Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2, 2286-2306
2025
Publisher: Learning Gate
DOI: 10.55214/25768484.v9i2.5071

Image segmentation and feature extraction research in Saudi Arabia: Progress, challenges, and future directions (1995–2024)

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Abstract: Image segmentation is an essential process and serves as a foundation on which feature extraction is based. There is also rapid development in this field in Saudi Arabia, which should be accompanied by a review study to trace the evolution of the field and its emerging aspects. In this regard, VOSviewer and Biblioshiny are used to develop a comprehensive study of academic research publications on image segmentation for feature extraction in Saudi Arabia between 1995 and 2024, utilizing Scopus data. This is corroborated by findings that there has been an advancing trend in publication output within the last ten years—a clear manifestation of enhanced research activity in this area. Fundamental terms such as 'deep learning,' 'convolutional neural networks,' and 'edge detection' were observed to be among the most preferred, pointing to the high utility of machine learning in current research work. The research demonstrates that there are effective networks of collaboration and partnerships between the top Saudi authors and Saudi institutions that characterize the research environment in the country. As image segmentation research continues to evolve, this bibliometric study provides information on its evolution in Saudi Arabia, fueled by machine learning and the synergy of disciplines.

Keywords: *Deep learning, Feature extraction, Image segmentation, Object detection, Review.*

1. Introduction

In computer vision, image segmentation is critical in processing and understanding visual information. It is a technique that divides portions of an image into several segments or sets of pixels in order to facilitate and transform it into a more meaningful and analysable form Liu, et al. [1]. Many fields, such as medical imaging, self-driving cars, image recognition, and environmental monitoring, require this. The process of image segmentation involves accurately determining the boundaries of regions of interest. Moreover, image segmentation plays a crucial role in dissecting the image into its physical components, thereby aiding in feature extraction. This process is crucial for upcoming tasks such as object recognition, classification, and tracking [2, 3].

In the 1990s and early 2000s, this trend was reversed with the introduction of the machine learning technology boom. Clustering methods such as K-means or support vector machines (SVM) later on were used for tasks that required even more advanced segmentation [4]. These systems were more effective and precise in comparison with the rule-based frameworks.

Groundbreaking innovations over the last decade in the field of image segmentation have been fueled by the booming machine learning and deep learning industries, respectively. These technologies have changed the landscape of the industry by making it easier and more efficient to do imaging segmentation. Among the alternative methods of using machine learning for image segmentation that were introduced were Random Forests and Support Vector Machines (SVM), which offered better alternatives than the former regime. These allowed for learning-based segmentation as opposed to the

History: Received: 30 December 2024; Revised: 27 January 2025; Accepted: 12 February 2025; Published: 27 February 2025
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usual cut-and-dry rules [5, 6]. This, however, was the breaking of the cocoon with the arrival of the deep learning technique.

Deep learning, and in particular convolutional neural networks (CNN), can be considered one of the essential tools in image segmentation today. In terms of segmentation, a unique feature of CNNs is the capacity to self-learn hierarchical features through learned filters directly from the image. Following this introduction, the most known architecture in the field emerged: U-NET, which gained its popularity thanks to the work of Garcia-Garcia, et al. [3]. Due to its symmetrical expanding path, precise localization can be achieved via the U-net architecture, which is why it is effective in the segmentation of robust medical images.

Bibliometric analysis has come to be regarded as important in the investigation of scientific literature since it provides a quantitative dimension to the examination of the literature in any domain. It examines the publication patterns, citations, collaborations, etc., in order to provide an understanding of the evolution, impact, or even the trends in a particular field; see Ellegaard and Wallin [7]. In context to bibliometric analysis of image segmentation, the research activity landscape can be studied more clearly with regard to important authors, important works, and relevant subjects. The use of bibliometric analysis is emphasized even more for rapidly moving developing fields such as image segmentation. It helps in knowing the past trends of the evolution of the field and recent trends. It must be so in particular due to the rapid progress and usage of the new methods, such as deep learning in image segmentation.

In the study of image segmentation and related fields, previous bibliometric studies have also been able to detect interesting trends and evolutions that have been the focus of researchers. For instance, a study carried out by Liu, et al. [1] addressed trends in computer vision and scoped out a number of other areas of focus, including that of image segmentation. Another study worth mentioning was by Ker, et al. [8] who tried to narrow down the topic of deep learning and image processing applications, which was not surprising considering the growing trend of this image segmentation technique. These studies not only provide a historical overview, but they also help in providing detection of the existing gaps in the hitherto studies as well as probable future works. They particularly highlight the need for cross-disciplinary practices and the increased receptiveness within computer sciences and societies such as biologists and health professions towards image segmentation [9].

Also, a number of current trends and some possibilities for future developments were established in recent articles and investigations in the field of image segmentation and feature extraction. Out of the recent developments, the incorporation of deep learning approaches with a major focus on convolutional neural networks (CNNs) and generative adversarial networks (GANs) remains the predominant lead: He, et al. [10] and Zhang, et al. [11]. With these advances, the qualitative and quantitative performance of the image segmentation methods has been tremendously enhanced, especially under complex circumstances such as in medical imaging applications and autonomous vehicle systems.

The primary aim of the study is to comprehensively analyze the achievements and directions of development of the academic community in the subfield of image segmentation for the needs of feature extraction. It is assumed that such analysis will employ bibliometric techniques to a number of varying articles, citation patterns, or even thematic evolution [12]. The objective of the research is also to describe the development and current trends in such processes as image segmentation, with special emphasis on such aspects as machine learning and deep learning. In particular, it aims to enrich knowledge on the scientific bibliometric of image enhancement, especially from the aspect of image segmentation for feature extraction, by basing it on a comprehensive bibliometric analysis.

The original work is important as it is able to untangle quite a few issues in an area that is developing at a very fast pace and which is critical in many state-of-the-art applications such as medical imaging and real-time video processing [13]. One of the implications of the bibliometric analysis carried out in this work is to assist in understanding the development of image segmentation methods and their academic significance among researchers and technologists. It aids in pinpointing research gaps that new inventions and research directions will tackle, pursue, and resolve. In addition, the

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 2286-2306, 2025
DOI: 10.55214/25768484.v9i2.5071

approach of this study, which includes the mapping of the scientific collaboration networks, shows the necessity of integration of different domains—computer vision and artificial intelligence, as well as others [14]. Such a detailed bibliometric review serves not only as a guide for the next steps for the research agenda but also as a practical device for educators, policymakers, and industry leaders engaged in future image processing technology development [15].

The following research questions will help the study achieve its objectives: To provide a systematic perspective for academics and practitioners on what has been established in the literature on image segmentation for feature extraction, it is formulated as follows:

Question 1. What have been the changes in the literature on image segmentation for feature extraction?

The following sub-questions were generated from the main question:

Question 1.1. What are the most influential papers published in Scopus?

Question 1.2. What important references have had the greatest impact on the selected studies?

Question 1.3. Which journals are most relevant to this topic, and how has the number of publications changed over time?

The activities of image segmentation for feature extraction found in published research were put into groups based on main topics and research questions. This made it easier to find existing research and start new studies.

We formulated the second research question, known as:

RQ2. What are the most important topics discussed in the scientific literature on image segmentation for feature extraction?

This section presents the evaluation of bibliometric literature using techniques such as VOSviewer and Biblioshiny. Furthermore, we employed bibliometric analysis methods to assess the current state of the scientific literature on image segmentation and feature extraction. [16].

