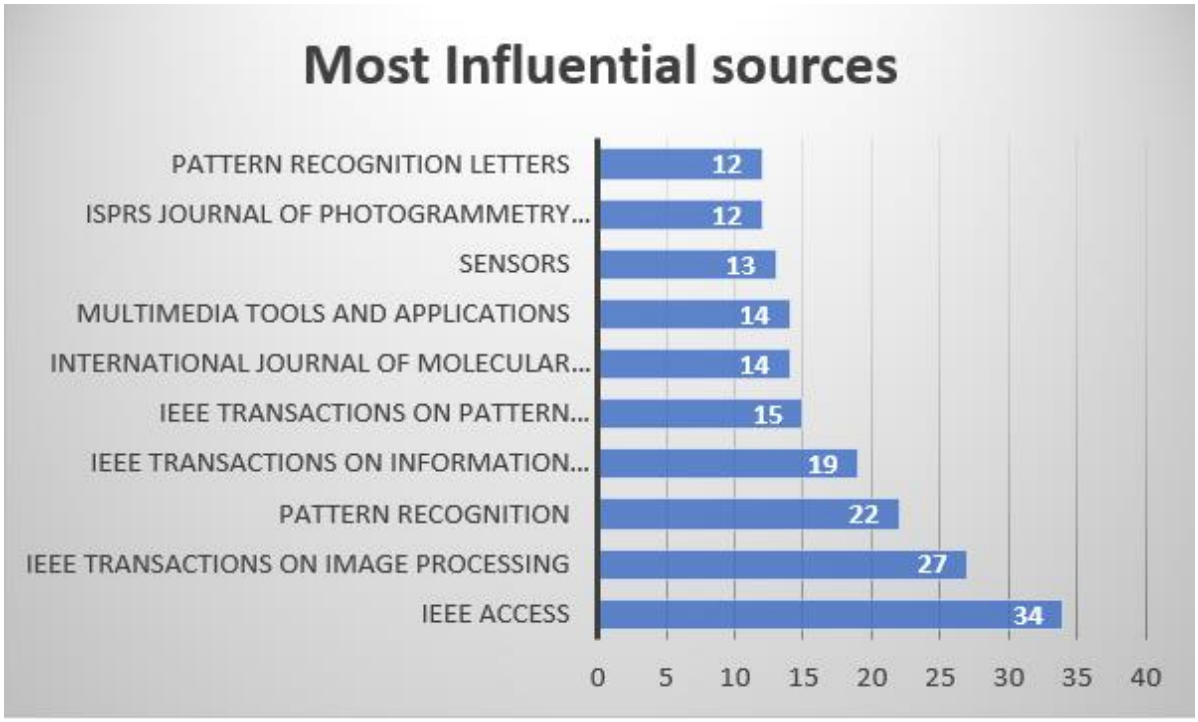

Figure 3: Most Influential Sources

3.3 Most Influential Authors

The dataset on synthetic biometrics, with a focus on synthetic signatures, highlights several prolific authors in the field. Fierrez J leads with 12 articles, followed closely by Ferrer MA and Galbally J, each with 10 articles. Morales A and Zhang J have each contributed 9 articles to the body of research. Busch C has 8 articles, while Li J, Ortega-Garcia J, and Zhang L each have 7 articles to their name. Boutros F has contributed 6 articles. These authors are key contributors to the advancement and dissemination of knowledge in the domain of synthetic biometrics and synthetic signatures.

