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REVIEW ARTICLE

# Image Segmentation Techniques: Statistical, Comprehensive, Semi-Automated Analysis and an Application Perspective Analysis of Mathematical Expressions

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**Abstract**
Segmentation has been a rooted area of research having diverse dimensions. The roots of image segmentation and its associated techniques have supported computer vision, pattern recognition, image processing, and it holds variegated applications in crucial domains. To compile the vast literature on machine learning and deep learning-based segmentation techniques and proffer statistical, comprehensive, semi-automated, and application-specific analysis, which could contribute to the ongoing research. 16,674 studies have been filtered out from the pool of 22,088 studies collocated by executing a search string on the Scopus database. These studies are analyzed for their meta-data, comprehensive content and reviewed to identify key research areas using the topic modeling-based method (LDA). Also, the segmentation role for mathematical expression recognition has been fathomed out. IEEE is a ubiquitous name in the terms of the renowned publisher, reputed journal (IEEE Access), and most cited affiliation (#10,472). Three out of five extracted topic solutions by the LDA model be evidence of streaming research areas in image segmentation. Medical Image Processing, Machine Vision and Object Identification are the accentuated domains in the context. The streamlining of comprehensive analysis puts forth neural network-based approaches as a trend. Inquisition of segmentation techniques for mathematical expressions articulate neural-based segmentation techniques (CNN, RNN, LSTM) as preeminent segmentation techniques and geometrical features as focused features of the process. To sum up, the purpose of the current study is to summarize the best available research on image segmentation after synthesizing the results of an assorted set of studies.

## 1 Introduction

As a fundamentally challenging aspect of image processing and computer vision, image segmentation techniques have sustained their dominance and significance in the research era for many decades. The researchers and scientists of the milieu have expanded its applications beyond critical disciplines such as medical image processing [159, 169] for tumors [95, 143], [263], cancer [30], and heart disease detection [46, 164] to mundane tasks such as pedestrian track detection [98, 139], video surveillance [262] or casual handwriting [151, 238] or drawn structured document recognition [64]. The emerging trend of applying this partitioning-based method to applications such as augmented reality and extended reality such as meta-verse [126] has made a riveting appeal for researchers of the century. The research on the miraculously advancing domain of image segmentation is gaining consistent prevalence and hype for myriad reasons and facts. The purpose of this study is to boost the ongoing research in this field by extracting the facts and conclusions that have never been previously discovered and noticed. The study introduces new aspects and dimensions by performing analysis on meta-data of around 16,000 studies extracted from segmentation literature. It has also targeted to identify context of these 16,000 text based documents from the literature by deploying formally generative model of documents called LDA [93].

Apart from sublimating the central research area from the selected corpus through topic modeling, the study has insights into segmentation techniques for mathematical expressions. The reasons for focusing on mathematical expressions from the pool of image segmentation

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applications have been explored in detail in the latter part of the introductory section. Covering just the gist, the authors have set their sights on the segmentation of math expressions attributed to the reason that the upcoming trends witness the online mode of education being alarmingly advancing. Being visionaries of the field, we have targeted this specific problem from the pattern recognition application of image segmentation. Moreover, the sphere of pattern recognition welcomes advances in IS techniques now and then. Also, handwritten mathematical expression proffers a scope of more challenging aspects to be explored and investigated in handwriting recognition tasks. Thus, the study has extended its enthrallment to this prototypical aspect.

### 1.1 Research Intent and Objective

The research on image segmentation is progressing, and evidentially so is the count of research literature on the subject. The authors have compiled the current study with the following intent and objective:

Objective 1: To compile and analyze the existing value literature on image segmentation and extract its meta-analytical aspects. Extracting meta-data information becomes crucial for comprehending the hyping research and its direction.

Objective 2: To preview a massive number of documents on image segmentation with a vision to identify the ongoing research trends in the field.

Objective 3: To analyze a specific application of image segmentation in handwritten mathematical expression recognition.

### 1.2 Review of Reviews and Surveys

Numerous surveys have been documented and launched in the domain of image segmentation and its associated techniques. Some of the significant reviews and surveys compiled over-segmentation literature are listed in Table 1.

The analysis of several reviews and surveys, as presented in Table 1, relieved the monotonous trend and culture of analysis where the researchers of the past have limited themselves to comprehensive, comparative, and application-specific reviews. The preview of past surveys analyzed in the paper's later sections of the paper witnesses the prosaic timeline. The considerable amount of research and publications on image segmentation and associated topics has led to a decent space and scope for a survey that could approach the compilation of literature distinctly. So, that is the motivation for formalizing this survey which has four characteristical insights into the emerging domain of image segmentation, making it a novel concern. The preponderancy and pertinence of the review analysis have been depicted vividly in Fig. 1. The review analysis diagram illustrated in Fig. 1 also exhibits the ideation of four approaches of analysis undertaken in the study.

Thus, the novelty of this review is its perspective of analysis. The four perspectives of analysis comprise ***statistical, comprehensive, semi-automated,*** and ***application-specific analysis.*** Also, the associated research questions targeted in the four analysis state are highlighted in Fig. 4. The details of each formulated are defined in proceeding Sect. 1.3. Before reaching the compilation of studies for this survey, the qualitative analysis of significant existing surveys related to segmentation has been scrutinized. Several brainstorming sessions have been conducted to make this review a worthwhile work of reference to the research community. The foremost approach of analysis revolves around extracting and assimilation of meta-analytical facts from a wide range of segmentation literature that has never been done before. Exploring the meta-analytical aspects of a large assortment of segmentation-based literature and articles can be tactically helpful in adding a dimension of thought for future work. That makes this review quantitatively featured and strengthened in terms of statistical analysis. Thereafter, the second form of analysis is focused on the comprehensive aspect, where all the segmentation methods have been extracted and arranged in categories, leading to a classification model of all the leading segmentation methodologies. The comprehensive analysis part also gives insights into the pros, cons, and application areas of deployment of a specific segmentation technique. Elaborating significant aspects of this comprehensive details and information, the focus of the study is then shifted to perform a semi-automated analysis. This part concerns about extraction of key terms from the bulk of studies to predict the significant ongoing research trends in the domain. And also, to be the best for our knowledge, this will be the first-ever semi-automated review analysis where a generative formal text mining-based model (LDA) has been deployed for formulating the active research areas in the segmentation process.

The fourth analysis format includes the application-specific analysis. The result of trend analysis depicted certain domains that have been explored exponentially. The reviewers have targeted a specific application problem from the challenging domain of pattern recognition. This is the problem of handwritten mathematical text recognition. Handwriting recognition is a pioneering problem in pattern recognition, posing a significant segmentation challenge. The authors focused on posing segmentation techniques for handwritten mathematical expressions due to the numerous inherent difficulties encountered throughout the recognition process.

Additionally, the era is transforming educational mediums, which are currently shifting to an online mode, and our future is likely to demonstrate an increased reliance on this medium. Thus, problems with the segmentation and

**Table 1** Review of reviews

| References | Description | Merits | Demerits |
|---|---|---|---|
| [55] | This is one of the surveys that classifies the segmentation techniques into three categories, majorly feature thresholding or clustering, edge detection, and region extraction | Equips with comprehensive details and also author-based comments on thresholding, clustering, edge element detection, combination, parallel, and sequential segmentation techniques | Lacks attention to application-based usage of the covered segmentation techniques |
| [74] | The survey covers and describes the literature works on the very conventional segmentation techniques | Focused on surveying such as measuring space clustering, single and hybrid linkage, region growing, spatial clustering, and split and merge techniques | Less concentration on differentiating different existing techniques and comprehensive, varied studies are presented |
| [167] | The paper summarizes some of the existing methods of segmentation | Comprehensively covers all existing prevailing techniques | Barely leaves scope for surveying segmentation of colored images and calls for attention to fuzzy as well as neural network-based segmentation approaches |
| [207] | This report contains an extensive survey of algorithms for segmentation of the color image | It performs categorization of varied approaches based on the list of attributes and also provides critical remarks for improvement | Surveys cover only a few of the segmentation-related algorithms |
| [203] | The article vividly covers several algorithms and methods related to the segmentation of digital images | The article discusses the six image segmentation algorithms by describing the technique and com· paring different algorithms | Lacks more descriptive analysis of experimentation performed |
| [240] | The study particularly targets the evaluation methods for image segmentation | The evaluation methods compiled with practical choice of the specific algorithm according to deployment necessities | Segregation of different evaluation parameters for segmentation has been vividly performed, yet the study leaves scope to explore the dimension of forming groups of measures that are best suited for any conclusion about the segmentation technique |
| [173] | The survey critically appraises the current status of semi-automated and automated methods for segmenting anatomical medical images | It covers the advantages and disadvantages of each segmentation method discussed | It ignores the in-depth analysis as well as statistical aspects of researched segmentation techniques |
| [260] | The survey reports the analysis and comparison of the evaluation methods are performed according to the classification and assessment criteria for processes and performance metric | A unique study that holds novelty as it covers the evaluation metrics related to it and also compares their performances and potential | It is falling short of analysis descriptions pertaining to the results |
| [89] | The study talks about the segmentation techniques specifically for 3d image segmentation | Creatively discusses the problems related to 3D image segmentation | The broad field of machine learning applied to image segmentation has not been covered |
| [132] | This paper introduces the relationship between a general theory based on Markov random field method and the images and provides a general framework for image segmentation | It covers the varied aspects of the Markov random field-based methods for segmentation | It lacks descriptive comparative analysis |
| [256] | The study covers unsupervised evaluation measures for the evaluation of segmentation techniques for images | Analytical and empirical evaluation analyzes the advantages and shortcomings of the underlying design mechanisms in the discussed methods | The empirical shreds of evidence and discussions presented for the experimentation process of unsupervised methods are complex to analyze |
| [202] | The core objective is better understand the soft computing approach to image segmentation | The article primarily focused on multicomponent images segmentation and discussed the benefits that could be extracted from its environment | It covers vividly only soft computing-based applications of image segmentation |
| [188] | This survey addressed various segmentation techniques, discussed fundamental methodologies | It encompasses issues and addresses associated issues and problems | It lacks research trends prediction and description, and the approach of review is redundant |

**Table 1** (continued)

| References | Description | Merits | Demerits |
|---|---|---|---|
| [102] | This paper is a survey on different clustering techniques to achieve image segmentation | The article presents a comprehensive survey highlighting other clustering techniques used for image segmentation | It covers only complete aspects and lacks comparison |
| [72] | The paper provides a review of advanced methods used for the segmentation of color images | The article brilliantly represents a report on segmentation techniques exclusively based on color information, with a few exceptions | This total comprehensive survey lacks essential representation to illustrate the myriad range of techniques addressed by them |
| [217] | This study provides a comprehensive survey of color image segmentation strategies adopted over the last decade covering spatially blind approaches as well as spatially guided segmentation methods | In addition to the segmentation technique, they provided associated future trends | This survey covered only a few of the segmentation-related algorithms |
| [107] | The article provides a comprehensive review of significant types of segmentation methods | Looks at a wide assortment of image segmentation techniques like Edge-based, Fuzzy Theory-based, Threshold-based, ANN-based, PDE-based, and Region-based Segmentation analyzes them and describes the issues | Deprived of content related to comparative analysis of the described techniques |
| [171] | The author focused on graph-theoretical methods for image segmentation in which partitioning a graph into several sub-graphs to extract the valuable image | They represent automatic and interactive segmentation methods | The focus of the study limits itself to graph-based methods whose insights are limited to a domain |
| [196] | A survey highlighting different clustering techniques used for image segmentation has been presented | It portrays the clustering and segmentation basics vividly | The descriptive analysis is short and calls for more illustration |
| [189] | The primary purpose of this survey is to provide a comprehensive reference source for the researchers involved in Fuzzy C Means-based medical image processing | Varied fuzzy c means algorithms for segmentation are discussed | The description of algorithms lacks details and misses out on illustrations |
| [105] | This paper tries to put light on the basic principles of the methods used to segment an image | It discusses primary segmentation methodologies and algorithms assuredly and also compares several segmentation techniques | This paper lacks concentration on the more advanced segmentation methodologies |
| [106] | The article covers image segmentation methodologies tha have been used in the last five year | This article comprehensively covers major six categories of image segmentation techniques | This article reviews and covers segmentation techniques in a short time span of five years and lack comparative analysis |
| [50] | This paper systematically summarizes the image segmentation techniques in solar image retrieval and the recent applications of image segmentation | It talks about the merits and demerits of each segmentation technique | The article is inadequate in terms of comparative analysis |
| [250] | This survey compiles information about block-based image segmentation IS techniques | Well-organized survey which covers varied methods and techniques lying under both region and edge-based image segmentation type | In spite of the well-structured documentation, the study published in 1980 loses its impact as it misses out on the emerging and recent trends in image segmentation |
| [206] | The contents of the study concentrated on some core and fundamental types of segmentation techniques and equipped with the provision of an overview of the focused techniques | Analysis and comprehensive assessment of these image segmentation techniques have been performed with minute detailing | Dearth in comparative analysis and calls for attention to many unattended segmentation procedures |
| [144] | The study represents discussions on the application of Metaheuristics to image segmentation based on deformable models | Analyzes and contextualize the most notable and recent works on deformable model-based segmentation techniques | Though the work has a novel direction yet, it doesn't cover descriptive solutions to the described problems related to deformable models based on segmentation |