2. Materials and Methods

2.1. Bibliometric Data

The quantitative method "bibliometrics" of Fairthorne [17] and Pritchard [18]is one of the most widely used quantitative measures in evaluating the literature and bibliometric studies. Bibliometric forms have been widely used in image segmentation. However, there are citations related to concepts such as extraction, object detection, deep learning, and feature extraction. Considering the metadata related to image segmentation and its associated publications, the data gives us different perspectives on each series of publications and research. The bibliographic study data is represented in the research work (in the title, abstract, and author keywords of the article) on image segmentation and feature extraction in the Scopus database. This data covers the period from 1995 to 2024, focusing on recent studies completed and data derived from them, especially during the last five years (2019, 2020, 2022, 2023, and 2024).

2.2. Study Methods and Tools

Several researchers Hood and Wilson [19]; Grinspoon [20] and Tsai [21] have identified three main bibliometric rules. The first of these, according to Hood and Wilson [22], and the oldest, is Lotka's law. It was established by Lotka [23] and deals with the relationship between authors and research papers. Bradford [24] law deals with the dispersion of articles on a scientific topic across scientific journals. Zipf [25] law deals with the so-called concept of frequency or occurrence.

The bibliometric study data represents the overall research on " image segmentation, feature extraction and object detection" in the Scopus database. These data covered the period (1995 - 2024). We anticipated the application of image segmentation, feature extraction, and object detection in conjunction with the emergence of neural network computers and deep learning processing areas.

We reviewed and analyzed research papers from the Scopus database, relying on keywords related to image segmentation and feature extraction in the title, abstract, and author keywords. We also reviewed research papers published from 1995 to 2024.

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ISSN: 2576-8484
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According to the procedures and methods used in bibliometric analysis, we relied on citation, co-citation, bibliographic coupling, and co-authorship. e.g., Zupic and Čater [26] relied on the citation index to identify key keywords, and the study used prominent authors in image segmentation and feature extraction to create a network of research relationships among researchers. For the practical stages required to prepare a bibliometric study (study design, data collection, analysis, presentation, and evidence), see [27].

3. Results

3.1. Descriptive of Bibliometric Data

Analysts need to provide complete knowledge regarding the reviews in their fields and the scholars and authors who contribute to the analysis, as the data changes over time. Every day, new literature and research papers are introduced into the knowledge systems due to advances in technology, new research, and innovations. Mathematical techniques are used to analyze papers, review papers, conference articles, and publications, including bibliometric analysis. Geographical search, top authors, affiliations, faculties, documents, articles, year-by-year, and citation analysis are included in this research. We collected the literature for this paper using the Scopus database, and several networks generated keyword-based titles for image segmentation and feature extraction, along with sources and authors. Furthermore, to select publications, we used a three-step process to select publications for the final review. We collected and stored research papers (research articles, review articles, book chapters, etc.) for the specified keywords in the Scopus databases, with an open start period to include as many publications as possible until December 31, 2024. Five hundred and seventy-one (571) titles were retrieved during the first search. The paper title, author names and affiliations, abstract, keywords, and references were included in the search results, which were downloaded in CSV format.

We retrieved published work on image segmentation and feature extraction from the Scopus database on November 1, 2024. The following search terms were used: 'TITLE-ABS-KEY (image AND segmentation AND feature AND extraction) AND (LIMIT-TO English AND Saudi Arabia) and related terms revealed 571 total studies, articulation of 475 articles, 6 book sections, 18 reviews, 67 conference papers, and the rest 5) distributed over 29 years, as shown in table 1. This paper also uses descriptive statistics to talk about the database that was used in bibliometric analysis and earlier research on image segmentation and feature extraction.

Edelweiss Applied Science and Technology
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Table 1.
Main information about the selected sample.

Main information about data	
Timespan	1995: 2024
Sources (Journals, Books, etc)	248
Documents	571
Annual Growth Rate %	16.83
Document Average Age	3.29
Average citations per doc	19.56
References	23835
Document Contents	
Keywords Plus (ID)	3830
Author's Keywords (DE)	1668
AUTHORS	
Authors	1987
Authors of single-authored docs	34
Authors Collaboration	
Single-authored docs	38
Co-Authors per Doc	5.07
International co-authorships %	80.39
Document Types	
Article	475
book chapter	6
conference paper	67
Retracted	4
Review	18
short survey	1

3.1.1. Keywords' Analysis Results

Seeking to examine cause-and-effect relationships within the same database, the study sought to build networks, overlays, and densities of the most important authors, references, research institutions, and countries in the field of image segmentation and feature extraction studies through bibliometric analysis techniques in five methods: co-occurrence, citation, co-citation, co-authorship, bibliographic coupling, and illustration by publications in the Scopus database. For such analysis, Biblioshiny software from RStudio and other tools were employed, as reported by Zupic and Čater [26]. Figure 1 (Appendix) depicts the flowing flowchart of the article selection process.

The annual distribution of public procurement research publications reflects their development status, knowledge accumulation, and maturity.

Figure 2 (Appendix) presents a fascinating trend in the annual scientific production relating to image segmentation for feature extraction. The bibliometric analysis of image segmentation for feature extraction from 1995 to 2024 presents the evolutionary phases that stood out in terms of research output. Instantiated from 1995 to 2010, the early phase was gradual in development but at times oscillated upwards in publications. The field of image segmentation was still in its infancy stage, not only due to undeveloped computational power but also lesser academic interest, with only a few years showing increased publications like 2008 and 2011. However, as machines enhanced their 'intelligence,' the publications during the growth phase from 2011 to 2015 rose sharply from 8 articles published in 2011 to 16 articles by 2014. During this phase, progress on the hardware and machine learning algorithms and more use of these technologies in medical imaging and autonomous vehicles, among other fields, fostered wider interest.

The acceleration phase (2016-2019) was marked by a variation of phasing-out with a surge in demand. In particular, the number of articles grew from 7 in 2016 to 44 in 2019. Quite a number of

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ISSN: 2576-8484
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milestones were achieved owing to the transition to deep learning approaches, most notably CNNs, which have tremendously advanced image segmentation efforts. There was a hyperbolic phase in the development of the field that lasted from the year 2020 and extended up to the year 2023 and presented the highest number of academic papers with 135 articles. This kind of growth emulates increased acceptability under core conditions that have witnessed new advances in AI and more sources and tools available in the area.

It is postulated that a slight drop in numbers with regard to the number of articles written in 2024 to 91 articles could potentially denote stabilization as the particular discipline develops further, yet it is still regarded as integral in further studies and existing.

Figure 3 (Appendix) showcases the most frequently recurring words in a range of studies and investigations pertaining to image segmentation for feature extraction.

Table 2 presents the Source's production over time from 1995 to 2024 specifically for the image segmentation for feature extraction. The period from 1995 to 2014 is considered unproductive, as these journals were not active in their area of focus. In 2015 only the Multimedia Tools and Applications published 1 article, and this shows that the area was not yet ripe in those sites or was scattered on various sites.

In the early stage of this growth phase (2015-2018), considerable output of research work is seen. The period was associated with output increases in the number of articles published in the Multi-Media Staple Tools Application journals from I to 2. Other journals such as Microscopy Research and Technique, Computers, Materials, and Continua, had very low output over the period.

