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Techniques of image segmentation: a review

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ABSTRACT

Image segmentation is a popular topic of research. Image segmentation divides an image into different parts that can be used for further analysis. By doing so, the image becomes simple and more meaningful information can be extracted. The segmentation techniques divide an image into multiple parts based on certain features of the image namely: color, texture, and intensity value of the pixel. Segmentation is considered as one of the toughest tasks for extracting features from an image, detection of objects and lastly classification of the image. The applications of image segmentation in every aspect of life such as satellite image analysis, object detection and recognition, in agricultural field, self-driving vehicles, and medical imaging. Has become indispensable. Till date, though researchers have developed many segmentation techniques, they are unable to design a generalized methodology for the image segmentation problems. A review of image segmentation techniques has been presented in this study. A summary of the advantages and disadvantages of these techniques has been presented. The focus of this manuscript is to provide a summary of the available research work on segmentation which will benefit the enthusiastic researchers in gaining better understanding about segmentation models in various application domains.

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1. INTRODUCTION

A subfield of digital image processing called image segmentation is concerned with dividing a picture into distinct sections based on the attributes and characteristics of each region. Simplifying the image for further analysis and identifying the object of interest is the main objective of image segmentation. Using image segmentation techniques, one can draw lines, define borders and isolate some things (essential components) in an image from the other objects. These techniques can group as well as divide particular pixels within an image. Also, they can assign labels to them and classify the pixels based on these labels. Each image is made up of individual pixels and segmentation is the process of breaking the pixels apart based on shared features. Some major challenges affecting the performance of image segmentation techniques are [1].

a) Variation in the illumination of the image which is due to the difference in lighting conditions while capturing the image. The intensity values of the pixels of such an image widely vary and thus causes difficulties in segmentation process.
b) Intra-class variation arising from the fact that the region of interest exists in varied forms or appearances. Such a variation makes the segmentation process difficult.

c) Images with complex background presents a major challenge in the image segmentation tasks. Such a complex background degrades the performance of the segmentation algorithm.

Till date, several algorithms has been designed to overcome such challenges. There are innumerable segmentation techniques available in the literature, however no single method is universally effective or equally suitable for a given type of image. Furthermore, it is possible that algorithms created for one class of images won't always work for other classes.

The manuscript has been organized into the following sections: In Section 2, applications of image segmentation has been summarized. A detailed description of the methodology used for searching the relevant research papers is provided in section 3. Then, section 4 describes various image segmentation techniques along with discussion of related review papers. Section 5 provides a relative comparison and analysis of various segmentation techniques with its advantages and disadvantages. The results and discussion along with the key findings of this paper is presented in section 6. Lastly, section 7 draws the conclusion.

2. APPLICATIONS OF IMAGE SEGMENTATION

Image segmentation is applied in almost every domain of our day-today life. Some of the prominent applications of image segmentation has been discussed below.

2.1. Interpretation of remotely sensed scene

From the analysis of images that are remotely sensed, several data about natural resources can be recovered. These include agricultural, mineral, hydrological, forest and geological resources. For analysis of remotely sensed scene, sensors on board the satellites used for remote sensing or a multispectral scanner mounted in an aeroplane take pictures of the surface of the earth. These pictures are then sent back to the Earth Station so that they can be processed further.

2.2. Biomedical imaging techniques

For medical diagnostics, a variety of imaging devices are widely utilized, including ultrasound, computer-aided tomographic (CT) pictures, and X-rays. Image segmentation has been used for the disease diagnosis in human beings such as the following.

2.2.1. Identification of lungs diseases

On a chest X-ray, solid tissues look lighter while air-containing structures appear darker. The anatomical features that are easily seen on a typical X-ray film of the chest are the heart, the ribs, the thoracic spine and the diaphragm. The corresponding segments of the chest X-ray are analyzed to check for abnormalities in these regions.