**Table 1** (continued)

| References | Description | Merits | Demerits |
|---|---|---|---|
| [43] | Clustering techniques segmentation has been discussed in this study | Detail description of the clustering technique is discussed | Limited to one type of segmentation technique |
| [116] | This paper compares and analyses the performance of diverse edge detection techniques for recent digital image processing like canny optimal edge detection, Sobel operator, prewitt operator, and LoG | Highlights exciting facts and conclusions related to linked segmentation techniques and parameters | It pines for more theoretical as well as practical aspects |
| [249] | This paper mainly describes the five segmentation algorithms for simple analysis | Analyses and summarizes these image segmentation algorithms, and compares the advantages and disadvantages of different algorithms | The article yearns for comparative analysis |
| [35] | Article emphasis is on core Soft computing approaches like Fuzzy logic, Artificial Neural networks, and Genetic Algorithms used for image segmentation | This paper elaborates to readers about all dimensions associated with image segmentation | This paper segmentation technique only focused on soft computing methods |
| [94] | The study describes the primary prevailing segmentation techniques | The study analyses and summarizes image segmentation algorithms, and compares the advantages and disadvantages of different algorithms | The study is well-written yet leaves a decent scope for delving deeper into a few chosen topics of discussion |
| [65] | This article approaches these various deep learning techniques of image segmentation from an analytical perspective | A unique and well-documented survey that investigates deep learning-based segmentation methods profoundly | In this article, some statistical discussions over the literature can be added |
| [146] | The comprehensive review covers the deep learning-based evolving segmentation techniques | The article investigates the relationships, strengths, and challenges of DL-based segmentation models and examines well the datasets along with comparing their performances | Lacks statistical aspect of the literature present on image segmentation |
| [147] | This paper reviews various existing clustering-based image segmentation methods | The paper vividly diagnoses and bifurcates clustering-based segmentation methods and covers performance parameters for the quantitative evaluation | The paper deprives of comparative aspects |
| [197] | This paper presents a comparative analysis of existing segmentation techniques | It covers concepts related to modification techniques to form new segmentation techniques, which can overcome some of the drawbacks of the existing approaches | In the paper, statistically, coverage of the literature is still a scope |
| [161] | This paper provides a comprehensive review of different image segmentation techniques | This paper compares each of the existing methods very appropriately | Tabulated comparison of details |

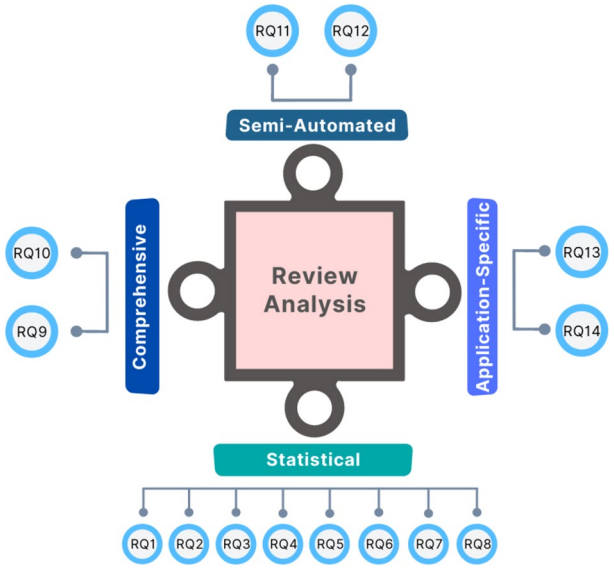


**Fig. 1** Concerns of review analysis

recognition of handwritten text should be prioritized, as handwriting is one of the most straightforward modes of input. Segmentation of mathematical text poses more perplexing problems than segmentation of traditional English text. Thus, the researchers in this article focused exclusively on the use of segmentation in recognition of handwritten mathematical expressions.

### 1.3 Upcoming Extracts of the Study

The subsection upfront the formulated research questions as listed in Table 2. Accordingly, the rationales or motivations for posing these research questions have been aforementioned, corresponding to each study extract (refer to Table 2).

### 1.4 Value Outcome of the Study

The study is determined to contribute to the existing informational literature sets and push the research limits by adding an entirely new spectacle to the current lookout and directing the future works to be carried out in the domain. Following are the ways by which the study will fruitfully provide board for value outcome:

a) By providing a statistical overview, highlighting the distinct frame of reference (authorship, continent wise, publication channels, journals, time growth) with context to the targeted amount of literature on image segmentation.
b) By subliming the current research-related facts and information related to the meta-data aspect of the publications over the years.
c) By strategically determining the ongoing research trends and active areas in image segmentation by successfully deploying a text mining-based topic modeling concept called LDA.
d) By perpetrating comprehensive analysis of pertinent image segmentation techniques and drawing a classification diagram representing the categorical association.
e) By specifically targeting the role of segmentation in mathematical expression recognition and extracting the deployable segmentation-based details and prospects.

## 2 Predominance of the Proposed Survey Method

This article portrays an exceptionally prototypical survey, groundbreaking and innovative in every aspect. The survey presents the multiple scenarios and visionary colloraries that carry impactful intent and potential to frame the existing research literature on image segmentation statistically, comprehensively, analytically, and suggestively. This remark has been made after accomplishing intense research and dense genesis of existing surveys, reviews, and reports on image segmentation. The timeline of survey studies reported to date has been thoroughly analyzed for their genre, style, and prototype standpoints. Afterward, they are mapped on the timeline series, keeping their characteristically and prototypical aspects in mind. So, proving the novelty of the proposed survey style, the authors have analyzed all existing surveys of the past and presented a timeline of surveys.

Also, the literature on segmentation has been mounting with hypes and types, and the constant launch of surveys has been witnessed throughout the chronicles of segmentation. At the onset of this survey, the authors have covered the significant surveys that have been periodically reported in Table 1. Here, in the section, the reporters of the review have endeavored to plot a timeline of surveys and reviews launched since 1980. From the foremost survey to the recent reviews that are being consistently reported, the trend and figures depict the compelling urge of the research community to advance the literature on image segmentation. The genesis and the entire history of these surveys and reviews can be visualized from different scenarios and perspectives. Every time frame of history has different genres of surveys to offer. Our best efforts have been to compile these surveys and introduce a timeline highlighting the genera of surveys w.r.t. four broad brackets of time frame. Every differentiated time bracket has varied types of surveys to be displayed. Thus, the reported survey timeline has been drawn, as evidenced in Fig. 2. The four shelves of time are nomenclate

**Table 2** Research questions

| Research Questions | Rationale |
|---|---|
| 1.Statistical analysis | |
| RQ.1 Which are the chief publication channels for research production in image segmentation? | To extract and analyze the publication sources for publishing segmentation-based research articles |
| RQ.2 What are dominating journal names for looking for image segmentation-based research articles? | To envisage and ferret out popular journal names when it comes to publishing IS-based articles |
| RQ.3 What are the pre-eminent names of digital databases prevailing in image segmentation research? | To investigate the digital libraries like Springer, Elsevier, etc., in terms of their research papers |
| RQ.4 What are domineering authors contributing to research in image segmentation? | To highlight and adduce the names of researchers and practitioners contributing significantly well to the field of IS |
| RQ.5 Which countries and continents are advancing exponentially in the domain? | To perform a comparative analysis of the research conducted by various countries and continents and highlight the countries actively conducting research on IS |
| RQ.6 Which universities are predominantly progressing for research in the domain? | To catalog and analyze research activities in image segmentation over a time frame |
| RQ.7 What is the year-wise statistic report of growth in this domain? | |
| RQ.8 What are prevailing keywords in image segmentation? | To trace out primary keywords involved in image segmentation-related research articles to guide the other procedural research steps like search string formulation |
| 2.Comprehensive analysis | |
| RQ.9 What are the major image segmentation methodologies? | To elicit and capture all latent segmentation methodologies that have a convicting trend in the present era |
| RQ.10 How be the extracted image segmentation methodologies classified? | To evince and draw a classical and categorical reference hierarchy from extracted segmentation methodologies |
| 3.Semi-Automated analysis | |
| RQ.11 How to extract key research areas? | To illustrate the course line of semi-automated analysis performed to extract the key research areas discussed in the next question |
| RQ.12 What are the extracted key research areas? | To identify and determine chief areas of research in image segmentation. This question is formulated to target also cardinal research applications of image segmentation |
| 4.Application-Specific analysis | |
| RQ.13 What is the significance of segmentation in mathematical expression recognition? | To legitimize and rationalize the role of segmentation in mathematical expression recognition |
| RQ.14 What are prominent segmentation techniques used for mathematical expression recognition and significant features for segmentation in mathematical expression? | To deduce all types of segmentation techniques purposefully used for the mathematical expression recognition process and infer the informational details around them. Also, equipped with the details of major con-centered features involved in the recognition process |

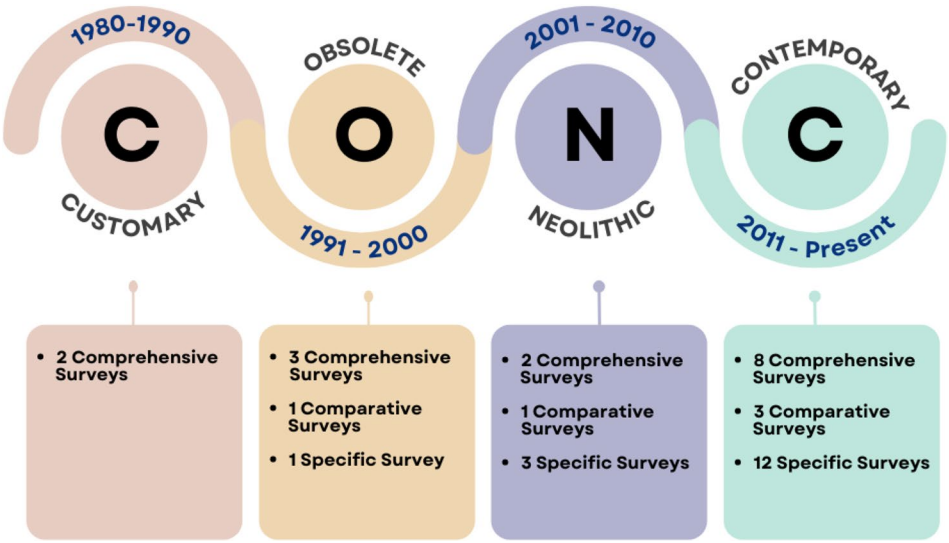


**Fig. 2** Timeline of reported image segmentation based surveys

according to their characteristical aspects, and the surveys approached in the specific period have been described as follows.

- Customary: 1980–1990

The most ancient considered time frame ranging from 1980 to 1990 witnessed a very classical trend of surveys, mostly of comprehensive type. The comprehensive surveys are of the kind which presents descriptive details of the segmentation-related methodologies and techniques. This genre of survey has its own pros and cons to be identified and labeled. One of the prevalent merits of such comprehensive reports is that they can discuss well and cover most aspects related to all posed technologies. These types of surveys may overpass the comparative analysis of the focused techniques related to segmentation. The exhibited timeline analysis depicts the occurrence of only two such comprehensive surveys [55, 74, 102] in the time bracket of the customary phase, as displayed in Fig. 2. The inference can be drawn that this was the onset period, so not much attention was paid to conducting surveys.

- Obsolete: 1991–2000

This decade introduced a variety of types of surveys being conducted and reported. The genres of surveys been recorded are comprehensive, comparative, and specific. Detailing down to how these terminologies have been used for nomenclature, the authors made an effort to recognize and classify the recurring patterns in surveys. The comparative term is self-explanatory, which apparently depicts the articles based on performing comparative analysis between several types of segmentation methodologies. Later, the term specific-type has a broader aspect to cover.

The specific-type term refers to surveys targeting specific aspects, like applying segmentation in a specific field. It can be specified in terms of a category of segmentation technique. For instance, the survey covers clustering-based segmentation techniques. Such types of detailed surveys are consolidated under this category. Thus, the approach followed by several researchers for the compilation of literature has been overlooked. Three comprehensive survey articles [167, 207, 240] and single instances of comparative [203] and specific-type [173] based reviews have been explored. Thereby, the inference can be portrayed that the obsolete era has phased three genres of surveys, as exhibited in Fig. 2.

- Neolithic: 2001–2010

The Neolithic phase proved to be a kind of medieval era of the time history of segmentation surveys where the published surveys focused on compiling more specific types of reviews. All the three genres defined (comprehensive, comparative, and thorough) have been witnessed in the surveys considered in this time frame. There have been reportedly three specific types of surveys, two instances of comprehensive surveys and a single instance of comparative surveys. The inference can be drawn from this phase that comprehensive surveys have been prevalent in the last three decades. Still, shifting attention towards specific type-based surveys has also been noticed. The comparative analysis-based survey is still found to be on the verge of seeking more attention from the survey community of research.

- Contemporary: 2011–Present

The trend of surveys reported in this decade went on an interesting roller coaster ride as the decade witnessed an escalating rise in the number of surveys being launched and published. To our amazement, we discovered and extracted as high as 23 surveys in the time bracket which is genuinely a jaw-dropping count. There have been 12 specific types of surveys [35, 43, 50, 55, 65, 94, 102, 116, 144, 146, 147, 189, 196] been listed in this phase, eight comprehensive surveys [72, 106, 107, 171, 206, 217, 249, 250] and three comparatives [105, 161, 197] surveys as postulated in timeline diagram (Fig. 2). The inferences thus drawn from this finding sum up that attention of researchers in the past decade has been allured by specific field-based surveys related to segmentation. Also, the comprehensive classical surveys never got out of trend, and the thoroughly comparative surveys seem so spaced out and call for more attention at large.