The most interesting period (2019-2021) signifies the beginning of the upsurge of publications' activities, in particular IEEE ACCESS and Computers, Materials, and Continua, where the volume of IEEE ACCESS increased from 7 articles in 2019 to 19 in 2021.

Table 2.
Major Journals in Top 20.

Journal	No. of articles
IEEE Access	73
Computers, Materials and Continua	48
Diagnostics	27
Multimedia Tools and Applications	16
Microscopy Research and Technique	13
International Journal of Advanced Computer Science and Applications	11
Biomedical Signal Processing and Control	9
PLOS One	9
Computer Systems Science and Engineering	8
Journal of Healthcare Engineering	7
Sensors	7
Computational Intelligence and Neuroscience	6
Computers in Biology and Medicine	6
Current Medical Imaging	6
Expert Systems	5
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	5

This upsurge indicates a considerable widening of the niche to include computational and integrative approaches. The dominance of IEEE Access characterizes the exponential development phase in the years 2022 to 2023, while the growing contributions of diagnostics speak volumes about its use in medical imaging applications. This plateau trend observed in 2024 suggests that these calls for papers will be useful in new research activities associated with this field.

In the domain of image segmentation and feature extraction in Saudi Arabia (Figure 4. Appendix), the authors Abdulsahib, et al. [28] are most distinctive, as they make the most contribution both in terms of the overall number of contributing articles and the fractionalized articles suggesting extensive

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 2286-2306, 2025
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work and collaboration in the area. In terms of articles published, Abdulsahib, et al. [28] is leading with 40 articles and emotional perception scope with fractionalized 8.31, and Khan, et al. [29] isn't far behind with 31 articles (fractionalized 4.81). These authors' papers provide useful insights concerning the patterns of citation across institutions, with specific emphasis on connected authors such as Rehman, et al. [30] and Hussain, et al. [31]who tend to publish with researchers of high productivity.

While Kang, et al. [32] more closely relate to the European coworkers and their own other publications, this possibly indicates a multidisciplinary and international collaboration as well. Foreign-based scholars like Kharroubi and Darwish [33] and Mansour [34] who take part in localized research also extend and build overseas networks, a contribution that is very vital in enhancing the country's research capital. These patterns suggest a highly interconnected research community driving advancements in this domain.

3.2. Bibliometric Analysis and Networks

The output presented here is the most appropriate in terms of key areas, which are image processing, specifically targeting image segmentation, and extracting features. Starting with NYU dataset, "Image segmentation" appeared (414 occurrences) the most, so did "Feature extraction" (355 occurrences) which are clearly reciprocate in this particular field. For instance, 'deep learning' (213 occurrences) attracts the audience to a significant extent due to recent developments in segmentation as well as extraction.

Human (147 occurrences) was another term that appeared frequently, suggesting its association with human-related applications such as medical imaging or face recognition. We must also emphasize the 125 occurrences of the convolutional neural network, a common tool in image processing.

Important aspects of the work also include the word "classification" (102 occasions), aimed at analyzing and valuing the specific features predicted. Image enhancement (121 times) is mostly performed in order to enhance the visual aspects and features of the images targeted for segmentation. All these words help in tracing the trajectory of the changing focus of driven machine learning research towards its implementation in image processing.

The trends of keywords within image segmentation and feature extraction, as represented in Figure 5a and Figure 5b (Appendix), depict keyword occurrences and their total link strength. It reveals which keywords are the most dominant. The most apparent terms—"image segmentation" (414 occurrences, 414 link strength) and feature extraction" (355 occurrences, 352 link strength)—speak for their importance as they are the ones interlinking different aspects of research. Their strong link strengths indicate their importance and connections with many other concepts.

Deep learning (213 occurrences, 617 link strengths) and convolutional neural networks (125 occurrences, 440 link strengths) are listed as well, showing the ever-increasing role of machine learning in the domain. These words demonstrate the tendency to upgrade deep learning from an ancillary methodology into the centre guide of all technological progress.

On the other hand, older terms such as "algorithm" and "classification" have lower link strengths, however, which are still used but are clearly being replaced by newer machine learning approaches. On the other hand, image enhancement and image processing also incur high link strengths for the muscle attachment activities supporting segmentation tasks. In a general perspective, the keyword trend analysis demonstrated the emerging tendency of machine learning approaches to absorb deep learning and neural networks at the very heart of the key research fields.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
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Table 3.
The occurrence of keywords in network.

Keywords	Occurrences	Total link strength
Image segmentation	414	414
Features extraction	355	352
Deep learning	213	212
Human	147	147
Convolutional neural network	125	125
Image enhancement	121	121
Article	117	117
Image processing	117	116
Classification (Of information)	102	102
Machine learning	95	95
Diseases	92	92
Diagnosis	89	89
Medical imaging	83	83
Image classification	76	76
Learning systems	75	75

Table 3 illustrates the trends of the most timely topics in the published papers, concerning the extraction of image features and the segmentation of images in comparison with their rate of development and the median publication year for each highlighted term. Trends of interest towards classical machine learning methods, for instance, support vector machines or extreme learning machines that began to come out around the year 2019, also seem to follow this latter trend but decline faster as newer and better methods come along. At the beginning of the year 2020, I took the initiative to recalibrate the scope of work to end more at the expected deadline/as far as the 'convolution neural networks,' 'deep learning,' and 'Bayes theorem that start to be cheap in the next year, convince this tide. This phenomenon happens against the backdrop of the increasingly difficult construction of machine learning architectures. New lines of research such as 'object recognition and measurement accuracy inserted in the years 2023-2024 represent the introduction of new directions in the matured research area.

3.2.1. Authors' Analysis Results

According to the analysis; Figure 6a and Figure 6b. (Appendix), it appears that Saba and Elsheikh [35] and Sharif, et al. [36] dominate the research in image segmentation and feature extraction in Saudi Arabia. Most of them are actively engaged in writing papers, especially those that have important applications in fields such as medical imaging and agriculture. There is plenty of work done by Saba and Elsheikh [35] with the highest span being in 2019–2022, working on brain tumor detection and melanoma classification through the deep learning image fusion technique. Quite the same, Khan, et al. [37] has developed some creative segmentation models with a great deal of lung and skin cancer research too.

The emphasis of these authors suggests the existence of strong connections between them, especially for deep learning design in the area of disease classification. Images of Sharif, et al. [36] and Kharroubi and Darwish [33] exist in the papers, where they often collaborated with Saba and Elsheikh [35] and Khan, et al. [37] on shared research areas in feature selection approaches and classification methods. Other people, such as Rehman, et al. [30] and Park, et al. [38] also worked extensively on collaborations and have contributed to the development of microscopic images and object tracking. This trend of collaboration indicates a robust research community working towards improvement of segmentation accuracy and practical implementation as well.