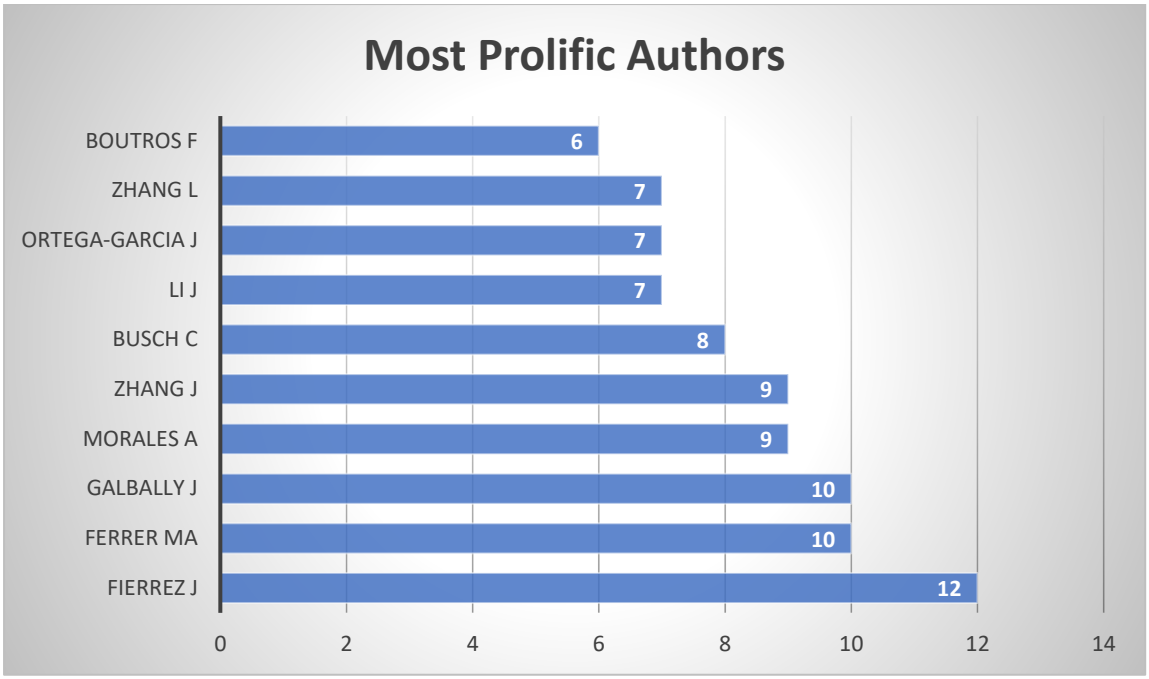

Figure 4: Most prolific authors

3.4 Most Prolific Documents

The dataset on synthetic biometrics, particularly focusing on synthetic signatures, identifies the most highly cited papers in the field, providing insight into the key contributions and their impact summarised in table 1. The top paper is by Hong D in 2019 with 699 total citations, an average of 116.50 citations per year, and a normalized citation count of 20.46. Tao D's 2009 paper in IEEE Transactions on Pattern Analysis and Machine Intelligence has garnered 535 total citations, 33.44 citations per year, and a normalized citation count of 7.40. Galbally J's 2014 paper closely with 509 total citations, averaging 46.27 citations per year, and a normalized count of 7.93. Antoni J's 2016 publication in Mechanical Systems and Signal Processing has 506 total citations, 56.22 per year, and a normalized count of 9.25. Li J's 1996 paper in IEEE Transactions on Signal Processing has 411 total citations, 14.17 per year, and a normalized count of 2.73. Another 2014 paper by Galbally J in IEEE Access has 325 citations, 29.55 per year, and a normalized count of 5.07. Cobéna G's 2002 paper in the International Conference on Data Engineering proceedings has 316 citations, 13.74 per year, and a normalized count of 6.59. Wang C's 2012 paper in IEEE Transactions on Pattern Analysis and Machine Intelligence has 252 citations, 19.38 per year, and a normalized count of 6.35. Cappelli R's 1999 paper in IEEE Transactions on Pattern Analysis and Machine Intelligence has 251 citations, 9.65 per year, and a normalized count of 1.90. Finally, Zobel J's 1998 paper in ACM Transactions on Database Systems has 232 citations, 8.59 per year, and a normalized count of 1.92. These papers are seminal works, significantly contributing to the development and understanding of synthetic biometrics and synthetic signatures.