2.2.2. Identification of heart disease

Size and shape of the heart are two quantitative parameters that are crucial diagnostic characteristics for categorizing heart diseases. Radiography images can be processed using image analysis techniques to help in heart disease diagnosis.

2.2.3. Tumor detection

When a breast tumor is suspected, digital mammograms can identify characteristics (such as micro-calcification) that are highly helpful. Mammograms are analyzed by using the techniques of image processing. These include contrast enhancement, segmentation, extraction of feature, and analysis of shape. The tumor's form establishes whether it is benign or malignant.

2.3. Autonomous vehicles

An essential tactic for the efficient operation of autonomous cars is image segmentation. Autonomous vehicles can perceive and comprehend their surroundings through three crucial forms of visual segmentation: detection of the object, segmentation of the lane, and semantic segmentation. Autonomous vehicles are a crucial piece of technology for the transportation of the future since they can travel the road safely and effectively with precise picture segmentation.

2.4. Object detection and recognition

One significant application of computer vision is the identification and recognition of objects. Here, the object could be a face, a pedestrian, or any number of aerial items, such as highways, forests, and farms. Since it is essential to first extract the desired entity from the image, such an application is essential to image segmentation**.**

2.5. Agriculture

The emerging technology of image segmentation can help farmers increase crop yield. The increase crop yield will ultimately lead to a more sustainable food supply. It has the capacity to revolutionize the agricultural industry in future. This is mainly due to its ability to estimate the yield of crops and also its ability to detect the weeds. Thus, we can conclude that segmentation is of great importance in almost every aspect of agriculture.

2.5.1. Estimation of crop yield

In agriculture, image segmentation can be used for estimation of crop yield by analyzing the vegetation index of crops. Remote sensing can be used to measure the spectral reflectance of crops, which is then used to calculate vegetation indices of the crops. Image segmentation methodology are applied to these images to identify and count crops. Thus, ultimately the estimation of crop yield can be done accurately.

2.5.2. Detection of weed

Again, detection of weed is another important application area of image segmentation in agriculture. Traditional methods of weed detection need a great deal of physical labour and time. By the use of various image segmentation techniques, the farmers can detect weeds in real-time. By doing so, the farmers can take timely action to remove the weeds.

2.5.3. Plant leaf disease detection

For an agricultural country, the economy depends highly on the agricultural productivity. As plants get infected by several types of diseases, the detection of disease in plants is very important in agricultural field. The overall product in terms of quality, quantity or productivity gets highly affected without timely care in this area. Thus, to increase the growth as well as the productivity of crops in agricultural field, there is a need for automatic monitoring of diseases affecting plants rather than monitoring them manually. Using image segmentation techniques, plant leaf diseases can be detected automatically. Thus, detecting plant leaf diseases in the early stage will help to treat it appropriately by providing the details to the farmer. This ultimately helps the farmers in cultivating healthy plants in a farm and consequently increase the crop productivity.

3. METHOD

This study is based on a systematic review methodology. The approach analyzes and then evaluates the available studies which are related to image segmentation techniques. The study has been conducted through three phases: i) preparing for the review, ii) conducting the review, and lastly iii) creation of a summary of the review. In this review, we collect and analyze various papers on image segmentation which were published in reputed journals and conferences. The goal is to analyze the models so as to study the contributions and limitations of the models developed by the researchers. For collection of the relevant papers, we implemented a two-fold strategy: 1) searching by the use of several popular search engines by using the keywords, “review”, “image segmentation”, “clustering", “thresholding”, “region-based segmentation”, "watershed algorithm", "convolutional neural network", “edge-detection”, "deep learning", "artificial neural network", and 2) evaluating the selected papers and eliminating those papers that were not relevant for our study. Those papers from reputed journals, conferences which are published full in English text has been selected. Figure 1 depicts a detailed organization of our methodology. Through a comprehensive examination of the collected papers, we have identified several domains of application for image segmentation. Collection of research papers is done from various renowned research databases. For conducting this research and to achieve an overall broad coverage for this review, we used the following prominent research databases as our key resources: "MDPI", "Web of Science", "ACM", "Scopus", "Cornell University-arxiv library", "IEEE Xplorer", "Springer", "ScienceDirect", and " Wiley Library".