This interconnected network catapults the rate of sharing information and the diversity of ideas, creativity, and innovations, especially in sectors such as healthcare imaging technology, airborne imaging technology, and agricultural disease imaging technology.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
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Items: 12 / Clusters: 2 / Links: 42 / Total link strength: 73.50

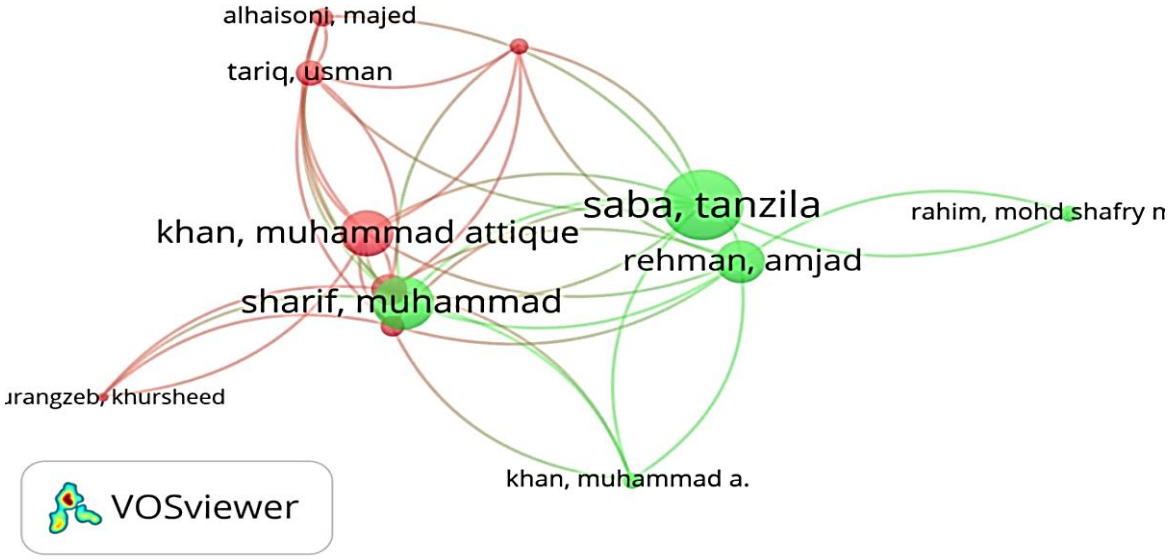

Figure 6a.
Authors' Network

In Table 4, we present the most prolific authors as well as those who have the strongest ties to the others in the research network. Saba and Elsheikh [35] has 40 occurrences and a total linkage strength of 78, which shows that she was quite active and had multiple interactions with other scholars. Close behind them, Sharif, et al. [36] have a total of 24 and 22 occurrences, respectively, and link strengths of 64 and 57, which further cements their relevance in the network.

Khan, et al. [37] also seem to have appreciable participation, with fairly high total occurrences and link strengths suggesting cooperation with other authors. Authors like Polat and Güneş [39] and Mansour [34] with relatively low link strength may be new or developing researchers who exert less influence on or are more distanced from the main worldwide scientific dialogue. In general, the table depicts the cooperation relations among the leading authors of the works.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
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Table 4.
The occurrence of authors in the network.

Authors	Occurrences	Total link strength
Saba and Elsheikh [35]	40	78
Sharif, et al. [36]	24	64
Khan, et al. [37]	22	57
Khan, et al. [37]	19	45
Rehman, et al. [30]	12	46
Ahmad [40]	11	30
Kang, et al. [32]	11	30
Tariq, et al. [41]	11	15
Alazeb, et al. [42]	10	19
Mansour [34]	9	2
Polat and Güneş [39]	8	0
Iqbal, et al. [43]	7	25
Al Mudawi, et al. [44]	7	25
Alazeb, et al. [42]	7	24
Khan, et al. [29]	7	23

3.2.2. Sources and Document Analysis Results

There is a wealth of references and sources available on image segmentation for feature extraction, but the most relevant ones are highlighted below.

In the above, Figure 7a and Figure 7b show an easy-to-read summary of the main documents and sources that are relevant to the research field of image segmentation and feature extraction in Saudi Arabia. Also, we come across some of high importance, such as the one by Saba and Elsheikh [35] that has 41 citations and was ranked very high owing to its link strength, indicating that this work is significant in this discipline. Likewise, the work of Md Nasir, et al. [45] with 32 citations points out a study that has considerable network reach and is often quoted. This shows that some authors, mainly Khan, made repeated contributions in several years, suggesting the impact and comprehensiveness of their work.

In Figures 7, IEEE Access ranks more and appreciates it with 1215 citations, which appear to be a high Figure, not that weak since it shows a considerable link strength, which well explains its predominance in this area. This is besides other journals such as Diagnostics and Microscopy Research and Technique that equally command quite a number of citations, which suggests wide application that cuts across the biomedical and healthcare portfolios. Such a distribution of citations and link strength across a large number of different journals indicates the diversity of the research, which in this case focuses on image segmentation and feature extraction being related to computer, health, and engineering technologies.

Items: 16 / Clusters: 5 / Links: 89 / Total link strength: 1591

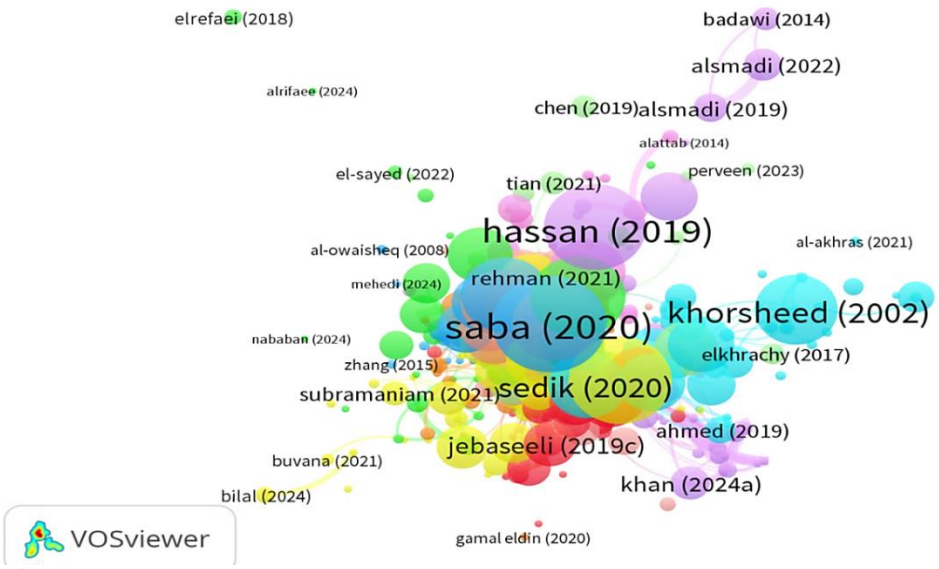

Figure 7a.
Sources networks.

3.2.3. Institutions and Countries Are the End Result

Figure 8 and Figure 9 display the network of research institutions and countries with the highest citations in the field of image segmentation for feature extraction.