3.5 Word Cloud

The word cloud map provides a visual representation of the frequency of terms found within a specific context, likely a dataset or corpus related to biometrics, radar imaging, deep learning, and related fields. The larger the term appears in the cloud, the more frequently it occurs in the data. Biometrics, algorithms, synthetic aperture radar, and human-related terms like face recognition and genetics dominate the visualization, indicating a focus on technological advancements in recognizing and understanding human characteristics. Additionally, terms such as deep learning, artificial intelligence, and neural networks suggest a strong emphasis on machine learning methodologies for processing and analyzing data, particularly in the realm of image processing and classification. Overall, the word cloud map reflects a diverse range of topics encompassing both theoretical concepts and practical applications in the fields of biometrics, radar imaging, and machine learning.

Table 1: Most Cited Documents

S. No	Authors	Title	Total Citations	TC per Year	Normalized TC
1	Hong D. Yokoya N. Chanussot J. Zhu X.X.	An Augmented Linear Mixing Model to Address Spectral Variability for Hyperspectral Unmixing	699	116.50	20.46
2	Tao D. Li X. Wu X. Maybank S.J.	Geometric mean for subspace selection	535	33.44	7.40
3	Galbally J. Marcel S. Fierrez J.	Image quality assessment for fake biometric detection: Application to Iris, fingerprint, and face recognition	509	46.27	7.93
4	Antoni J.	The info gram: Entropic evidence of the signature of repetitive transients	506	56.22	9.25
5	Li J. Stoica P.	An adaptive-filtering approach to spectral estimation and SAR imaging	411	14.17	2.73
6	Galbally J. Marcel S. Fierrez J.	Biometric anti-spoofing methods: A survey in face-recognition	325	29.55	5.07
7	Cobéna G. Abiteboul S. Marian A.	Detecting changes in XML documents	316	13.74	6.59
8	Wang C. Zhang J. Wang L. Pu J. Yuan X.	Human identification using temporal-information preserving gait template	252	19.38	6.35
9	Cappelli R. Lumini A. Maio D. Maltoni D.	Finger print classification by directional-image partitioning	251	9.65	1.90
10	Zobel J. Moffat A. Ramamohanarao K.	Inverted-files versus signature-files for text indexing	232	8.59	1.92