The reason for looking back at the most conventional and old surveys is to indoctrinate the entire conceptualization of surveys and reviews that have been recorded to date. The voyage of diving down in the past to rising present aids and abets in comprehending all the perspectives of visualizing and presenting the literature. The timeline discloses four survey styles and contrasts, which had limits and limitations (as mentioned in Table1). The idea of visualization has been extended to cover up these gaps and add a new vision to the existing records. Prospective of bringing up this article is the accrue to the existing conceptualization of surveys by introducing a completely newest embodiment version of scrutinization with broadened scope. The survey has covered all major genres of statistical, comprehensive, semi-automated, and application-specific types. Thus, sublimating concise and significant facts and conclusions from a massive set of literature recorded on segmentation contributes to the novelty of our survey methodology.

## 3 Research Methodology

The review methodology at the planning phase of the report has been attentively planned and developed. The developed methods and research phase include a step-wise procedure, as depicted in Fig. 3. At the onset, the very first step in the planned methodology is (1) setting the research objective, (2) formulation of research questions, (3) Search procedure, (4) Corpus Collection, and (5) Corpus Analysis. The research objectives finalized for the conduct of this survey have been decided at the onset. According to the second step, the research questions have been formulated. An extensive search procedure has been carried out where a specific search string has been formulated and executed for the fetching corpus. As the objectives depend on corpus related to segmentation techniques associated with machine learning, artificial intelligence, and deep learning, the string has been designed and executed on Scopus digital database.

The string for corpus collection:


**Fig. 3** Research methodology

("image segmentation" OR "segmentation methods" OR "segmentation techniques") AND ("machine learning" OR "deep learning" OR "artificial intelligence").

The search string retrieved as high as 22,088 studies. Later, this crude corpus collection has been filtered based on inclusion–exclusion measures mentioned in Table 3.

After imposing all the inclusion and exclusion parameters as stipulated in Table 3, the final set of the corpus is mustered up. The final corpus with a count of 16,674 has been retrieved.

After accomplishing corpus construction, the corpus analysis has been taken as a phase to be executed where the corpus has been investigated as per the formulated objectives of the study. The analysis includes statistical, comprehensive, semi-automated, and application-specific analysis and pictorial representation of the research methodology as portrayed in Fig. 3. Later, as per the analysis, the results are extricated and discussed w.r.t. the formulated research questions. The key concerns of each analysis category are described as follows:

1. The statistical analysis is all about reviewing the meta-data of the collected studies and concerns about the extraction of facts based on statistical information.
2. The comprehensive analysis focuses on analyzing all the existing image segmentation techniques and drawing out categorical classification based on their types and methods.
3. The semi-automated analysis extracts the ongoing trends in the segmentation domain by deploying a generative formal document model called LDA.
4. The application-specific analysis has been conducted for particularly probing into segmentation methods and techniques implemented in handwriting recognition of mathematical text.

**Table 3** Inclusion–exclusion parameters

| Inclusion parameters | Exclusion parameters |
|---|---|
| Text of articles should be in English | Multi-lingual articles are extricated |
| Meta-data details should be mentioned clearly | Other than that, English is also excluded |
| Directly related to the segmentation process should be considered | Studies not directly associated with segmentation problems are discluded |
| Thoroughly relevant in terms of objectives of the research questions | Articles with missing information or incomplete meta-data details are proscribed |
| Only the journal version will be included for a study that has both conference and journal versions | The studies published in unidentified sources and channels are also omitted |
| For duplicate publications of the same study, only the most complete and newest one will be included | |

## 4 Research Questions and Discussions

### 4.1 Statistical Analysis

RQ1. What are the dominating publication channels for the domain of image segmentation?

The research literature on image segmentation has been mounting at an alarming rate. The idea for analyzing publication venues for research production is inspired by the concept of directing and sublimating the facts regarding the significant publication channels for segmentation-based studies. The meta-analytical aspect of 16,674 studies has been revisited, estimated, and calculated with precision, and the conclusive figures related to publication channels are depicted in Fig. 4.

The authors have attempted to determine the publication venues that have made a contribution to the compendium of studies. The purpose of this analysis is to assess and deduce the origins of relevant studies so that, ever the need arises to delve deeper into the papers and refer to additional documents in this domain, these high-ranking sources could be shortlisted for use as secondary sources of literature. Additionally, this analysis establishes a level of priority for future researchers by serving as a secondary database for comprehending this research domain and helping them apprehend which channels contribute tremendously to the research production of segmentation-based articles. The cosmic range of articles has been found in journals and conferences by analyzing Fig. 4. Around 53% of studies are published in conferences, and 45% are obtained from journals. Other sources like reviews, book chapters, and miscellaneous publication channels contribute the remaining marginal percentage of the count.

Conferences are revered as venues for reporting on Computer Science (CS) research [170]. In contrast to other academic fields, the length of conference papers in CS enables sufficient detail to be reported and discussed in work. While some researchers castigate the use of conferences as the primary mode of dissemination in computer science [53, 218], others argue that high-quality conferences have a higher average citation rate than journals in the same stratum [220], indicating that they serve as a distinct mode of scholarly communication, rather than a mere precursor to journal publications [90].

RQ2. What are the chief journal and conference names in image segmentation?

Analyzing the popular journal and conference names becomes crucial for the newcomers or beginners in the research community to become familiar with journals and conferences for publishing their articles. The inquisitive researchers of the domain will know where to submit their fresh works or penned articles on segmentation.

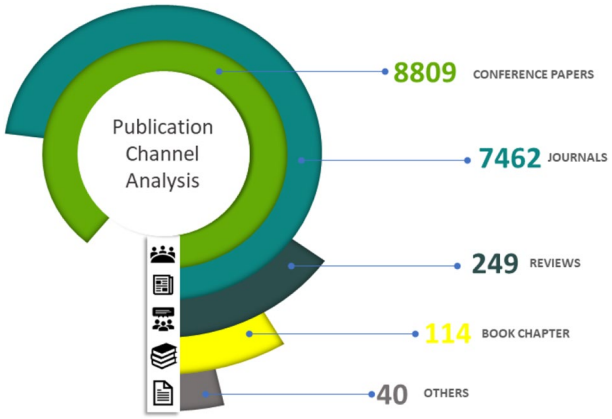


**Fig. 4** Publication channel analysis

According to our analysis, the comprehensive resource of publication is Lecture Notes on Computer Science. This particular name canopies a vast scale as the LNCS series can deal with varied aspects of computer sciences. The second prominent name that comes up is IEEE Access. A significant number of articles have been published in IEEE Access. Next, a popular conference proceeding has been witnessed called SPIE Proceedings or Proceedings of SPIE. This conference series equips with access to innovative and novel research-based articles. The prevailing names of the societies conducting these conferences are Progress in Biomedical Optics and Imaging and The International Society for Optical Engineering. These names make significant as per the number of articles they contributed. Other popular journal names are IEEE transactions on Medical Imaging and IEEE transactions on Pattern Analysis and Machine Intelligence. Looking at the broader scenario, it can be inferred from Fig. 5 that most of the IEEE journals are progressively publishing articles on image segmentation.

RQ3. What are the pre-eminent names of publishers prevailing in IS research?

The source of the 16,674 studies in the collected corpus has been investigated regarding the publication organization. In light of the findings as exhibited in Fig. 6, it can be concluded that the topmost publication authorities actively dealing with publications based on segmentation-based articles include IEEE, Springer, Elsevier, MDPI, SPIE, and Wiley, among others. In accordance with the findings of an analysis of the total number of published articles, IEEE publishers are the most actively engaged publication authority in this domain. Springer is the second most prominent name on the list, and Elsevier is the third most notable name on the overall index. The articles are associated with journals or other publication channels affiliated with IEEE publishers, accounting for approximately 30% of all articles. Springer's percentage contribution amounts to roughly 16% of the

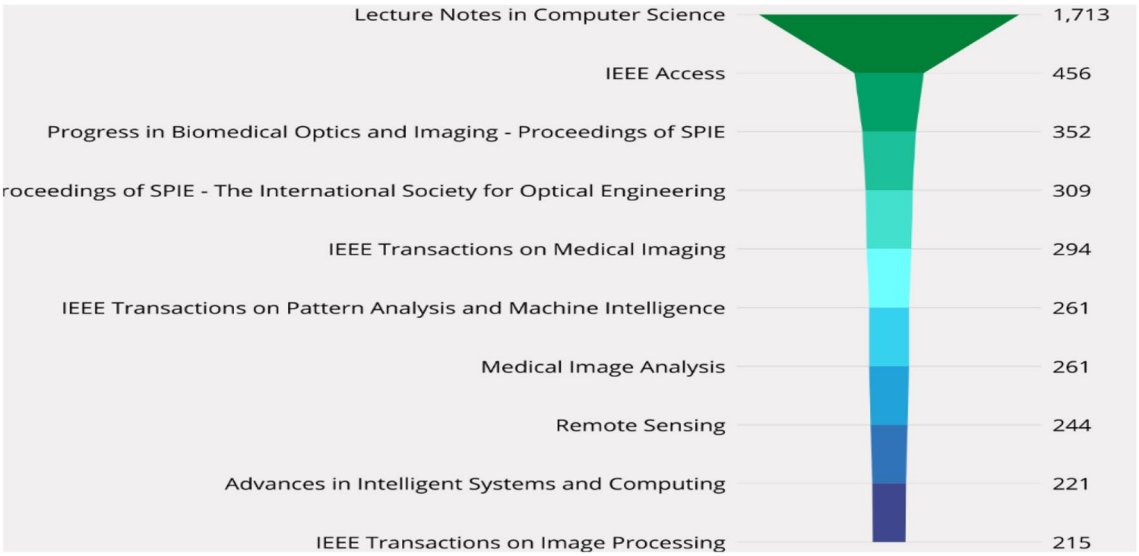


**Fig. 5** Journal and conference analysis for image segmentation

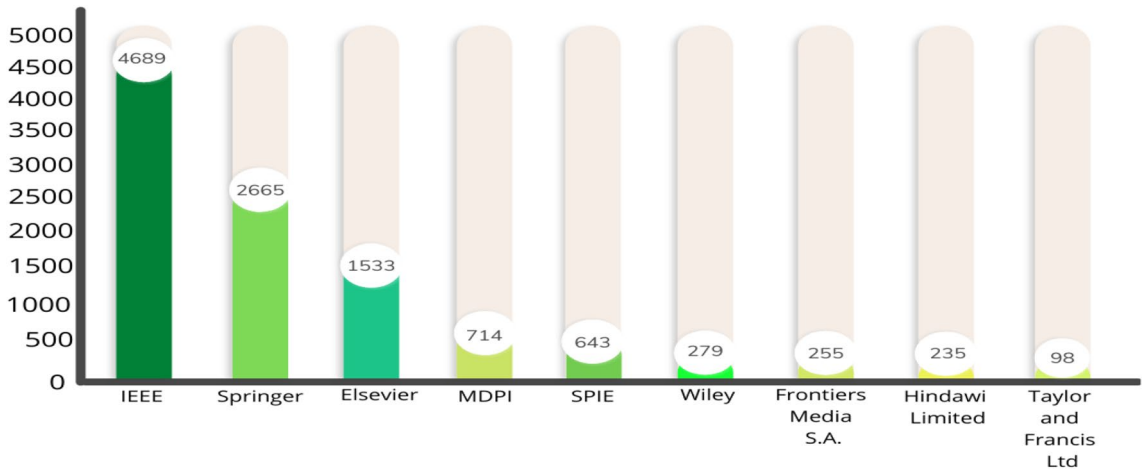


**Fig. 6** Publisher-wise analysis

total. Drawing the attention of researchers to the publishing authorities and summing up their contribution can be highly beneficial to verifying and authenticating the credibility of the publishing venue or the publishing channel.

RQ4. What are domineering authors contributing to research in image segmentation?

According to the authorship information provided in each research publication, the following chart depicts the distribution of the total number of research publications. Some authors can be recorded as having made significant contributions to this emerging and challenging research domain of image segmentation by publishing high-quality papers over a long period. It is presumed that the researchers who scored highly on this graphical distribution of studies have a strong interest in and knowledge of the research theme of segmentation techniques and methodologies. With the extraction of the metadata, this analysis ground also relieves the domain experts, researchers, and practitioners who have gravitated more towards this research problem and have worked extensively on these segmentation-based problems. Each of these leading authors' names was deliberately crafted and presented in Fig. 7 based on the number of documents they have published and the number of citations they have received in their chosen associated fields of interest. Aside from the number of articles written by a researcher, the factor of citation contributes to the credibility and plausibility of the persona who has been considered in the context of the

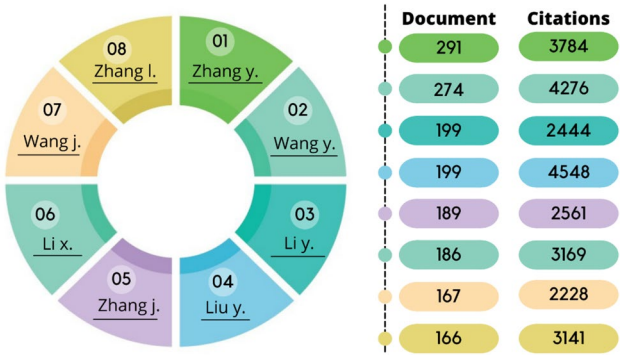


**Fig. 7** Authorship analysis based on citations and documents

authorship sphere. Figure 7 depicts Zhang as the maximum number of documents as part of our formulated corpus.