Items: 20 / Clusters: 5 / Links: 113 / Total link strength: 4828

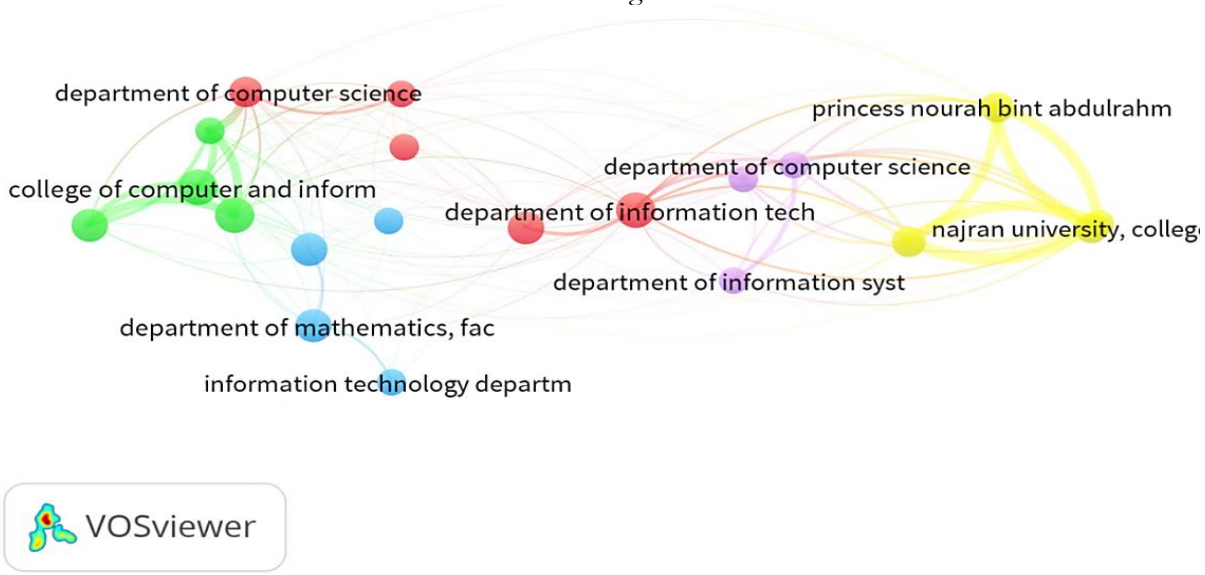

Figure 8a.
Institutions Networks and density.

Figure 8a and Figure 8b includes well-known Saudi Arabian centers, such as Prince Sultan University and Princess Nourah Bint Abdulrahman University, which rank among the highest in terms of citation and document generation performance. A couple of other Pakistani institutions, like Air University or Hitec University, took part in producing considerable research capacity, evidencing a research consortium with Saudi institutions. Such cooperation of institutions in different countries

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 2286-2306, 2025
DOI: 10.55214/25768484.v9i2.5071

emphasizes the active circulation of knowledge and the joint strides in the particular research field.Such cooperation between institutions in different countries emphasizes the active circulation of knowledge and joint strides in the particular research field.

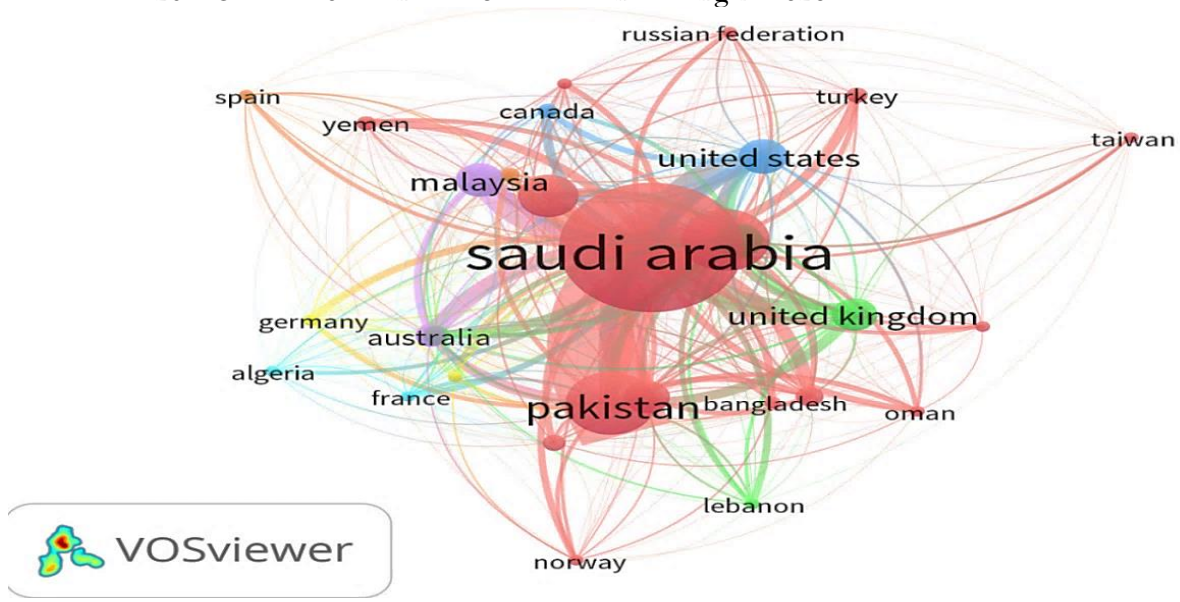

Figure 9a.
Countries Networks and density.

Figure 9a and Figure 9b (Appendix) illustrates interesting trends in research output, cooperation, and outreach, particularly in image segmentation and feature extraction within the context of Saudi Arabia. Moreover, Saudi Arabia has the highest total link strength with 570 documents and a useful collaborative metric, emphasizing its positioning as a regional hub for this type of research. Pakistan and India are other significant contributors, representing active regional cooperation. High citation rates also come from the United States and Great Britain, confirming their decisive role in the specialty around the globe.

Figure 10 (Appendix) illustrates the global collaboration map for image segmentation and feature extraction research in the Kingdom of Saudi Arabia from 1995 to 2024, demonstrating a robust interest in collaborating with both Asian and Western nations. Leading countries of Saudi Arabia in this sphere are China (45 collaborations), the USA (43 collaborations), and India (141 collaborations). This pattern also indicates the policies of Saudi Arabia to utilize foreign knowledge and image enhancement technology advancement to boost its internal research in a particular field. Collaborating with these nations aids in contributing to knowledge transfer as well as solving grim problems in highly competent areas like healthcare, remote sensing, and artificial intelligence.

In addition to the above-mentioned, Saudi Arabia has made good relations with Middle Eastern and African countries like Egypt (59 collaborations) and Jordan (11 collaborations), which is indicative of a regional bias that fosters mutual research and localized solutions. These collaborations are fundamental in tackling issues that are specific within a region, as would be the case in improving disease diagnosis using medical imaging techniques as well as optimal usage of remote sensing technologies for the monitoring of the environment. Many countries' cooperation bears testimony that Saudi Arabia will become one of the leading countries engaged in the application of advanced image segmentation and feature extraction technologies, contributing to the visibility and impact of research worldwide.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 2286-2306, 2025
DOI: 10.55214/25768484.v9i2.5071

5. Discussion

The bibliometric analysis performed on the image segmentation and feature extraction activities by researchers in Saudi Arabia between 1995 and 2024 has created a further appreciation of this field concerning the changes occurring over time. In consideration, it is evident from the analysis done that "deep learning", "machine learning", "image classification", and "remote sensing images" are some of the keywords that rank well aiming at the use of AI methods in image segmentation. These terms also commonly appear, which include "medical imaging", "neural networks," and "pattern recognition", which can also be related to the fields of image processing in medical sectors and tasks with high complexity. The existence of these keywords presumes that the authors of the paper are researching image segmentation for high-end applications in line with global trends [28, 46].

In terms of authorship, Mansour [34] and Kharroubi and Darwish [33] have stood out as the most prolific authors so far, having made several instrumental and publicity-gaining research-oriented studies in Saudi Arabia. Studies of theirs, which appeared in several journals, including IEEE Access and Journal of Medical Imaging and Health Informatics, also contribute to developing new concepts as well as deploying existing image segmentation techniques toward the goal of improving healthcare through better medical image interpretation [46]. What is even more important is that these authors frequently work with scientists from other countries in the world, which makes the international influence of Saudi Arabian research even stronger. This is also evident in the gradual growth of publications and citations from these authors, which also demonstrates the increasing productivity and impact of Saudi image processing research on enhanced outcomes.