4. IMAGE SEGMENTATION TECHNIQUES

The process of image segmentation is considered as one of the most challenging tasks in image processing. The effective evaluation of an image largely depends on the quality of the segmented image. Segmentation process segments an image into a number of parts on the basis of pixel's characteristics in the image. The foreground of an image is separated from background through the process of segmentation. The technique also involves clustering or grouping different regions of pixels with respect to similarities in attributes like color, texture or intensity of the pixels. There are several techniques for image segmentation proposed by many researchers till date. All these techniques have their own importance. For the sake of simplicity, mathematical description has been avoided and thus all the techniques are described theoretically. Figure 2 shows different techniques of image segmentation.

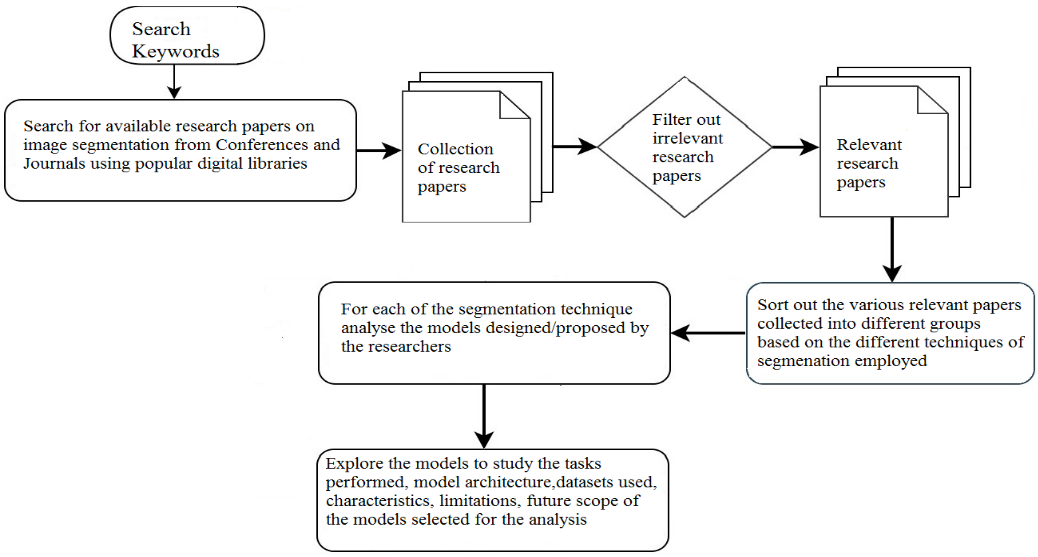

Figure 1. Methodology of the review

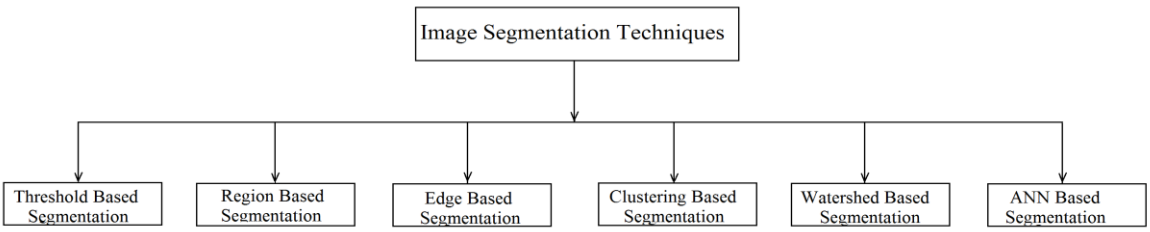

Figure 2. Classification of techniques of image segmentation

4.1. Thresholding based segmentation

Thresholding technique is a simple and a significant image segmentation method. Though simple, this method is effective for segmenting images with bright objects against dark backgrounds. Thresholding technique transforms a multilevel image into a binary image. Here, an appropriate threshold **T** is selected which splits the image's pixels into many regions and the objects are isolated from the image background. Depending on the value of threshold being selected, thresholding methods are of two types [2], global thresholding method and local thresholding method. When the threshold value **T** is constant for the entire image, the type of thresholding is global thresholding. And if the value of **T** changes for the sub-images obtained from the entire image, it is termed as local thresholding. The techniques of global thresholding fail when there is non uniform illumination of the background. In a complex image containing multiple objects, multilevel thresholding is applied in an effective manner. Researchers have made remarkable contribution in the study of multilevel thresholding for image segmentation and is still an ongoing task [3]–[5]. The EMT technique, the P-tile method, the Mean method, Histogram-Dependent-Technique are some of the well known thresholding methods.

Devanathan and Venkatachalapathy [6] proposed a multilevel thresholding technique of segmentation and classification method for diagnosis of brain tumor. Image preprocessing is performed in three levels for improving the image quality. For segmenting the image, artificial bee colony algorithm with multi-level thresholding has been employed. Gray-Level-Co-occurrence Matrix feature extractor is used for extraction of feature vectors. Lastly, classification task is performed using SVM technique. Simulations are done on Kaggle datasets. The model thus presented were able to achieve 97.90% sensitivity, specificity of 97.91%, and 97.56% accuracy.