Along with the count of documents and corresponding citation score is also impressive. Gravitating toward the citation score, the author with a highly healthy citation score is Y. Liu, who successfully obtained a citation score as high as 4548. The analysis sublimes the names of the top eight authors who have contributed potentially well to the research direction and growth.

RQ5. Which countries and continents are advancing exponentially in the domain?

The image segmentation methods-based publications in conjunction with geographic and demographic analysis of articles are illustrated in Fig. 8. China is the country with the highest number of publications (#4492), and the second name of the suit is of United States, with a lavish count of 3904. The third most powerful name on the list is India, which has contributed 1608 publications. Following that, in terms of research production and contribution, the United Kingdom (#1062), Germany (#922), Canada (#757), France (#691), South Korea (#598), and Australia (#510) are ranked in descending order. In contrast, a completely different picture is presented when the analysis is conducted in terms of citations. The United States is the country with the highest number of citations, with a total citation score mounting up to 138,640. Europe has made a distinguished contribution with a massive count of 5803 publications. Other notable contributions are owned by continents North America (#4759) and Asia (#2011). Figure 8 vividly represents the number of citations and the number of counts headed by various continents. Eventually, after completing the analysis, it was discovered that the same sequence of dominance is followed when citations are noted and evaluated, assuring the prevalence. Again, Europe (#170,863), North America (#161,624), and Asia (#145,291) are the continents with the noteworthy count of citations.

RQ6. Which universities are predominantly progressing for research in the domain?

Aiming to analyze the affiliations, universities, and organizations producing most of the studies included in this large corpus, the authors set out to explore this sphere of meta-data. An illustration of the graphical representation of the extracted data with sublimated facts is provided in

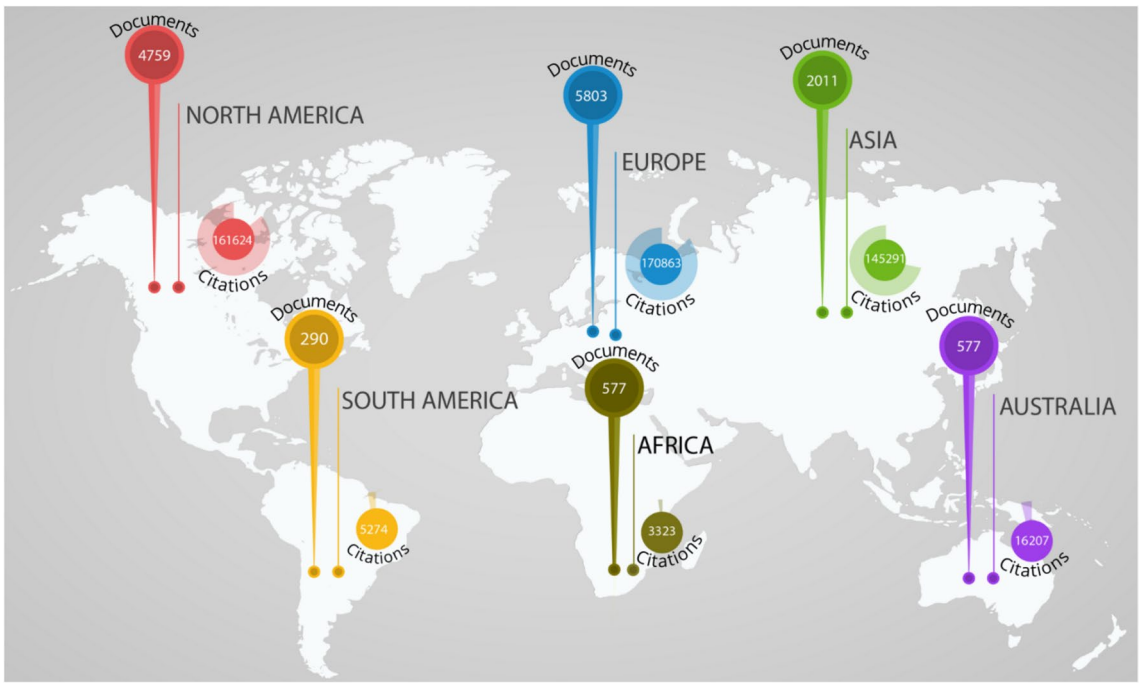


**Fig. 8** Country-wise and continent-wise analysis

Fig. 9. IEEE (#10,472) is the organization with the most cited articles, and Stanford University (#2101 citations) is the next-highest-ranking university on the list with a brilliant score of 2101 citations. The names of the universities appear in descending order on the list, starting with the Chinese University of Hong Kong (#2018), followed by Korea University (#1959), University of Chinese Academy of Sciences (#917), University of Notre Dame (#825), and Inception Institute (#761), respectively. Figure 9 shows how these universities are ranked based on their citation scores, and the illustration shows how they are organized. The top eight affiliations can be visualized clearly by glancing at the same Fig. 9.

RQ7. What is the year-wise statistic report of growth in this domain?

It is absolutely critical and a vital necessity to keep a record of and verify research trends because they are the fuel that drives and sustains the passions of the people who work in this field. Research trends can also reveal the underlying factors that have led to the observed research trends in the chosen scope over the past year. Figure 10 depicts the trends in research as measured by the number of research papers published each year. From the year 1970 till the present day, the publications have been analyzed based on the year lane of publication. It can be visualized clearly that there has been a gradual rise in the number of publications every year. The record of publications has been tremendously immense in the year 2020 as it recorded a lavish number of 4302 articles. The past two decades have witnessed a gradual rise in the number of publications launched yearly. From 2019 until now, the analysis brandishes almost more than double the count of articles than the former time frame of 2015 to 2018. This analysis, corroborated through Fig. 10, brings to view that the current era is evolving and consistently working on the IS domain. As a result, the number and launch of articles reveal that the research is perpetually rising. Figure 10 shows the escalating slope of the graph after the year 2019, which extravagances evidently that the time-frame 2019 to the present year is the period where the domain of segmentation is seeking peaking attention from the research community. The enormous number of 8952 articles is

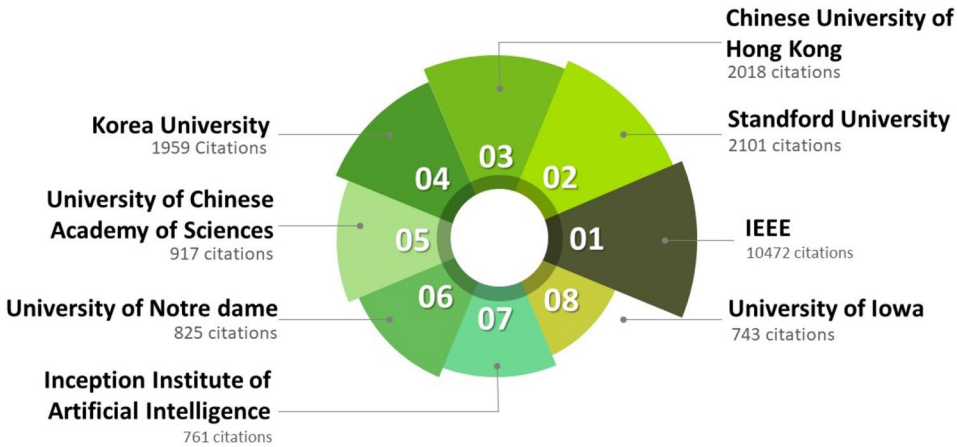


**Fig. 9** Affiliation-wise analysis

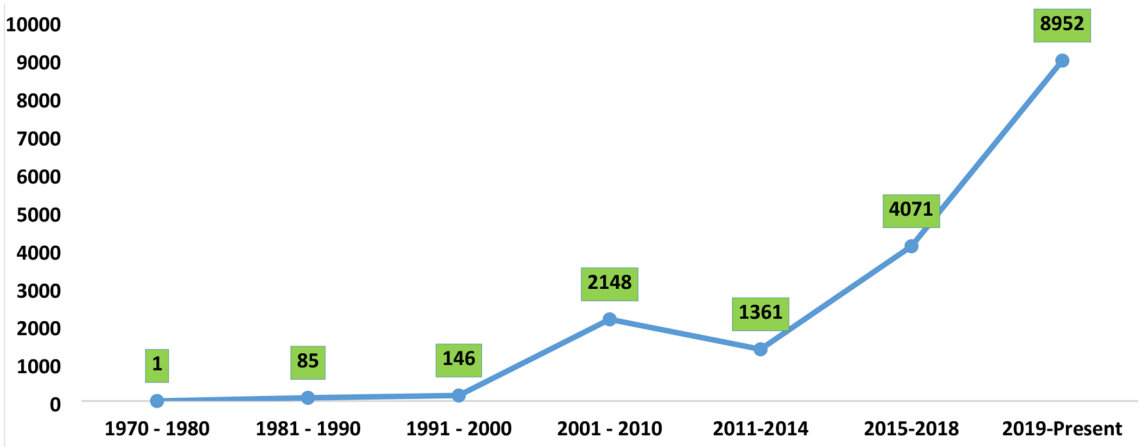


**Fig. 10** Year-wise analysis

significantly appealing to support the stated observation. The findings indicate their alignment with prior research to highlight evidence of association.

RQ8. What are prevailing keywords in image segmentation?

It has become essential to analyze the prevailing keywords in the articles collected for this study. Keywords were provided by the authors of the paper, and for the analysis to be performed here, the authors targeted those keywords occurring very frequently. Finally, those keywords have been enrolled for analysis in our final keyword database. The keywords that appeared the most are "deep learning (#4296 occurrences)", "segmentation" (#1981 occurrences) "image segmentation" (#1832 occurrences), and "machine learning" (#1606). It can be palpably visualized from Fig. 11 that keywords that have appeared the most are "deep learning" (total link strength 5953) and "segmentation" (total link strength 2748), which has a strong link to "image segmentation", "machine learning", "semantic segmentation", "convolutional neural network", classification","image processing" and "artificial intelligence". A word cloud has been developed and presented to depict the crucial keywords. It is thus inferred from Fig. 11 that "segmentation" is profoundly impacted by "deep learning", and "machine learning" based approaches. Also, the decent and noticeable frequency rate of "semantic segmentation" depicts its prevalence and popularity among the segmentation techniques. Also, Table 4 has been extracted to show the frequency of occurrence and its associated link strength in the developed word cloud.

Our considered parameters of analysis are.

**Table 4** Keywords and their link strengths

| Keyword | Occurrences | Total link strength |
|---|---|---|
| Deep learning | 4296 | 5953 |
| Segmentation | 1981 | 2748 |
| Image segmentation | 1832 | 2406 |
| Machine learning | 1606 | 2408 |
| Semantic segmentation | 769 | 1139 |
| Convolutional neural network | 716 | 1178 |
| Convolutional neural networks | 566 | 1052 |
| Classification | 497 | 994 |
| Image processing | 481 | 840 |
| Artificial intelligence | 428 | 741 |
| Computer vision | 370 | 718 |
| u-net | 351 | 664 |
| Feature extraction | 304 | 583 |
| CNN | 284 | 530 |

(A) Co-occurrence of keywords: The number of nodes and the size of the nodes indicate the frequency of occurrence. The co-occurrence of the nodes in the same publication is represented by the curves connecting them. The greater the distance between two nodes, the greater the number of times the two keywords appear together in the search results.

(B) Word cloud: 93 keywords that occurred more than 50 times are enrolled and considered for the generated word cloud. The font size represents the frequency of occurrence. Keywords such as "Segmentation", "deep learn-

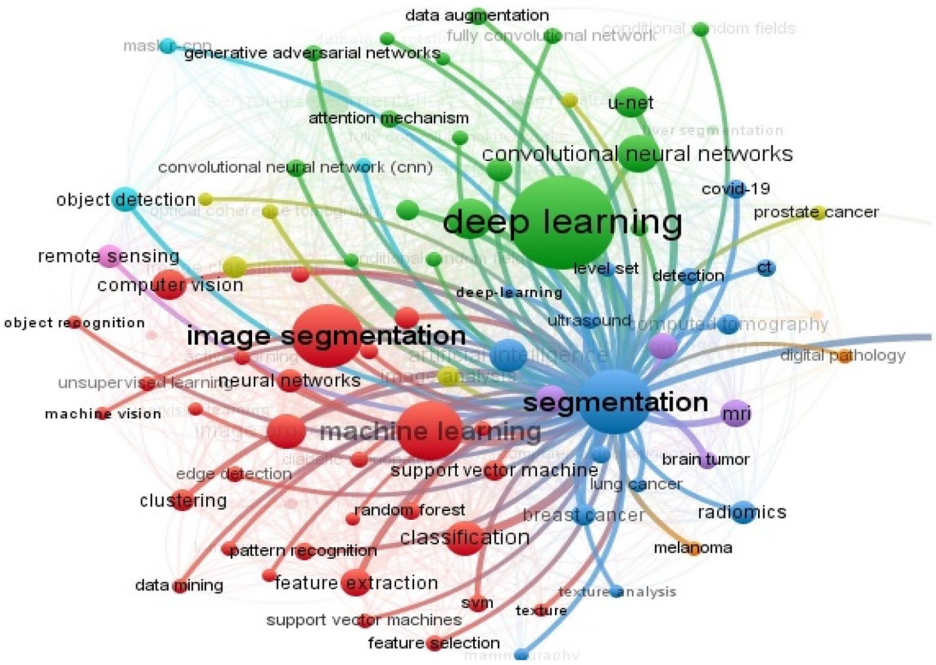


**Fig. 11** Network analysis graph for keywords

ing," and "machine learning" occurred most commonly. "region of interest" and "mammography" are rare.