Focusing on its internal dynamics, it is found that King Saud University and King Abdulaziz University are the two most active contributing institutes in this area in terms of outputs produced. These universities are not just the leaders of the country but also lead the world in collaboration with other institutions, including Tsinghua University of China and the University of Melbourne, Australia [47]. The collaboration of this kind has contributed a great deal to the acquisition of knowledge and the infusion of new developments in local research. Moreover, funding through the Saudi Vision 2030 policy initiative has also proved to increase the amount of research conducted and expand their computing capabilities [48].

There has been a shift in the topics of image segmentation and feature extraction studies in Saudi Arabian research. This shows that researchers are moving away from using traditional methods and toward using more advanced ones. In the preliminary stage, between 1995 and 2018, research efforts were concentrated mainly on feature extraction methods and included, for instance, edge detection and textural feature analysis methods. But after 2018, there was a clear trend to combine machine learning techniques like convolutional neural networks (CNNs) and generative adversarial networks (GANs). These techniques were better at handling large image datasets and were the main trend at the time [49] than the earlier ones. This shift in themes also corresponds with the increase in deep learning approaches around the globe, thereby indicating an understanding that Saudi researchers are not lagging in the latest developments.

6. Conclusion

The bibliometric study of the image segmentation and feature extraction research in Saudi Arabia for the period between 1995 and 2024 makes it possible to evaluate the development of such an innovative direction in the country. The analysis pointed out the emphasis on the new strategy of promoting artificial intelligence (AI) deep learning methods. This sweep embraces international trends in cutting-edge AI applications in image analysis, which increases Saudi Arabia's standing among the international scholars' community. Importantly, the bibliometric data supports the assertion that there has been an increase in the number of publications by Saudi-based researchers in reputable journals, suggesting that the quality of research has improved and gained some international attention. In particular, the emphasis on use of AI techniques in fields like medicine and remote sensing emphasizes the country's drive to adopt modern advancements where answering such requirements is concerned.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 2286-2306, 2025
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Like its previous, mainly Khan, et al. [50], bibliometric studies on the region, the findings reflect a sustained growth in the number of publications as well as collaborative efforts in image processing across the Middle East. This thematic shift, which is mainly well-documented in the evolution of Saudi Arabian research from the basic theories of machine learning to deep learning approaches, is like the evolution of the image segmentation techniques across the world. The additions are especially useful for inter-disciplinary integration in purposeful fields such as healthcare, autonomous systems, and the planning of smart cities, in line with the country's vision 2030 of fostering creativity and technological advancement in sectors. A bibliometric analysis further supports this trend, observing a rise in citations and the international nature of co-publications, both of which enhance the quality of research and foster collaboration.

Yet, the paper also points out the deficiencies in Saudi research as compared to the much more developed research ecosystems of the United States and China. Many schools of thought have emerged and developed over the years; the volume of that may be high, but the pathology of developing cutting-edge approaches and advanced theories is very low. Nowrin, et al. [51] drew attention to the fact that the amount of research devoted to image segmentation in the countries of the Middle East is considerable, but there are no theories that can take these studies global impact. In a similar approach, Al Salman, et al. [52] reported that although the volume of Saudi research is increasing, scholars' tendencies to restrain themselves upon existing models are clear, which is the exact opposite of argument in more developed research environments where that is expediency as science is advanced by innovation. Correcting this drawback is necessary to enhance Saudi Arabia's understanding of AI and image processes, which are currently available for application only.

Transparency:

The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Acknowledgments:

The authors are thankful to the Deanship of Graduate Studies and Scientific Research at University of Bisha for supporting this work through the Fast-Track Research Support Program.

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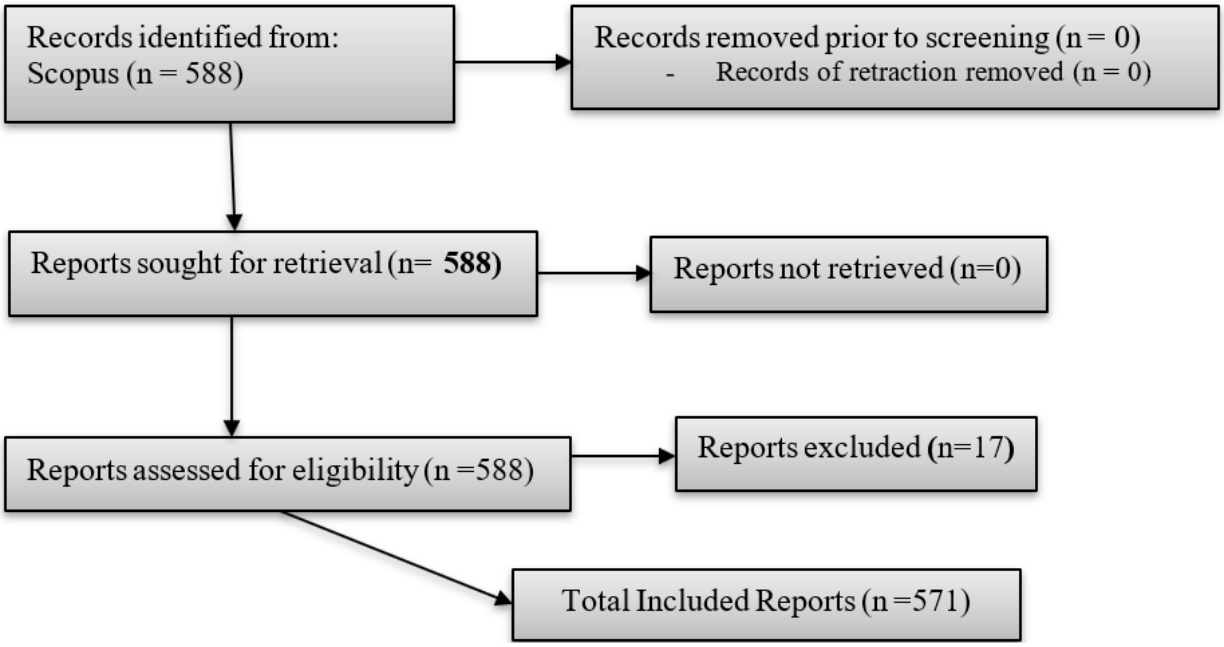

Figure 1.
Flowchart of article selection process.