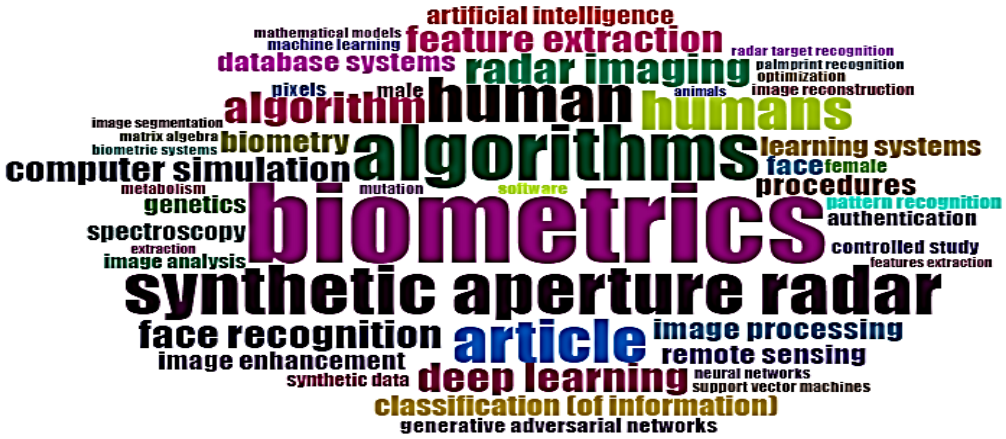

Figure 5- Wordcloud

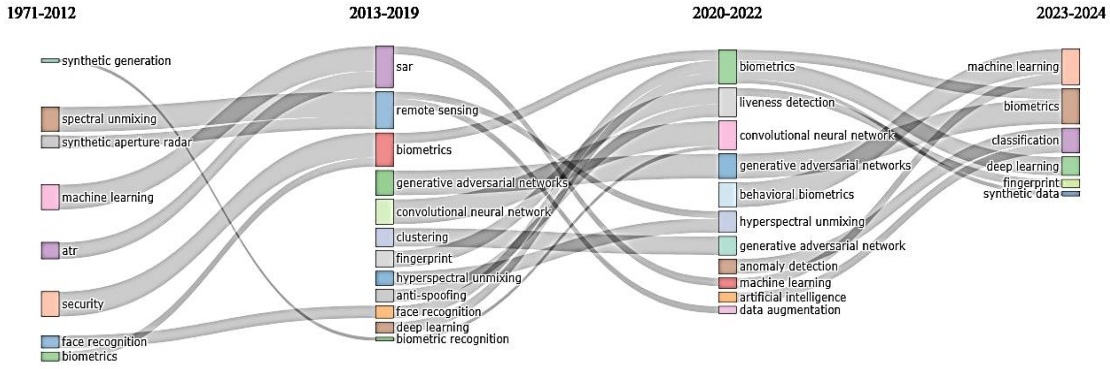

Figure 6: Thematic Evolution

3.6 Coocurrence of Authors across globe

Figure 7 illustrates a global collaboration among researchers facilitated by the Vos viewer software. Evident are the intricate connections spanning continents, indicative of the diverse expertise and perspectives converging in joint research endeavors. This visualization captures the essence of modern academia, where geographical barriers dissolve in the pursuit of knowledge. Through the collaborative efforts depicted, authors from around the world converge their insights, enriching the scholarly landscape with a tapestry of ideas and innovations. The dynamic network showcased underscores the power of technology in fostering interdisciplinary collaboration and driving scientific progress on a global scale.