Major Sublimates

The prominent publication venue for targeting research production of segmentation-based studies: ***Conference and Journals***

The thriving conference proceedings of the domain: **LNCS and SPIE Proceedings**

The important journal names associated with image segmentation area: **IEEE Access**

The renowned publishing organization: **IEEE (#4689)**

The domineering authors of the field: **Y. Zhang and Y. Wang**

The country with the highest number of documents: **China (#4492)**

The continent with the most research association (in terms of count and citations): **Europe (#5803 doc, #170,863 citations)**

The country with the highest citation score is: **USA (#138,640)**

The highly cited affiliations: are **IEEE (#10,472) (1), Stanford University (#2101) (2), and Chinese University of Hong Kong (#2018) (3)**

The year recording the highest count of publications: **2020 (#4302)**

The pre-eminent keywords allying with the domain: **image segmentation, segmentation, deep learning, and machine learning**

## 4.2 Comprehensive Analysis

Q9. What are the major image segmentation methodologies?

Since the onset of image processing techniques, varied segmentation-based methods and procedures have evolved. The concern and objective for picking and posing various image segmentation methodologies are to highlight the existing segmentation methods and technologies that have been deployed and famous in the domain. To delve more profoundly into the conceptual and comprehensive aspects, the authors in the comprehensive analysis part have selected the prominent names associated with the segmentation field and stacked them perfectly in Table 5.

Table 5 mentioned the crisp yet significant descriptive analysis of more than 20 identified image segmentation techniques and methods. All the stacked segmentation techniques have their purpose, pros, cons, and applications; thus, all of the necessary details of each method have been extracted and jotted down in the tabulation form (Table 5). The instance-based, semantic-based, or any other type of segmentation technique overall targets a region of interest from the entire image or pattern and easies the further processing and recognition tasks for machine learning-based models or algorithms. There are apparently observed the two types of approaches that define the working procedure of most of the segmentation techniques. Some approaches focus on the similarity of the pixels to generate a segment (similarity approach).

In contrast, other approaches concentrate on dissimilar pixels of distinctly different intensities and cut them out as segments (discontinuity approach). Understanding the definitive descriptions of mentioned segmentation methodologies and techniques, it can be concluded that thresholding and clustering-based methods distinctly work on the similarity principle. In contrast, the approaches where line, edge, and crucial point-based segments are extracted lie in the discontinuity approach for segmentation.

Q10. How the extracted image segmentation methodologies be classified?

Influenced and motivated by the pre-existent listed segmentation techniques, the authors contemplated that the methods used for image segmentation have a potential scope of being classified. Apart from the generic names (like instance and semantic segmentation) in the list, there has been an observation that many segmentation techniques have neural networking, thresholding, clustering, and other region/edge methodologies at their anchorage. Thus, the different adjuvant strategies can be categorized under these considerable classification headers, and a hierarchy chart of the compiled segmentation techniques has also been plotted in Fig. 12. The instance and semantic segmentation have generic approaches and are arranged independently in the classification diagram (Fig. 12). All the other individual segmentation techniques are placed and categorized under specified headers as displayed.

### 4.2.1 Instance Segmentation and Semantic Segmentation

The instance segmentation task is detecting and delineating each distinct object of interest in an image. The goal of instance segmentation is to detect and locate a specific object in an image. During its experimentation and execution, instance segmentation is expected to present one of the most significant technical challenges [21]. The objective of instance segmentation is to provide an image of the same class of objects divided into individual instances. The number of instances is unknown in order to automate this process, and the evaluation of the produced instances is not based on pixels [135]. This is an underexplored subject, but the potential for practical application gratifies interest. When the object is labeled, more information is extracted that can be used to infer new scenarios, count items of the same class, and identify items that need to be recovered [24, 73]. To summarize, it can be said that instance segmentation revolves around aspects like the count of several instances in an image, object detection of all objects in an image, classification of individual objects, and object localization using a bounding box [266].

The semantic image segmentation technique is used to classify images pixel by pixel. Semantic segmentation differs from the more common practice of separating things by their labels, such as "person1" and "person2," which results in different colors for the same object [255, 259].

**Table 5** Descriptive analysis of image segmentation techniques

| Type of technique | Description | Pros | Cons | Application |
|---|---|---|---|---|
| Instance Segmentation | Segmenting an image into its constituent parts is the process of identifying and outlining each different object of interest that appears. In instance segmentation, multiple instances of the same class are treated as unique individuals [73] | 1. Good for the cases which involve detecting objects separately within defined categories<br>2. Robust and comprehensive | Labeling is expensive | Object Detection, Classification [209, 228, 230], robotics [24, 239], autonomous driving [266], surveillance[63], analysis of geographical images [110], video analysis [152, 267] |
| Semantic Segmentation | Every pixel in an image is labeled as part of the Semantic Segmentation process. Segmentation uses semantics to group together objects of the same type | Suitable for the cases which involve detecting objects within an image and grouping them based on defined categories | Cannot assign subclass to each detected pixel | Autonomous driving [51], robotic [5], navigation [148], localization [18], and scene understanding [221] |
| Threshold-based segmentation | An IS technique known as thresholding entails altering a picture's pixels to facilitate further analysis. A binary image is one that is just black and white, and thresholding is the process of doing so | It is simple to implement | It is sensitive to noise and challenging to set a threshold in case of varying pixel values in the input image | Used for separating an object from its background. Deployed for tumor [104] or other crucial cancer detection [252] |
| Local threshold | A technique known as "local thresholding" uses threshold values specific to each image's partitioned sub-images | Better thresholding because of the localized value of thresholding value for each region | Slower because a new threshold value must be selected for each patch or sub-image<br>It may fail to separate the pixels accurately into suitable regions [62] | Used for separating an object from its background [62] |
| Global Threshold | When transforming an image to a binary image, global thresholding involves using a single-pixel intensity threshold value for any pixels in the image | Faster than Local thresholding because of a constant threshold value for each operation<br>Suitable images with contrasting backgrounds provided the objects in the image of uniform intensity | It works only if all the images are taken under the same light conditions. Not suitable for extractions of ROIs [62] | Used for separating an object from its background [62] |
| Multilevel Thresholding | The image that undergoes multilevel thresholding splits a grayscale (B/W) image into several distinct regions. It works contrary to the normal thresholding process, where the image is split into only two regions | It provides a varied range of thresholding values to detect the hidden features in the input image [80, 81] | Determining optimal thresholding value can be time-consuming [1] | Used for separating an object from its background<br>Used in the images where the ROIs have a wide range of pixel intensities |
| Otsu Binarization | For binarization in image processing, Otsu's technique uses an adaptive thresholding approach. Cycling overall potential threshold values may find the ideal threshold value for the input image (from 0 to 255) [133] | Precise real-time segmentation of underwater features and proven performance compared to threshold segmentation methods (https://learnopencv.com/otsu-thresholding-with-opencv/) | Noise Susceptible | Under Water images [194] |

**Table 5** (continued)

| Type of technique | Description | Pros | Cons | Application |
|---|---|---|---|---|
| Mean Shift Binarization | Segmentation using the Mean Shift is a local homogenization approach that is highly beneficial for dampening shading or tone variances in localized objects [85, 87] | | | In medical Imaging [222] |
| Adaptive Thresholding | For smaller regions, adaptive thresholding calculates the threshold value, which means there will be various threshold values for each [49] | Improves sensitivity increases the stability of the states | Compromises with specificity to a certain degree | Used to isolate required foreground image objects from the background image. It is accomplished using each region's difference in pixel intensities [2] |
| Edge-based segmentation | Pixels are classed as edge or non-edge depending on their output from an edge filter. Those not separated by an edge are assigned to the same category in edge-based segmentation [245] | Excellent for the images witnessing high contrasting objects, as the edge detection can be performed well | Not suitable for wrong detected or too many edges, not ideal for smooth boundaries | Used in the application where the objects have a great degree of difference in contrast and objects in the image have sharp edges [243] |
| Canny Edge Detector | A wide variety of edges in images using a multi-stage process can be detected using the Canny edge detector [244] | Reduced noise because of Gaussian filter, adjustable effectiveness (https://brainly.in/question/1586608) | It consumes a lot of time and is hard to implement for real-time tasks because of the low speed | Used if there is a wide range of edges in the input image [4] |
| Region-based segmentation | Similarities between nearby pixels are sought using the region-based segmentation method. There are distinct areas for pixel types that share properties. To create regions, adjacent pixels with similar attributes, such as intensity, are combined [227] | More immune to noise, applicable when it is easy to define similarity criteria | An expensive method in terms of time and memory | Detecting Tumors veins, finding targets in satellite/aerial images, and finding people in surveillance images [117] |
| Region Growing based | The region-based segmentation approach compares nearby pixels for similarity. As a result, pixels with comparable characteristics are sorted into distinct zones. To create regions, pixels with similar qualities, such as intensity, are combined into a single group [130] | Can provide the original images with transparent edges, simple to apply, and choose the multiple criteria, which is very efficient | Practically random memory access slows down the algorithm; if thresholding is not applied to the image, a continuous path of the points related to color may exist | Majorly used in medical imaging includes detecting cardiac disease, breast cancer, and tumor volumes [80, 81] |
| Region Splitting Merging | The core notion of region splitting is splitting an image into discrete, self-contained chunks. As a starting point, consider the image as a whole. Decide if all the pixels in the area of interest meet some similarity constraint [79] | Variables are selected by experimentation | The method is robust against noise | Use in the case of input image contains a high amount of noise |

**Table 5** (continued)

| Type of technique | Description | Pros | Cons | Application |
|---|---|---|---|---|
| Watershed Segmentation | Using a grayscale image as the starting point, a watershed transformation can be defined. The name alludes metaphorically to a geological watershed, also known as a drainage split, that divides neighbouring drainage basins from one another [136] | Results are more stable; detected boundaries are continuous | Complex calculation of gradients | Used for object segmentation purposes and separating different objects in an image [212] |
| Marker Controlled Segmentation | For watershed segmentation, a binary picture is employed containing either single marker points or more significant marker regions, with each connected marker placed within an object of interest | Provides closed contours, takes little computing time, and is a quick, straightforward, and intuitive approach for dividing an image into discrete sections. [118] | Over-segmentation i.e. over-cutting. Under-segmentation, also commonly known as leaking, refers to the inclusion of unwanted regions in the segmentation result [118] | In the medical field, specifically in the dental field. This segmentation is employed in orthodontic images |
| Clustering-based | It's a technique for performing pixel-wise image segmentation. In this type of segmentation, an attempt is made to cluster the pixels that are close together | | | |
| (a) Clustering by Merging | In this method, we can use the bottom-up strategy, which implies we delegate the pixel nearest to the cluster | In general, clustering by merging or agglomerative clustering is simpler than clustering by division [147] | These methods are not resilient or reliable, especially when dealing with noise and outliers. The computational cost of time complexity is high | In medical imaging [140] |
| (b) Clustering by Divisive or Divisive Clustering | In this technique, we can use the top-down approach, which implies we ascribe the pixel reasonably close to the cluster | More accurate [147] | Divisive clustering is more complex than agglomerative clustering in general since it splits the data until each cluster contains a unit data item. Time complexity has been computationally costly and non-trivial. [147] | This method is capable of dealing with both categorical and numerical data |
| K-Means Clustering | The objective is to achieve specific groups based on some kind of resemblance in the data, with K-means clustering representing the number of groups [44] | Suitable to use in the unavailability of labeled data [178] | Choosing an optimal value of K can sometimes be challenging [36] | Based on the values of the pixels, it can segment various objects in images |
| Fuzzy-C means | It is an unsupervised technique, and its basic idea is to cluster the data points by iteratively minimizing the cost function, which depends on the distance between the pixels and the cluster center in the feature space | Effective and concise segmentation algorithm [29] | It is susceptible to image noise [29] | In medical image segmentation |

**Table 5** (continued)

| Type of technique | Description | Pros | Cons | Application |
|---|---|---|---|---|
| Convolutional Neural Network-based | It works on images with three dimensions: height, width, and multiple channels. The first two dimensions represent image resolution, while the third dimension represents the number of channels (RGB) or intensity values for red, green, and blue colors. Typically, images served further into the neural network are decreased in size to shorten processing time and avoid under-fitting issues [155] | Higher performance as compared to conventional methods [70]<br>It results in more accuracy | Not specifically designed for the IS task [70]<br>It takes a lot of time to train the model | It can be employed in self-driving cars, traffic monitoring, etc |
| Supervised Techniques | These are based on human or operator knowledge to select training images and manually segment them into k regions. Each region is assigned a label, and the proposed architecture is trained using the chosen images as training data [9] | More accurate than traditional methods | Take a lot of time to train | When in the training phase, manual labeling is done |
| Multi-Layer Perceptron (MLP) | The most straightforward neural network-based [92] architecture for image segmentation is the multi-layer perceptron (MLP) | Better and adjustable accuracy | Need a lot of training time | In medical image segmentation [92] and text recognition [66] |
| Partial Differential Equation based segmentation | PDE-based methods are the most practical and efficient methods for image segmentation. [265]. The core concept behind PDE is to deform a curve, layer, or image per partial differentiation equations and achieve the correct segmentation results from the applied equation's solution [229] | The most significant advantage is that the theory underlying the concept and the techniques for attempting to solve it is reasonably well-formed in other areas of physics and mechanics. [265]<br>It is one of the fastest and best for time-critical applications [103] | It may struggle in cases where the target has a fragile edge [229].<br>It involves more computational complexity [103] | In Biomedical Imaging [200] |

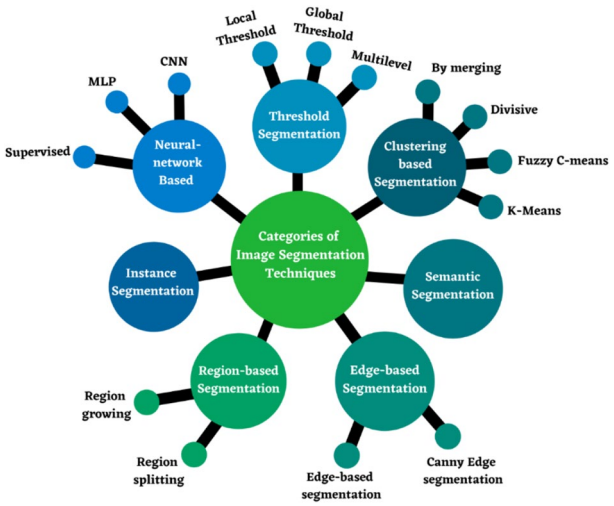


**Fig. 12** Categories of image segmentation techniques

More specifically, The primary objective of semantic image segmentation is to label each pixel of an image with the class of what it represents. The genuine issue is projecting and predicting for every pixel in the image, known as a dense prediction. The objective is to predict class labels for each pixel in the image [248]. A noteworthy point of concern is that, unlike instance segmentation, semantic segmentation doesn't deal with separating instances of the same class. The focus is on the category of each pixel [70]. Both instance and semantic segmentation models are helpful for a variety of tasks for self-driving cars or autonomous vehicles, in medical imaging like tumor detection [114, 235, 237], tissue volume measurement [111], anatomical analysis, in satellite image [235, 237] interpretation like detecting roads, highways, forests and crops in the fields.