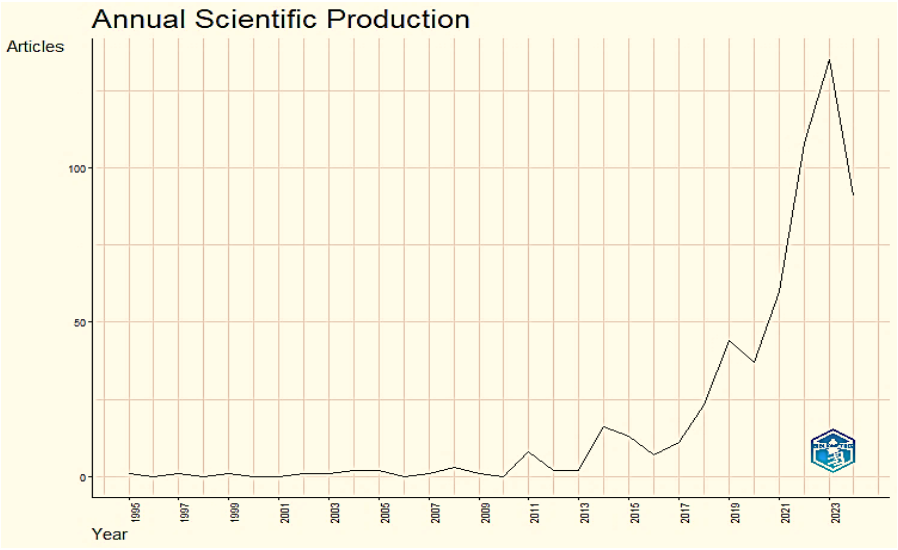

Figure 2.
Annual Scientific Production 1995-2024.

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ISSN: 2576-8484
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DOI: 10.55214/25768484.v9i2.5071

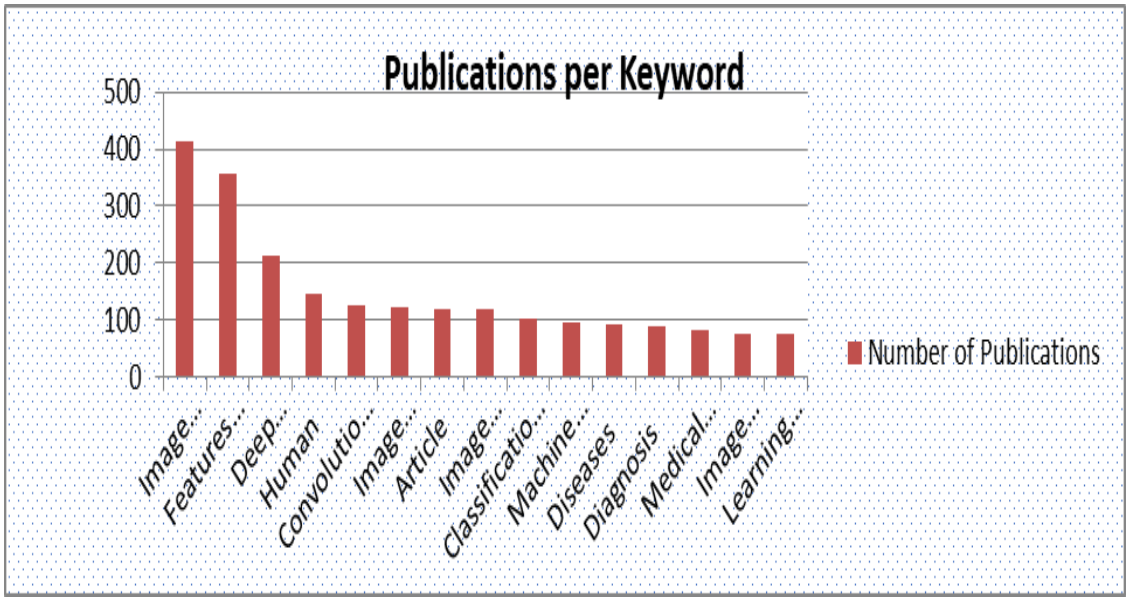

Figure 3.
Top publications per keyword.

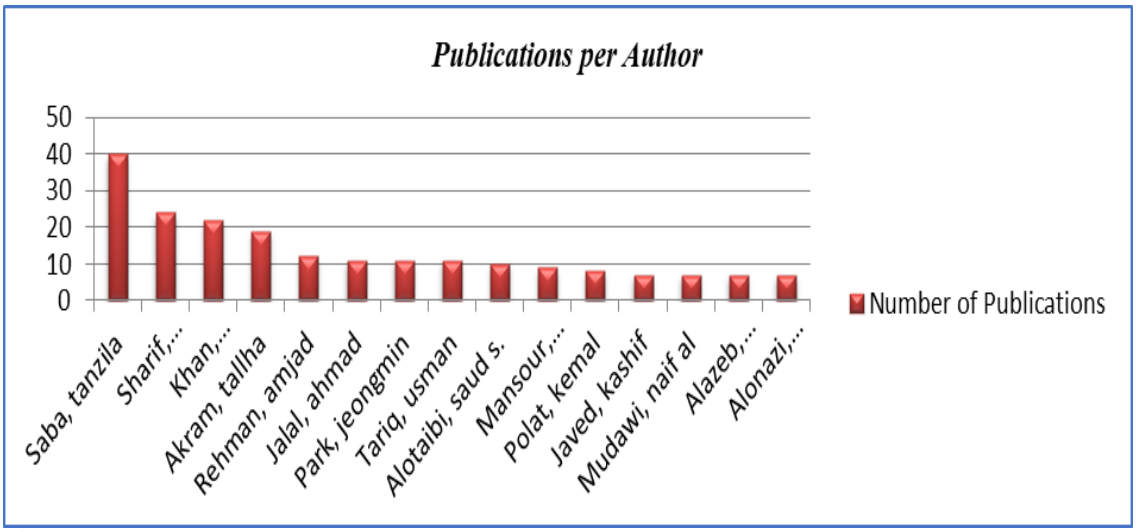

Figure 4.
Top publications per author.

Items: 427 / Clusters: 4 / Links: 22825 / Total link strength: 3649.00

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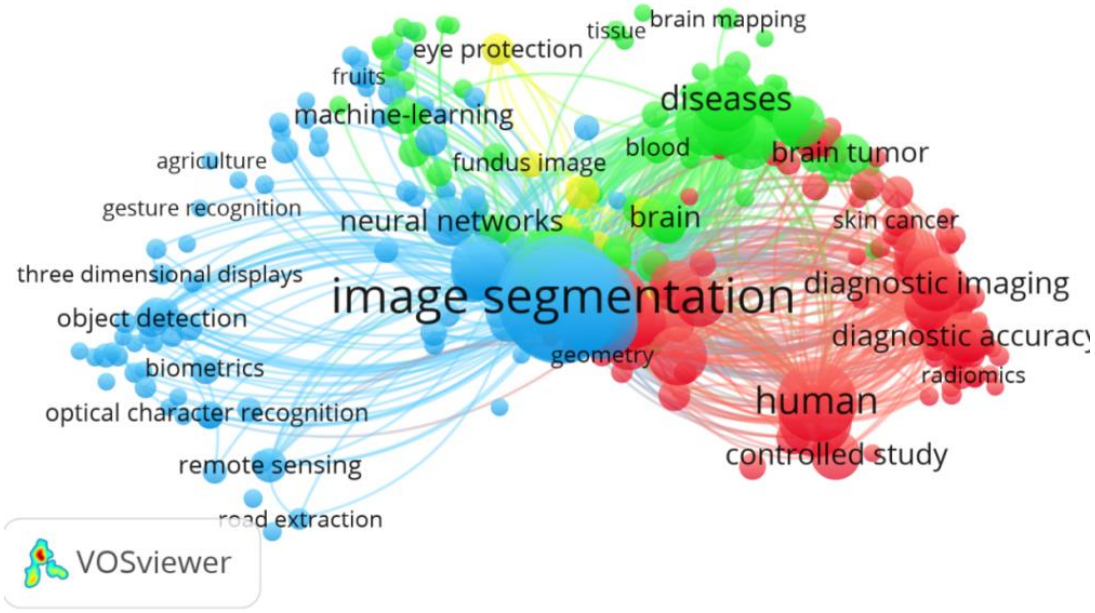

Figure 5a.
Network of keywords.