Al-Amri *et al.* [7] employed the different techniques such as the Mean method, HDT approach, P-tile technique, Visual method and EMT method to three number of images taken from satellite. Their objective was to establish which of the segmentation approaches produced the best segmented image. According to experiments and comparative study of techniques it has been demonstrated that the best thresholding approaches are HDT and EMT whose performance exceeded all other thresholding techniques.

Rahaman and Sing [8] developed a novel algorithm for segmentation of color satellite images based on adaptive-cuckoo-search algorithm. The methodology uses two evolutionary algorithms based on two popular functions such as Tsallis entropy function and Otsu's method. Comparison of the new ACS algorithm with other nature-inspired algorithms has been presented. Significant improvements have been achieved with the proposed algorithm. The computational complexity has been reduced by minimizing the CPU run time.

Jiang *et al.* [9] designed a new multilevel approach of segmentation based on threshold that uses particle swarm optimization and wavelet mutation (PSOWM). For images having multiple attributes, the proposed algorithm yields more accurate segmentation results and better optimized thresholds. The proposed algorithm can be implemented for multiple dimension optimization and performs better in terms of faster rate of convergence than genetic algorithm (GA).

4.2. Region based segmentation

Region-based approach of segmentation divides an image region into distinct areas that, when combined, make up the entire image. An image is segmented into different areas in accordance to certain criteria such as object, color, or intensity. Region based method of segmentation has been divided into three sub classes. They are region growing, region splitting method and the method of region merging [10].

4.2.1. Region growing method

In this method, the attributes of the pixel such as color, texture or intensity is compared to those of its neighbors and combine them into a cluster if they share the required attribute. The region growing segmentation approach can be seeded region growing or unseeded region growing type depending on whether the cluster centers are initially assigned or not.

A. Seeded region growing method

In this method, the image to be segmented is input along with some initial data values called seeds. It is completed prior to the actual segmentation procedure. Initially, the neighboring pixels are compared with the seeds and if they satisfy certain similar characteristics these pixels are assigned to a cluster.

B. Unseeded method of region growing

Initialization of the seeds is not required in the unseeded region growing approach of segmentation. However, some predefined value of threshold is needed that will determine if a pixel is to be allocated to a cluster or not. Moreover, this region growing approach suffers from certain drawbacks. This method is sensitive to noise, discontinuity or holes are observed in the extracted region and more complex in computation [11], [12].