### 4.2.2 Region-based Segmentation

The concern of this category of segmentation methodology is regarding the regions. A region is a set of connected pixels with similar characteristics like intensity, hue, etc. Specifying rules must be followed by each pixel to be classified into identical pixel regions in this sort of segmentation. In a noisy image, methods based on region segmentation are preferable over other methods like edge segmentation [149]. There are two subcategories of region-based strategies based on their approaches: region growing and region splitting. The region growing approach focuses on regions that are grown by starting with one seed pixel and then checking out neighboring ones [130, 253]. If the neighboring pixels meet the preset conditions, that pixel is added to the seed pixel's area, and the procedure continues until no similarity remains [12]. The bottom-up strategy is used in this procedure. The preferred rule can be specified as a threshold if a region expands. The region splitting approach works differently, where the entire image is first taken as a single region to perform region splitting. Areas are further subdivided into four quadrants if they do not follow predetermined rules. Then the predefined rules are applied to those regions to determine if they should be classified as regions or further subdivided. In the next phase, the regions are further divided until there is no longer a need for further divisions, meaning that every region adheres to the predetermined rules.

### 4.2.3 Edge-based Segmentation

Segmentation based on edges is a technique that uses various edge detection operators to find the edges in a picture. These edges are used to identify points in an image where the grey levels, color, texture, and so on are different. The grey level may alter as we walk from one area to another. As a result, the edge can be located by searching for a discontinuity. Various edge detection operators are available. However, the generated image is only an intermediate segmentation result and should not be confused with the final segmented image [153]. To segment the image, we'll need to do some more processing on it. An additional phase involves integrating edge segments obtained into a single segment rather than small borders that can impede region filling, thus reducing the number of segments [134]. To get a continuous border, this is done. Using edge segmentation as a starting point, we can move on to more advanced methods of segmentation, such as region-based or any other that we choose. The Canny edge detection mechanism comes into the picture for the scenarios where the edges are massive. The Canny edge detector uses a multi-stage method to detect images' wide range of edges. Four steps are involved in the detection of the Canny edge detection process [244]. Firstly, the removal of speckling and noisy data from the image is accomplished by blurring it using a Gaussian blur. The intensity and direction of gradients can be determined using a gradient operator. For an edge to be formed, the non-maximum suppression must be lower than the neighboring pixels. The distinct thresholding method can be used later to identify the boundaries of the formed dataset.

### 4.2.4 Cluster-based Segmentation

It is a technique for pixel-by-pixel segmentation of an image. This method of segmentation aims to group pixels that are close together. Segmentation by clustering can be accomplished in two ways. Data points from other groups that are more comparable to each other are clustered together using clustering techniques [115, 185]. Consider an image in which an apple and an orange are present. When compared to orange, the majority of the pixels in apple should be red/green. Each object can be distinguished from the others if

we can group these points together. It is also possible for a single piece of data to belong to two or more clusters using the fuzzy C-means (FCM) approach. Fuzzy set theory gives rise to a multivalued logic known as fuzzy logic. Soft segmentations, such as brain tissue models, are frequently created using this fuzzy means of clustering [168]. Also, the unsupervised K-means clustering algorithm is often used to separate the relevant data from the irrelevant data [190]. However, before implementing the K-means algorithm, the image is first stretched to increase its quality.

#### 4.2.5 Threshold Segmentation

The process of changing the pixels in an image to make it easier to analyze is known as thresholding. A binary image is one that is just black and white, and thresholding is the process of doing so [252]. There are three categories under this head, local, global and multilevel thresholding. The grayscale image is converted to a black and white image in local thresholding using a local adaptive thresholding technique. Colors in the range of 1 to 254 are often represented by numbers from zero (white) to 255 (black) [197]. Local thresholding employs unique values for each partitioned sub-picture derived from the entire image, whereas global thresholding utilizes threshold values for the complete image. A technique known as "multilevel thresholding" divides a grayscale image into multiple separate zones. Numerous thresholds are determined for the provided image, and the image is divided into brightness zones corresponding to a single backdrop and numerous objects [261].

#### 4.2.6 Neural Network-based Segmentation

Most region- or edge-based segmentation methodologies are part of classical categories and segmentation approaches. The present era is pacing towards varied new and more robust approaches inspired by artificially intelligent methods and machine learning/ deep learning algorithms. Segmentation methods are currently being applied in artificial intelligence, especially using neural network approaches. These methods are classified under the neural network-based header. The research community has extensively explored several supervised and unsupervised machine learning algorithms for segmentation. In image recognition and processing, a convolutional neural network (CNN), a sort of artificial neural network, has been deployed to process the input pixels of the image to be segmented. CNN is crucial in executing two segmentation types [33]. Some CNNs can assist in identifying regions of interest in an image from one or more classes of semantically interpretable objects. Also, CNN's can be beneficial for performing classification. The classification CNNs can classify each pixel into one or more classes provided a set of real-world object categories are defined [228, 230]. A feedforward artificial neural network in the MLP class is fully linked (ANN) [42]. Multi-layer perceptron (MLP) networks (with threshold activation) are sometimes loosely defined as any feedforward ANN. At the same time, other times, the word is used solely to describe MLP networks (with threshold activation) [66, 92]. Supervised learning is a subset of machine learning and artificial intelligence. In this mechanism, datasets that have been labeled are used to train algorithms that can efficiently identify data or predict outcomes. When input data is supplied into the model, the weights are adjusted as part of the cross-validation process until the model is appropriately fit. The model modifies its weights when input data is fed into it as part of the cross-validation process until the model is appropriately fit. For example, supervised learning can be used to separate spam from your inbox and put it in a different location.

RQ11. How to extract key research areas?

The key research areas have been determined by deploying a generative formal document model called LDA.

The reason for performing this extraction of research areas from the literature is all attributed to the fact that LDA is one of the prominent topic modeling techniques used in machine learning, natural language processing, and information retrieval to study topic modeling. Also, it has subsequently inspired a series of popular research articles. Using a hierarchical Bayesian analysis of a collection of documents, topic modeling is the process of identifying the underlying semantic structure of a document [208]. Topic modeling can be applied to any document type [165]. As the amount of information that has been digitized and stored is consistently growing in recent years, more digital content, on the other hand, is becoming progressively unstructured [187]. Using topic modeling algorithms, large and unstructured collections of documents can be automatically organized, understood, searched, and summarised. Additionally, the techniques for topic modeling have been successfully applied in a variety of applications, including automatic document indexing, document classification, topic discovery, entity-relationship discovery, temporal topic trends, and community discovery of documents [40]. So, the authors decided to extract temporal topic areas from the massive literature taken for the analysis using LDA-based topic modeling.

The methodology to deploy topic modeling has been depicted in Fig. 13. The entire phenomenon includes a step-wise procedure once the corpus has been filtered and brushed up. The step-wise procedure and experimentation as the whole has been depicted below:

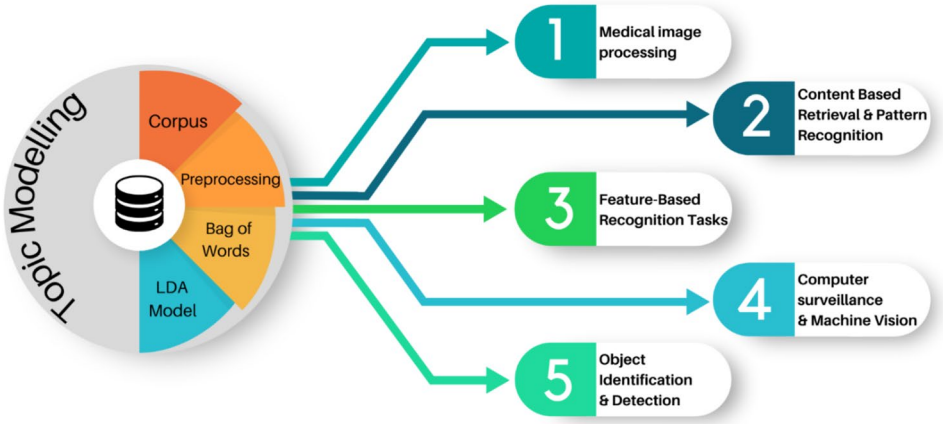


**Fig. 13** Identification of research areas in image segmentation using LDA

1. First Step: Corpus Loading

The corpus was compiled from various sources into a single.csv file. Manual filtration is already done in the inclusion–exclusion process. The duplicates are removed, and the final corpus of 16,674 abstracts is imported into the. csv file. The ".csv file "is then uploaded to the Google collab for testing.

2. Pre-processing

It is a pre-processing step for the dataset or information collected. Pre-processing is used to remove extraneous data from collected data. It improves the dataset's quality by systematically removing noisy words and characters. As a result, the final profile is more accurate and acceptable.

Pre-processing the literature dataset comprised of the following steps:

- Tokenization

This is the lexical analysis step. Tokenize all abstracts per title. The generated tokens are then lowercased for each document considered. The following section will look at punctuation marks such as exclamation points, commas, apostrophes, and question marks. Also, any abstract equations or formulas have been removed. Also, numerical values are removed to create textual tokens.

- Stemming

Stemming is reducing a word to its stem. Stemming is used in natural language processing to extract the root or core word from the English suffixes and prefixes. It removes all unnecessary parts of the word and roots out the true meaning. For example, stemming "useless", "useful," and "uses" yields "use". The Snowball stemmer algorithm [180] is used to stem words from their original form and store the base keywords in the cleansed corpus.

- Remove Stopwords

The stop words are words like "the", "if", "but", "a" or "an". These words take up space in our corpus and time in processing. So, in our experiment, we used Natural Language Toolkit (NLTK) to remove these stop removals (Hardeniya et al., 20 [75]. This toolkit has stopwords in over 16 languages. The NLTK library's stopwords and other phrases used to build the corpus were removed from our cleansed corpus.

- Lemmatization

The previously stemmed words must be lemmatized. Lemmatization [179] is the process of converting stemmed words into base words or lemmas. This phase aims to remove inflected words and output the dictionary form.

- Phrase Modelling Using Bigram and Trigrams

In a document, bigrams are two words frequently occurring together, while trigrams are three words frequently occurring together. For example, online handwriting, offline mode, etc., are frequently removed in this phase. Such phrases were removed using the gensim library. Gensim's Phrases model can build and identify these bigrams, trigrams, quadgrams, or even n-grams, allowing us to remove better and clean data.

1. Bag of Words Creation

In accordance with the authors' [19, 141], the pre-processed corpus was formulated with the formulated dictionary called the bag of words (total vocab size). In the end, the vocab size was reduced to 24,127 by removing high-frequency words (over 5000 occurrences). A second filter removes the

document's most and least frequent words for more qualitative results. The words with the highest frequency are deleted. So, words found in more than ten documents but less than 50% of the total are also destroyed. Finally, the filtered bag of words contains 5352 words. In other words, the bag of words is formed after the most and least frequent words are removed from the corpus.

2. Applying LDA

This implementation of the LDA model has been performed using python programming (NLTK toolkit and NLP package named mallet). The LDA-based topic modeling has three input parameters that usually direct the entire experimentation process. Amidst the three input parameters, the authors have named the number of topics, the hyperparameters α and β, and the number of iterations needed for the model to converge. α is the magnitude of the Dirichlet before the topic distribution of a document. This parameter is considered several "pseudowords", divided evenly between all topics in every document, no matter how the other words are allocated to topics. β is the per-word-weight of Dirichlet prior over topic-word distributions. The α value has been kept as 1/T [48], where T is the number of topics, and the β has been fixed as 0.01 for all topic solutions. A java-based NLP package named mallet is used to optimize the hyperparameters, efficiently selecting the number of topic solutions.