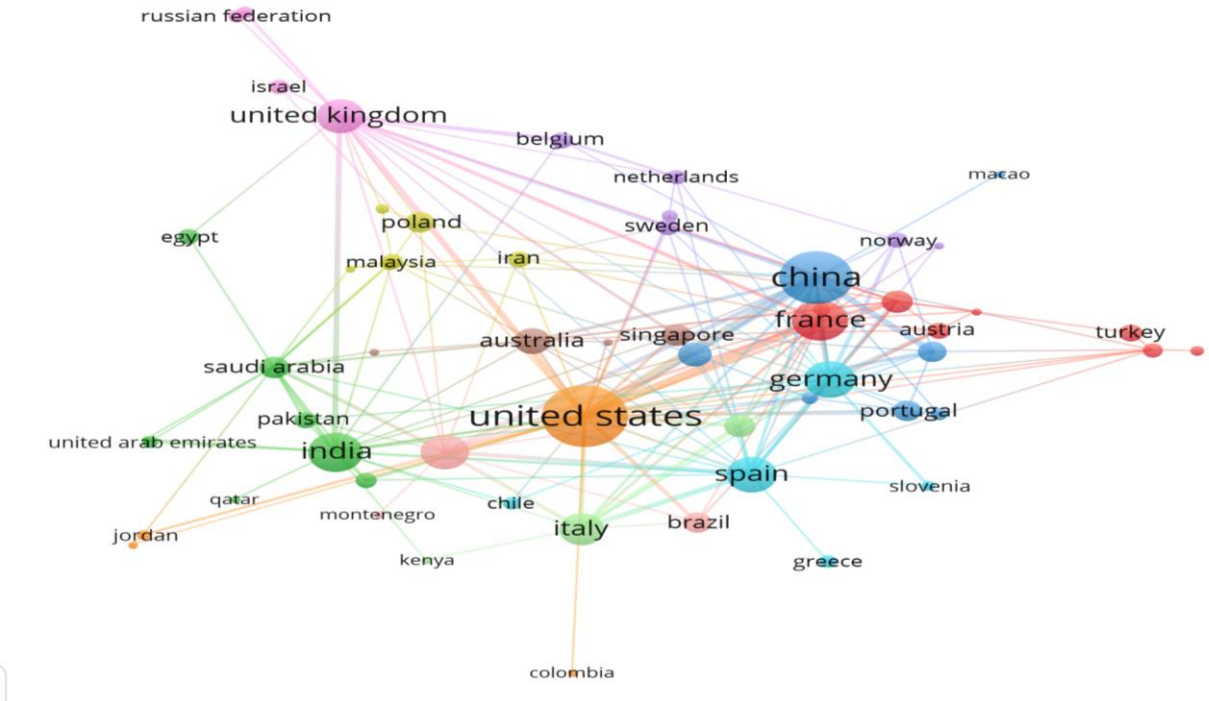

Figure 7: Coocurrence of Authors across globe

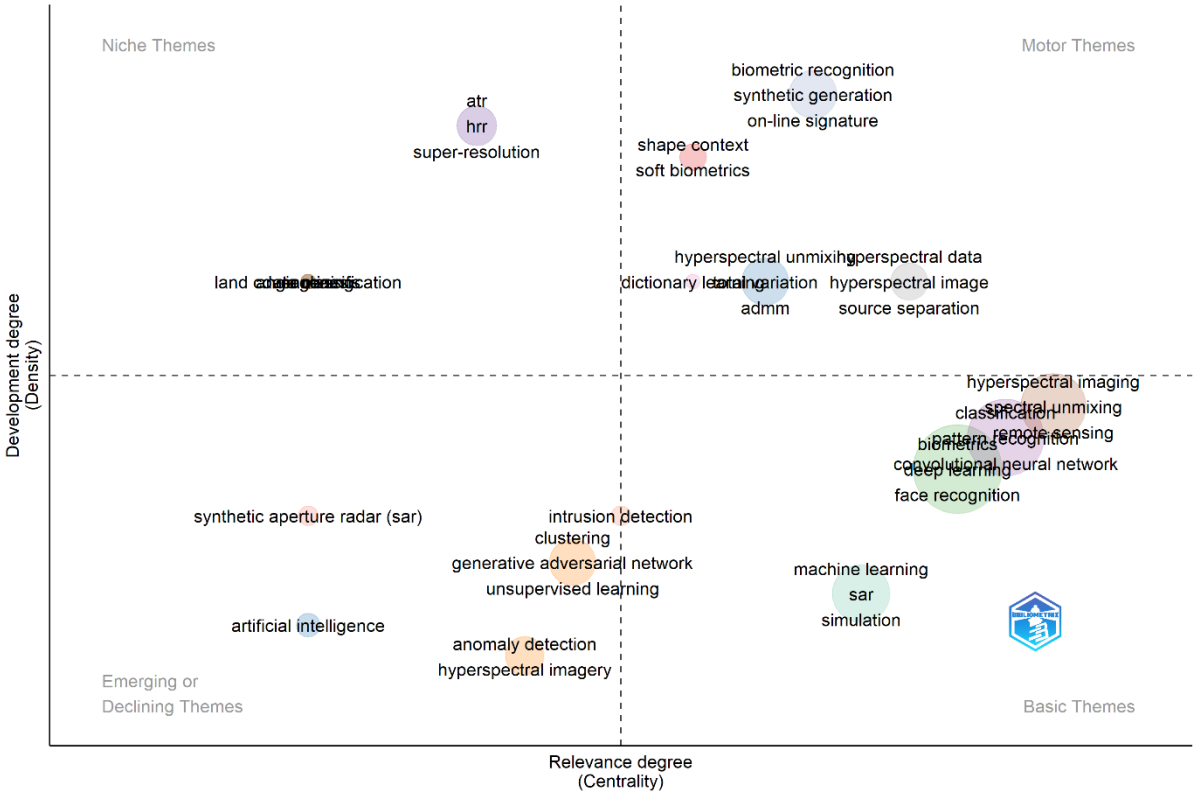

Figure 8: Cluster Analysis

4. CLUSTER ANALYSIS

4.1 Cluster 1: Hyperspectral Unmixing

This cluster predominantly revolves around hyperspectral imaging techniques, focusing on spectral unmixing and related methodologies. Hyperspectral unmixing involves decomposing mixed pixel spectra into their constituent materials, aiming to identify and quantify individual materials within a scene. Techniques such as total variation and ADMM (Alternating Direction Method of Multipliers) are employed for sparse unmixing, which deals with scenarios where only a few materials contribute significantly to the mixed pixel spectra. This cluster also encompasses topics like spectral variability and endmember variability, highlighting the challenges associated with the variability of spectral signatures across different scenes or materials. Applications of hyperspectral unmixing span various domains, including remote sensing, synthetic aperture radar, and machine learning, where accurate identification and characterization of materials in hyperspectral images are crucial. [14]