4.2.2. Region splitting and merging method:

This method uses two fundamental approaches, namely splitting the region and then merging them so as to divide an image into various regions. Region splitting is the task of repeatedly sub-dividing an image into regions with similar attributes. While region merging is the process of combining similar regions that are adjacent. This particular method works on quad tree which consists of four branches as in Figure 3. Here in Figure 3, let us assume that R represents the entire image region and we select a predicate P. For any region R_i , if the condition P (R_i) = FALSE, then we subdivide that region into four disjoint quadrants. The sub-division of quadrant into sub-quadrants is continued until some stopping criteria is fulfilled. The sub-division process is stopped when no further splitting is possible. If P (R_j U R_k) = TRUE, the adjacent regions R_j and R_k are merged if the regions share some common features. Finally, we stop when no further merging is possible [13]. Thus, in quad tree structure, two adjacent similar regions are merged and the process of merging is repeated till the time when no further merging is possible. However, this method is more complex and produces high-compositionality [14].

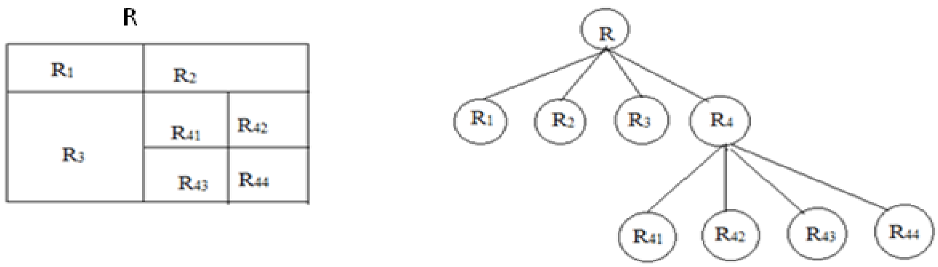

Figure 3. Quad tree [13]

Reddy *et al.* [15] developed a novel framework for effective diagnosis of diseases of the skin. The model uses region growing segmentation technique for segmenting the diseased lesions. GLCM and Weber-Local-Descriptor are used for texture features extraction from the segmented lesions affected by the disease. Finally, classification of the images with disease and those without disease is performed by utilizing the autoencoder technique. The proposed model performs better than CNN, LSTM, RNN classifiers.

Wang *et al.* [16] designed a novel region based model, RISA based on k-means clustering. The algorithm has been explicitly designed for applications that are meant for remote sensing. The methodology consists of five steps: the first is k-means clustering technique for seed generation, segment initialization, seed generation based on the clustered image, region growing based on spectral and shape measures, and region merging to avoid over-segmentation. SPOT 5 satellite imagery and Satellite Quick Bird imagery has been used in the study. The RISA algorithm exhibits certain characteristics such as multi-scale, scalable, flexible, reproducible and compatible.

Cigla and Alatan [17] demonstrated a novel color image segmentation technique with the objective of improving the normalized cut image segmentation (NCIS) method. Their method used image having a weighted undirected graph. Also, the nodes represented the regions, and the intensity match between neighboring regions is represented by weights between nodes. Their modified method has successfully resolved the issue of over segmentation. Images of mosaics, cows, and multi-resolution normalized cut image have been used for the experiments. Comparison of the results are made using the MSE criteria to the NCIS algorithm. The results demonstrate that the proposed methodology shows considerable improvement over the NCIS algorithm.

Qiao *et al.* [18] proposed an automatic method of liver segmentation. To reduce noise, adaptive median filtering is done on the image. For region growing algorithm, the centroid of the largest connected region of the CT image has been chosen as the seed point. Segmentation of image has been performed using dual-threshold technique. The results obtained demonstrated that the method solves the problem of selecting seed points manually for the region growing algorithm. Moreover, double-threshold method of segmentation improves the accuracy of segmentation of the liver region. Also, the edges and texture regions are sharper and smoother.