Here, an algorithm-based selection has been accomplished using the k means clustering algorithm; the optimal number of topic solutions for identifying research trends has been chosen. The deployment of k means clustering depicts the optimal choice of several topics for representing the core research areas is five. Thus, five topic solution has been selected optimistically.

3. Topic Modelling

The authors reviewed high-loading articles on all topic solutions in this study. To create the final topic label, each topic solution was labeled individually. The names of topic labels came about after several rounds of brainstorming and discussions between the two researchers. The task involved analyzing and interpreting extracted terms and abstracts of documents related to a particular factor or topic.

Determining a topic label is a difficult task requiring analytical skill and expertise. The two authors agreed on finalizing the key research areas based on the keywords retrieved for each topic solution. To help label each topic solution, the authors used key terms or high-loading terms and documents from classical factor analysis. Moreover, Table 6 lists the prominent high-loading terms (key terms) and documents that load satisfactorily (highly associated) for each topic solution. Because the labeling was done manually, this review is semi-automatic. The LDA model has finished keyword extraction and retrieving high-loading terms and documents.

In contrast, the reviewers collectively labeled all topics or factors. There are ten key terms and ten high-loading documents for each topic or factor in Table 6, with each contribution or factor-loading value. It indicates how closely a key term relates to a specific topic solution. High loading terms and documents load or relate well to the identified factor or topic label. Table 6 lists the various topic solutions, topic key terms (high loading terms), and high loading papers, along with their respective contribution value (factor analysis value). The contribution value in Table 6 is the probability value based on the estimated topic distributions. For example, "99.9" in the first row means that the occurrence probability of the first topic in the topic distribution of paper 16,674 is 0.999.

RQ12. What are the extracted key research areas?

The extracted vital research areas labeled are (1) Medical image Processing, (2) Content-Based Image Retrieval and Pattern Recognition, (3) Feature-based recognition tasks, (4) Computer Surveillance and machine vision, and (5) Object Identification and Detection. The authors have endeavored to nomenclate these topic solutions (based on extracted key topic terms) to form an appropriate topic label that reasonably predicts the key research areas. The discussions of each area of research have been lucidly carried out.

#### 4.2.7 Medical Image Processing

Being one of the most popular research areas that are very likely to deploy segmentation-based techniques and methods, medical image processing is one of the pacing research fields. Undoubtedly this field is working wonders by advancing segmentation methodologies significantly. The segmentation of medical images is crucial and significantly determinative in computer-aided diagnosis systems, which receive profound proximity for various medical applications. Medical imaging modalities such as microscopy, dermoscopy, X-ray, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography have received substantial investment and development, attracting researchers to implement new medical image-processing algorithms. Image segmentation is the most effective medical imaging procedure, which extracts the region of interest (ROI) using a semi-automated or automatic process. In medical applications, segmenting body organs/tissues for boundary detection, tumor detection/segmentation, and mass detection entails separating an image into regions focusing on a specific depiction. Apparently, when analyzed and overlooked, it has been observed that medical image processing has in-depth roots and associations with segmentation-based procedures.

**Table 6** Extracted topic labels with high-loading documents and their contribution

| Topic key term | Topic label | High loading paper | Contribution |
|---|---|---|---|
| Semantic, net, label, state, architecture, art, map, level, layer, multi, attention, loss, experiment, medical, scale, domain, tumor, brain, patient, clinical | Medical Image Processing | [247] | 99.9 |
| | | [39] | 99.89 |
| | | [37] | 99.87 |
| | | [145] | 99.86 |
| | | [231] | 99.85 |
| | | [142] | 99.85 |
| | | [27] | 99.84 |
| | | [211] | 99.84 |
| | | [68] | 99.83 |
| | | [77] | 99.82 |
| Handwritten, intelligent, face, filter, magnetic, resonance, automatic, tissue, automate, imaging, test, recognize, art, manual, scan, crime, develop, pattern, treatment | Content-Based Image Retrieval and Pattern Recognition | [232] | 99.88 |
| | | [223] | 99.88 |
| | | [54] | 99.86 |
| | | [96] | 99.85 |
| | | [198] | 99.84 |
| | | [138] | 99.83 |
| | | [25] | 99.83 |
| | | [123] | 99.82 |
| | | [181] | 99.82 |
| | | [86] | 99.81 |
| | | | 99.81 |
| Cluster, shape, function, level, local, face, graph, parameter, point, vector, process, iris, structure, texture, color, optimization, edge, biometric, noise, boundary | Feature-based Recognition Tasks | [213] | 99.88 |
| | | [67] | 99.88 |
| | | [192] | 99.86 |
| | | [183] | 99.85 |
| | | [23] | 99.84 |
| | | [216] | 99.83 |
| | | [226] | 99.83 |
| | | [85, 87] | 99.82 |
| | | [186] | 99.82 |
| | | [13] | 99.81 |
| | | | 99.81 |
| Recognition, video, processing, vision, process, application, detect, area, human, extract, computer, real, provide, field, extraction, research, work, develop, vehicle, test | Computer Surveillance and Machine Vision | [41] | 99.9 |
| | | [131] | 99.88 |
| | | [172] | 99.87 |
| | | [11] | 99.87 |
| | | [20] | 99.86 |
| | | [57] | 99.86 |
| | | [128] | 99.86 |
| | | [32] | 99.86 |
| | | [58] | 99.86 |
| | | [242] | 99.85 |
| | | | 99.85 |
| | | | 99.85 |

**Table 6** (continued)

| Topic key term | Topic label | High loading paper | Contribution |
|---|---|---|---|
| Cancer, cell, disease, diagnosis, breast, lesion, medical, lung, retinal, vessel, skin, computer, aid, detect, face, pedestrian, stage, processing, tissue, satellite | Object Identification and Detection | [109] | 99.9 |
| | | [10] | 99.89 |
| | | [22] | 99.87 |
| | | [201] | 99.86 |
| | | [210] | 99.85 |
| | | [182] | 99.85 |
| | | [191] | 99.84 |
| | | [236] | 99.84 |
| | | [99] | 99.83 |
| | | [137] | 99.82 |
| | | | 99.82 |
| | | | 99.81 |

#### 4.2.8 Content-Based Image Retrieval and Pattern Recognition

Content-based image retrieval focuses on extracting and identifying content from an image rather than targeting metadata. The term used "content" in the phrase content-based image retrieval refers to several contents of the image like the color of the image, the shape of the image, and its attributes like texture, quality, pixels, and other information that could be abstracted from the image as a whole. Context-based image retrieval is the approach for accomplishing automatic annotations in an image and performing the activities of retrieving them by labeling the contents of the image (Content-based image retrieval and feature extraction). Above all, Image segmentation is very significant for CBIR as segmentation-based methodologies assist in extracting crucial information and necessary features from the image. Overall, it can be summarized in the gist that the retrieval performance and efficiency of CBIR-based systems depend on effective results and outcomes of the segmentation process. Thus, CBIR systems rely on segmentation algorithms to determine their efficiency [166]. Additionally, all pattern recognition-based tasks like handwriting recognition, face recognition, speech or character recognition, and other problems associated with human–machine interactions involve segmentation as one of the most significant steps in their full recognition setup.

#### 4.2.9 Feature-based Recognition Tasks

Feature-based recognition tasks like face recognition, fingerprint or biometric recognition, iris recognition, or gesture-based recognition. All these tasks involve the extraction of fundamental features from an image. After the features are detected or extracted, a successful segmentation technique is needed to work on these features. Thus, the extracted features from an image become a crucial prerequisite for image segmentation. When it comes to segmenting a specific shape or structure in an image, feature extraction is one of the procedures that must be used to extract the relevant features for that region so that it can be distinguished from the surrounding regions. The intensity of an image refers to a fundamental component frequently used in image segmentation.

Consequently, we can divide the structure into different groups based on the intensity they appear in the image. For classification, feature extraction is used, and thereby relevant and significant features are used for labeling different classes within an image. Relevant and meaningful features are used for marking different classes within an image. The extraction of features serves as the foundation of any segmentation task. The extraction of features is the essential step in any segmentation process. For example, in the segmentation process in HME, various features such as edges, contours, and so forth are taken into consideration. In this instance, the feature detection process is based on contour detection. The detection of contours is followed by drawing those contours on the corresponding input image. The use of an approximate area and bounding box is optional. Although these subtasks are not required, they are highly recommended to achieve better segmentation results.

#### 4.2.10 Computer Surveillance and Machine Learning

For surveillance tasks, it becomes necessary to identify the moving objects from a video clip or video sequence. These are some of the crucial tasks in many computer vision-based

applications. These days, computer vision and machine learning-based methods and algorithms have been closely deployed for accomplishing several tasks. Segmentation has an essential and irreplaceable role when the task gravitates towards identification, recognition, and classification, significant inclusive challenges in computer-based surveillance methods and machine learning-based problems. Moreover, object and motion segmentation have been deployed in prominent in-process activities in video surveillance and other monitoring ventures. Present research trends witness a variety of applications that implement segmentation as a core phase in computer vision and machine learning-based experiments and projects.

#### 4.2.11 Object Identification and Detection

Object detection is a machine vision technology that recognizes occurrences of semantic objects of a specific class (such as people, buildings, or cars) in digital images and videos. It is associated with computer vision and image processing. Image segmentation is the primary requirement for object detection (localization + bounding box). To detect the object first, we need to comprehend the entire image. Processing the entire image is not always a good idea. This is where segmentation plays a crucial role in the process. The full image is converted into sub-images of smaller sizes. Object detection can be performed in these smaller segmented parts. For the object recognition phase, the most sophisticated task among the three, segmentation and object detection, play significant roles. IS is necessary for detection (localization + bounding box); the detected object is further processed for recognition for specific feature extractions using Deep Learning or other methods. The object may be recognized based on the features the model extracts.

Major Sublimates

The methodology deployed for extraction of key research areas is LDA- based text mining which has been processed on 16,674 documents associated with the image segmentation domain, and the key research area captured in the process are (T5.1) "Medical Image Processing", (T5.2) ("Content-Based Image Retrieval and Pattern Recognition", (T5.3) "Feature-based recognition tasks", (T5.4) "Computer Surveillance and Machine Vision", and (T5.5) "Object Identification and Detection". The highest contributing factor of the document in topics T5.1, T5.4, and T5.5. has mounted up to 99.9%

### 4.3 Application-Specific Analysis

RQ13. What is the significance of segmentation in mathematical expression recognition?

Mathematics Expression (ME) recognition has been a thriving research field in recent years, owing to the rapid growth of human interface devices and the growing interest in converting scientific papers into electronic documents [6]. In the recognisability of mathematical expressions, two issues need to be addressed: Recognizing symbols and analyzing structural relationships. [193–195]. The complete recognition scenario makes a strong rationale for good segmentation as a mathematical expression, and its associated contents are frequently complex and nested. As a result, to recognize the entire expression, we must first execute good segmentation of individual and constituent symbols embedded in mathematical expressions [194]. Segmentation is the most critical process in the recognition of offline handwritten mathematical expressions. The ambiguities associated with identifying superscript and subscript in complex offline mathematical expressions continue to be a significant issue. The role of segmentation in case of HME or ME can be attributed as a very important aspect for following two reasons:

1. Localisation of the entities or symbols in ME/HME.
2. Evaluation of HME as a whole.

1. Localisation of the sub-entities or symbols in ME/HME: Localization of sub-entities or symbols is necessary because these are an essential part of any ME as a whole. Segmentation leads to the localization of such entities, and recognition of them contributes as the stepping stone contributing to the completeness of an HME.
2. Evaluation of HME as a whole: Segmentation of entities and localization of each recognized entity would lead to the correct interpretation of the ME. Under segmented entities would lead to the incorrect evaluation of HME. Therefore, proper segmentation of the involved entities in any HME is necessary so the expression as a whole can be evaluated ideally.

RQ14. What are prominent segmentation techniques used for mathematical expression recognition and features used for mathematical expression recognition?

More than 79 studies have been analyzed thoroughly for segmentation-based methodology. All these articles have looked for the segmentation techniques deployed in the process. Yet, there have been instances where the studies proposed some segmentation-free methods, yet the majority count depicted the segmentation methods elaborated in detail as in Table 7. Note: Only those segmentation methods described there have been deployed more than once in the selected set of studies.