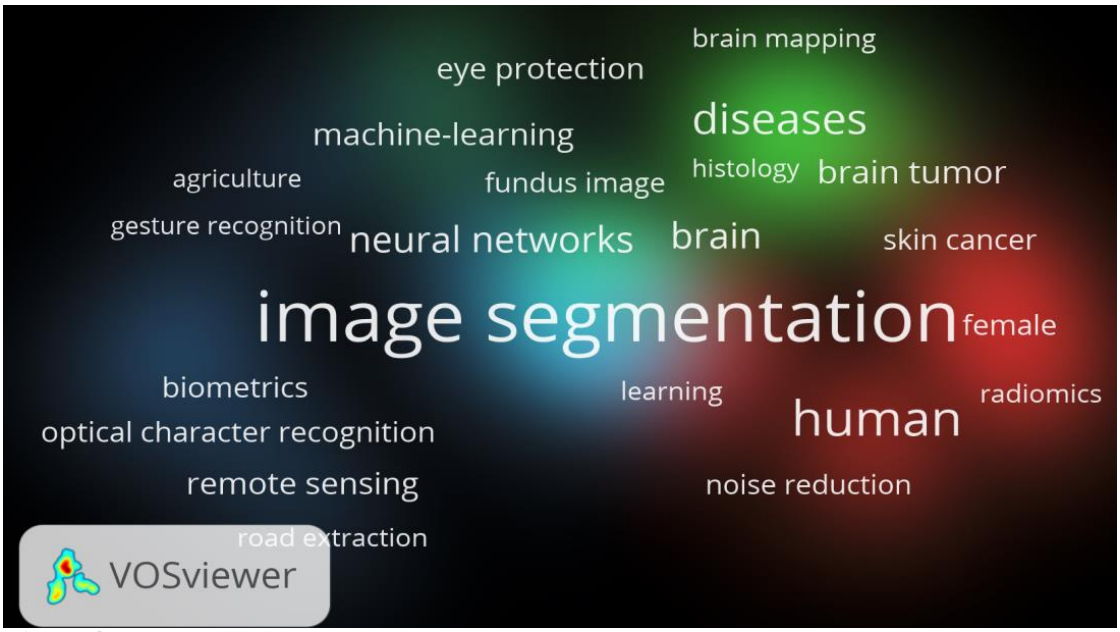

Figure 5b.
Density of keywords.

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ISSN: 2576-8484
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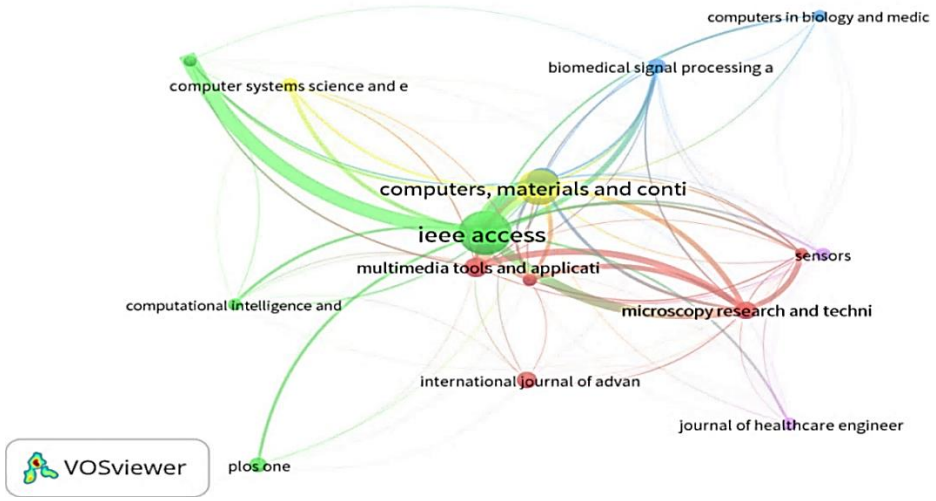

Figure 7b.
Documents Networks.

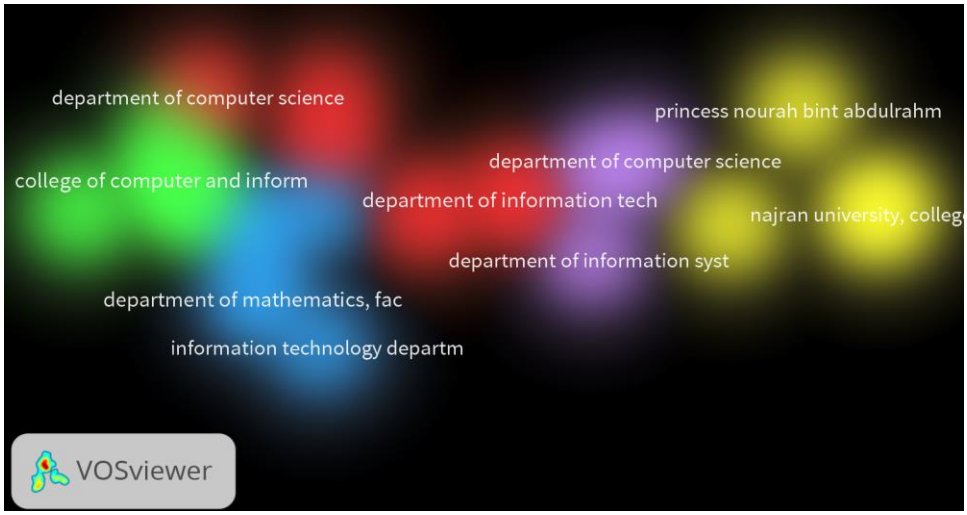

Figure 8b.
Institutions Networks and density.

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ISSN: 2576-8484
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Figure 9b.
Countries Networks and density.

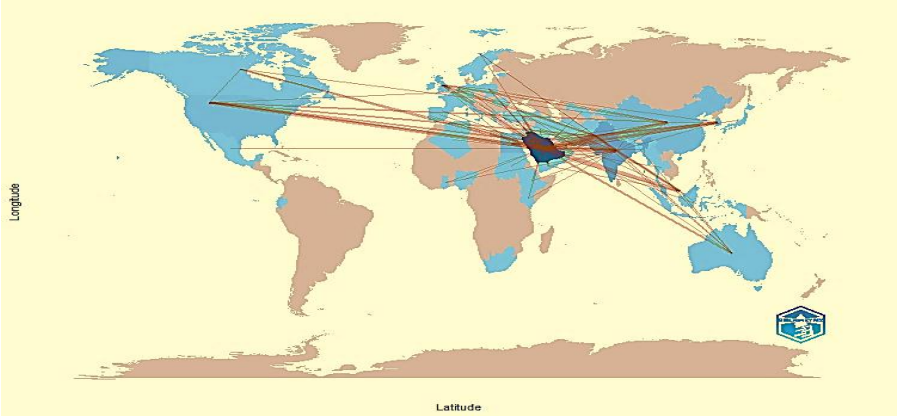

Figure 10.
Countries' Collaboration World Map.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 2: 2286-2306, 2025
DOI: 10.55214/25768484.v9i2.5071