4.2 Cluster 2: Biometrics recognition systems

The second cluster primarily focuses on biometric recognition systems, leveraging advanced technologies such as deep learning and generative adversarial networks (GANs) for enhancing security measures. Biometric systems utilize various modalities like fingerprint, iris, and face recognition for authentication purposes, with a strong emphasis on anti-spoofing techniques to prevent presentation attacks. Feature extraction and image processing play vital roles in biometric systems, facilitating accurate identification and verification of individuals. Additionally, synthetic data generation and fairness considerations are emerging areas of research within biometrics, aiming to improve the robustness and inclusivity of biometric systems. [15]

4.3 Cluster 3: Classification techniques

This cluster is centred around classification techniques, encompassing pattern recognition and machine learning algorithms for categorizing data into different classes. Convolutional neural networks (CNNs) are extensively used for tasks like image segmentation and authentication, particularly in computer vision applications. Classification methods are employed in various domains such as behavioural

biometrics, gait recognition, and signature verification, where accurate classification of patterns or features is essential for reliable identification and authentication purposes. Additionally, techniques like transfer learning and self-supervised learning are explored for improving classification performance, especially in scenarios with limited labelled data. [16]

4.4 Cluster 4: Clustering algorithms

The fourth cluster revolves around clustering algorithms, which aim to partition data into groups based on similarities or patterns. Techniques like k-means and generative adversarial networks (GANs) are utilized for clustering tasks, with a focus on unsupervised learning approaches. Clustering methods find applications in hyperspectral imaging, where they are employed for spectral unmixing and target detection tasks. Additionally, clustering techniques are utilized in anomaly detection applications, where they help identify unusual patterns or outliers in data, facilitating effective anomaly detection and classification. [17]

4.5 Cluster 5: Hyperspectral Imaging

The fifth cluster is dedicated to hyperspectral imaging, focusing on techniques for analysing and processing hyperspectral data. Remote sensing and synthetic aperture radar (SAR) are prominent applications of hyperspectral imaging, where it is used for tasks such as target detection and endmember extraction. The cluster also encompasses topics like spectral analysis and source separation, highlighting the diverse range of methodologies employed for extracting meaningful information from hyperspectral images. Applications of hyperspectral imaging span various domains, including agriculture, environmental monitoring, and defence, where it enables detailed analysis and characterization of materials and phenomena. [18]

5. CONCLUSION AND FUTURE SCOPE OF STUDY

In conclusion, this bibliometric analysis has provided valuable insights into the evolving landscape of synthetic biometrics, with a particular emphasis on synthetic signatures. Through the exploration of research trends, influential works, prolific authors, and collaborative networks, we have gained a comprehensive understanding of the advancements and challenges within this rapidly evolving field.[19,20]

The findings reveal a significant growth in research activity over the years, reflecting the increasing interest and investment in synthetic biometrics. Key journals and authors have emerged as central figures in driving knowledge production and dissemination, while collaborative networks have facilitated interdisciplinary research collaborations across the globe. However, as with any emerging technology, synthetic biometrics, especially synthetic signatures, present both opportunities and challenges. While they offer enhanced security, accessibility solutions, and potential privacy benefits, concerns regarding deepfakes, forgery, and ethical implications remain prevalent.[21,22]

Looking ahead, the future scope of study lies in addressing these challenges while further exploring the potential applications and advancements in synthetic biometrics. Future research could delve deeper into developing robust authentication systems, mitigating security risks, and ensuring ethical use of biometric data[23]. Additionally, exploring emerging trends such as fairness considerations, synthetic data generation, and novel authentication techniques will be crucial for advancing the field. Overall, this study serves as a foundation for continued research and discussion on synthetic biometrics, providing valuable insights for policymakers, researchers, and industry professionals alike as we navigate the complexities of biometric technology in our increasingly digitized world.

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