The extraction of methodologies involved in the segmentation of mathematical expressions has witnessed some recognition models that were segmentation-free. These studies [3, 255, 259] skipped the exclusive segmentation phase and accomplished the task of successful

**Table 7** Segmentation techniques for mathematical expressions and their description

| Technique | Description | References |
|---|---|---|
| Attention mechanism | Attention can be employed to extract the ROI (Region of Interest) from the input image, and that is the goal of segmentation. This mechanism can be beneficial in the segmentation process in HMEs. HMEs have a lot of features then the attention can be employed to look for only specific features in HME; the segmentation done using this technique would have better accuracy | [224] [82] |
| Gated Recurrent Unit | For the purpose of IS, the existing deep neural networks are made up of an intense encoder-decoder structure to fuse pixels, which requires heavy computations, extensive memory, and long processing time. So the combination of GRU with CNN can solve this problem. GRU network gets a long spatial sequence with lower computational complexity compared to traditional encoder-decoder architecture. In segmentation of very complex handwritten expressions can be crucial to speed up the process. GRUs can be used and would impact the performance of the model in case the input is very complex | [257, 258] [47] |
| SVM | To put it simply, a "Support Vector Machine" (SVM) is a supervised machine learning algorithm that can be applied to classification and regression problems. In practice, it's most commonly used in classification problems. The classification ability can be used to label each pixel with a specific class for the particular purpose of IS. The same could be said for extending this ability for segmentation in HME. When used in conjunction with an OCR system such as tesseract, it can simultaneously perform the tasks of segmentation and recognition | [121, 174, 175, 176] [122] [120] |
| Segmentation based on Clustering | Segmentation based on clustering may work with various factors like they may be based on color values of the pixel intensities. This segmentation technique, based on clustering, is broadly divided into two parts:<br>i) Clustering by Merging or Agglomerative Clustering<br>ii) Clustering by Divisive<br>The Handwritten Mathematical Expression, or HME's input images, consists of two color values, black and white if the input is appropriately preprocessed. Each character would be segmented using K-Means based on the k-means clustering, which calculates Euclidean's distance. The approximately center of each character or centroid of each character would be called the nucleus | [154] [26] [199] [6] |
| False hypothesis method | A false hypothesis method usually deploys object detection that combines top-down recognition with bottom-up image segmentation. There are two main steps in this method: generating hypotheses and verifying those hypotheses. An improved Shape Context feature, which is more robust to object deformation and background clutter, is used in the top-down hypothesis generation step. The false-positive regions are typically not aligned with any feasible IS in order to improve our performance. When performing HME segmentation, False Positive Pruning, also known as FPP, would be used to eliminate false-positive candidates from the proposed segmentation set | [100] [14, 17] [112, 233] [15, 127, 234] |
| Dynamic Programming Method | Dynamic programming (DP) was specifically used to detect lines in images, particularly in the field of road detection in satellite images, and was particularly effective. One of the most common applications of DP is to find a connected contour (line, boundary) in an image matrix or grid. From left to right (or top to bottom), this contour traverses the image in the shortest amount of time possible while passing through each image column (or row) exactly once. The contours consistently traverse the image from left to right. Still, these contours can also traverse the image from top to bottom by swapping the rows and columns and using this line or boundary as a separator, which would be the essential feature for the purpose of segmenting the image | [204], [69, 71] [56, 69, 71] [16], [84] |

**Table 7** (continued)

| Technique | Description | References |
|---|---|---|
| Contour Detection | Contours can be defined as curves connecting all continuous points (along the boundary) with the same color or intensity. Contours are a handy tool for shape analysis and object detection and recognition. Some contour features, generally curves, edges, and corners, are detected by binarizing the input image. After extracting the coordinates of the approximated square's corner, bounding boxes can be drawn on the original image, or the segmented portion of the image can be cropped from the original image. Apart from this, there is another possibility in which the squaring steps are omitted, and the images are segmented using the extracted contours, or they can be manually drawn otherwise | [34, 91], [254, 264] [76, 214] [122, 219] [16, 205] [251] |
| CNN-RCNN RNN(BiRNN)-BLSTM | CNN, RNN, BiRNN, and BLSTM all have a similar neural network-based architecture that has been employed to accomplish the process of segmentation. These are the popular deep learning techniques brought into play for practicing image segmentation of mathematical text. The entire bunch of pure neural network-based segmentation models (CNN-RCNN-RNN-BLSTM) have been prevailing exercised, and all of these are associated with each other with critical essence. For instance, LSTM is a famous type of RNN methodology | [257, 258], [158] [219, 257, 258] [52] |
| Unet | Unet is one of the most renowned names in structures deployed for segmentation, especially when it is a medical image. It is inspired by the concept of deconvolution. The capacity to construct shortcut connections between equal-resolution layers in the analysis and expansion paths is a crucial feature of U-Net. These connections aid the deconvolution layers because they contribute essential high-resolution characteristics. Moreover, its architecture is also inspired by the fully convolutional network | [162] [215] [6] [16] [84] |
| Character-based Segmentation | Character segmentation is a process that attempts to divide an image of a series of characters into individual symbol sub-images. It is a requirement for any character recognition task. Using a suitable segmentation technique, the entire image is partitioned into smaller pieces. Features can be derived from segmented sections after they have been segmented. For perpetration of segmentation in mathematical expression, individual characters are focused here, and varied types of character segmentation have been deployed | [61] [60] [97] [125] [150] |
| Projection-based method | The studies involving the segmentation of mathematical expressions very frequently deployed projection-based methods like projection profile cutting algorithms vertical and horizontal projection. Projection is a kind of mapping criteria that maps the flat image into a curved surface or vice versa. The projection-based methods are very often deployed for handwriting recognition and segmentation tasks. Most of the time, projection-based methods are employed along with morphological operations [205] to perform the segmentation of embedded characters | [31] [241] [38] [45] [246] [177] [78] |
| Threshold-based segmentation | The most straightforward and effective segmentation methodology is threshold-based segmentation. The conversion of color or grayscale image is finally performed to obtain a binary image. The key to this type of segmentation is the threshold value based on which the inputted image is segmented, and values of the constituting pixels are altered for easier comprehension of the image. Several thresholding methods are used for the segmentation of mathematical text | [241] [76] |
| Parsing and Grammars | The segmented parts of the inputted image are often parsed, and some productions or grammar-based rules are formulated to clock up the segmentation task in mathematical expressions. The parsing and grammar-based approaches often use structures like symbol relation tree, parse tree, and production rules for effectuating the whole of the segmentation process and associated criteria | [101, 119, 156], [129] |
| Gaussian Mixture Model | The Gaussian mixture model has been adopted to segment mathematical characters and equations effectively. The input image to the model contains the sequence of pixels, forming the array of pixels. These pixels have scalar values, and the implemented Gaussian mixture model partitions the pixels into matching segments. These similar segments can be put in effect for the auxiliary analysis part | [8, 15], [84, 88] |

**Table 7** (continued)

| Technique | Description | References |
|---|---|---|
| segmentation using connected components | This method aims to label the document image as a collection of connected components; this allows the document image to be represented in a structure other than a matrix of pixels. This entails the establishment of the component structure. This procedure is described as:- labeling the black and white connected components;—deriving relationships between these connected components. Two types of relationships can be defined:• as topological relations, which denote incorporating one component into another. The set of inclusion relations defines the components' hierarchical structure<br>• topographic relationships, which define the components' relative positions. In this case, we are only concerned with horizontal and vertical relationships<br>In the case of HME segmentation and recognition, we can estimate the location of various involved elements such as subscripts or superscripts by deriving a topographic relationship between two components separated by the same color, i.e., white, in the case where the HME input is preprocessed and converted to grayscale | [6, 7] |

recognition. While some studies [28, 83, 108, 160, 163, 184, 225] didn't explicitly mentioned the segmentation criteria or its baseline technology. Also, during the analysis of the studies that involved effective segmentation, the authors have extended their efforts to extract, pick and describe the features that have been used in the entire segmentation and recognition process. Major Features used in Segmentation for mathematical expression recognition are elaborately in Table 8.

Apart from the above-described features, fewer instances of Contour-based features [214], stroke-specific features [127, 234], sequential features [157], online and offline features [59, 84], has been observed. The authors omitted the descriptive analysis on these features as the instances of occurrence of these features are scarce. Another observation during the quantitative analysis process is that geometric features are the most prevailing features that have been chiefly targeted in a higher number of studies. Also, not all the articles extracted for analysis depicted or mentioned the extraction of features. These articles sometimes don't inclusively extend their experimentation to the feature extraction process. Some of them skipped mentioning the core features extracted during the segmentation or recognition process.

Major Sublimates

The most prevalent and accepted methods in the segmentation of mathematical expressions are found to be based on machine learning and deep learning **(SVM, CNN, LSTM, RNN, UNet),** which are directly or transitively deployed in 30 out of selected 79 studies. These other ubiquitous segmentation methods involve contour detection and projection-based methodologies. The most targeted feature used in the segmentation and recognition of mathematical expressions is ascertained as **geometrical features,** extracted in almost 35% of the selected studies

## 5 Contentions, Corollaries, and Other Potential Aspects

The contentions or investigations for the planned studies included varied methodologies. To summarize, the preparations for the presented article's entire novel concept have gone through successive rounds of brainstorming and exhaustive investigations. The vast pool of segmentation studies (#16,674) has been statistically analyzed for myriad exciting aspects, sublimating contemporary information about the ongoing research on image segmentation. The meta-data countenance of the segmentation-based research articles has been rigorously dissected and later wrapped up for the first time. Also, the implementation of topic modeling (LDA) concepts for predicting and identifying central application areas is one of the pristine and presiding contents of the compiled study. The analysis and contentions bring us to invigorating corollaries, which are listed as follows:

- The study revolves around the analysis of 16,674 segmentation-based studies. A total of 7462 articles are from reputed journals, and eventually, there has been an observation that the journal, publisher, and most cited affiliation is allied to IEEE. The renowned publisher pacing high with studies (#4689) based on segmentation is IEEE. Also, the prevalent top journal name for referring articles on image segmentation is IEEE Access. Additionally, the most cited affiliation is associated with IEEE, with citations as high as 10,472.
- The deployment of formal generative topic model LDA reveals exciting results, where out of five extracted research areas in segmentation, three topic solutions, (1) Medical Image Processing, (2) Computer Surveillance and Machine Vision, and (3) Object Detection and

**Table 8** Features extracted in IS

| Features | Description | References |
|---|---|---|
| Geometrical Features | Geometric features are characteristics of objects formed from a collection of geometric elements such as points, lines, curves, and surfaces. They can be classified as corner features, edge features, Blobs, Ridges, salient points image texture, and other types of features, all of which can be detected using feature detection algorithms. These features are more frequently used for segmentation and image processing-based tasks. These are the types of geometrical features:<br>I.Primitive Features: These include corners, edges, blobs, ridges, etc<br>II. Compound Features: These include geometric composition and Boolean composition | [31, 157, 174, 241], [121, 175] [154, 176, 219], [83, 204], [69, 71], [60] [97, 113, 119], [234], [112, 127], [124, 174], [7, 121], [122], [6, 120] |
| Visual Features | In computer vision and image processing tasks, Visual descriptors, also termed as image descriptors, are descriptions of the visual characteristics of the contents of photographs, videos, algorithms, or apps that construct such depictions. They include basic features such as shape, color, texture, and motion, among other things. They have an essential role while carrying out with segmentation process. A visual feature also describes a unique property of an image as a whole or an object within the image. It can either be a local property or a global characteristic of the image | [162, 177], [78] |
| Directional Features | These are the most common features derived and extracted from a handwritten text when segmented, and they are the most significant. The classifier extracts and concentrates on directional features usually encountered while dealing with online handwritten text. These are the characteristics that are deduced from the directions. It deals with statistical aspects of directional data. When directional features are concentrated for segmentation and recognition tasks, linear statistics and data points become a source of concern | [257, 258], [125], [157, 163] |
| Contextual Features | When it comes to contextual features, they are concerned with the contextual information contained within the entire mathematical expression/formula to be segmented. The context information and features define the image statistics most closely associated with the surrounding, connotation, content, and environment. This means that when a symbol's characteristic is sought throughout an expression, a search is launched for the locations in the content or image that are the most similar to the required symbol while also being the most dissimilar to its context. Because of the dissimilarity between the symbol location and characteristic and the context features, the detector is forced to gravitate toward an accurate estimate of the symbol location and characteristic | [121, 219], [16], [83], [129], [82] |
| Local features | Local features are patterns or distinct structures found in an image. Attributes of the input image can be a point, an edge, or a small image patch, which are referred to as local features. In most cases, they are associated with an image patch distinct from its immediate surroundings in terms of texture, color, or intensity. It makes no difference what the feature actually represents; what matters is that it stands out from its surroundings. Local features include blobs, corners, and edge pixels, to name a few examples | [76, 219], [16, 205] |
| Structural Features | The topological and geometric properties of the character serve as the basis for the character's structural characteristics. The number of horizontal or vertical lines, the number of endpoints, the number of cross points, the existence of horizontal curves at the top or bottom, and other structural characteristics are examples of these features. This style of depiction can also encode or convey information about the object's structure or components | [76], [129], [83, 100] |
| Directional Element /Vector-based Feature | Feature vectors or finalized vectors of the directional element type, also known as Directional Element Features (DEF), can be used as feature containers in the image processing domain. When continuing to work on handwritten character recognition, the following procedure is deployed to extract directional element features from the handwritten characters:<br>I. Step 1—Contour Extraction<br>II. Step 2—Dot Orientation<br>III. Step 3—Vector Construction | [56], [84, 91, 154] |

Identification divulges out that these are most trending domains and research areas using segmentation.

- Also, while exploring segmentation techniques in terms of a mathematical expression, the extracts promulgate that neural network-based segmentation techniques like

CNN, RCNN, and LSTM are widely deployed for image segmentation. Moreover, SVM comes up as a popular name among the machine learning algorithms for segmentation and classification. Contour Detection seems to have firmer belief among the research community as it has enormously prospected for a colossal amount of studies.

- Myriad features that have been extensively used to segment mathematical expressions have been fathomed out, revealing that geometric features are the most inspirited and inveterate ones among the set of features analyzed in the study.

The other leading potential aspects for future directions encompass the following points:

- Exploring the growth of deep neural network-based segmentation criteria, which has been massively investigated and has continued to be the consistent theme of interest for the research community.
- Analyzing how segmentation affects the broad-brush proefficiency of recognition systems and classification-based models.
- The extracted research areas in the study could be dealt with in the future with a seriatim approach so that independent analysis could lead to the preferential contrastive and correlative inquisition.
- Disquisition of distinct quality-based inputs (input images from both constrained and unconstrained environments) could be a favorable direction that calls for consideration and contemplation.
- Role of kinds of features in affecting the performance graph of discrete segmentation models could be a congruous investigated term for future research and progression.

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## Declarations

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