4.3. Edge based segmentation

Detection of the edges is an important preprocessing step in most of the machine vision applications in industry [19]. The edge of an object is the term for the local, discontinuous features in the image. In this class, segmentation is carried out by locating edges of the image on its gradient in order to determine boundaries of the objects. This method uses edges as a criterion for object identification. In first order derivative [20], convolution of the input image is done with a mask so as to produce a gradient image. Thresholding method is applied for detection of the image edges. Some of the traditional operators like Prewitt, Sobel, Roberts are the operators of first order derivative which are also called as the gradient operators. Detection of edges by the gradient operators is done by finding the values of maximum intensity and minimum intensity in the first derivative of the image. These detectors have more computational time. The second order derivative method is also called the Laplacian method. So as to find the edges in the image, this technique detects for zero crossing in the second derivative of the image. The 2nd derivative of image intensity being very sensitive to noise, needs to be filtered out before the process of edge detection. When a Gaussian filter is used with the Laplacian this method is called the Laplacian-of-gaussian (LoG) which was invented by Marr and Hildreth [21]. Certain parameters of this operator can be computed automatically [22], but in majority of the cases the user needs to fix them. LoG also suffers from main drawback. It is less accurate for determining the orientation of the edges as well as malfunctioning at the curves and corners due to the existence of variations in intensity function. As a solution to this problem, in the year 1986, Canny invented the Canny edge operator [23]. Canny operator is an optimal edge detector to detect edges from the image without influencing the elements of the edges and has gained the most popularity for edge detection.

Shah *et al.* [24] evaluated the performance of several edge detectors such as Robert, Prewitt, Sobel and Canny. Parameters such as MSE and PSNR has been used for the purpose of evaluation. The results of the experiment demonstrates that Canny edge detector can detect strong as well as weak edges and hence is more efficient than the other detectors.

Roy *et al.* [25] designed an edge detection methodology for segmentating the nuclei regions of H&E stained histopathology images of liver cancer. The designed method is insensitive to noise as it is based on the value of local standard deviation. The designed unsupervised algorithm could achieve a higher nuclei detection accuracy. The high value of PSNR achieved at the final image obtained after segmentation indicates that the image noise level obtained after segmentation is lesser as compared to other approaches. Thus, the designed algorithm exhibits better performance than the nuclei segmentation methods existing till date.

Rani *et al.* [26] performed the comparison of the efficiency of different edge detectors such as the Sobel operator, Laplacian operator and Hough Transform algorithms. These algorithms have been implemented for the detection of edges in the images of scanning electron microscope (SEM). The images considered were both metallic as well as non-metallic images. Several parameters such as accuracy of edge detection, efficiency of removing the noise, and speed of execution were used for comparison. The results demonstrate that Laplacian algorithm exhibits better performance compared to others in terms of voids, boundaries, curves or lines as well as the orientation detection.

Awalludin *et al.* [27] designed an edge-based method of segmentation for detection of changes in the images of coral reef. Images of coral species that were taken from the Malaysia's Redang Islands has been used in the study. Image enhancement has been performed by employing different methods such as contrast stretching, technique of histogram equalization and adaptive-histogram-equalization with limited contrast methods. The Canny detector is found to be the most sensitive with an average sensitivity of 96% compared to other detectors. The results obtained illustrates that the proposed approach performs better than conventional methods in detecting changes in the coral reef due to the influence of climate change.

4.4. Clustering based segmentation

The technique of clustering involves grouping objects according to certain similar characteristics such that each cluster contains related objects that differ from those in other clusters. In essence, a cluster can be defined as a group of objects that are comparable to one another which belong to the same cluster but not to those that belong to other clusters. Some commonly used algorithms for clustering are as follows:

4.4.1. K-means clustering technique

The K-means algorithm [28] is a commonly used iterative method which is mostly used due to its speed of convergence and ease of implementation. It is one of the most efficient, reliable, and straightforward unsupervised learning techniques for resolving the well-known clustering problem. When data sets are dissimilar, K-means clustering technique gives the optimum results. A set of data has been divided into k groups of data by using k-means clustering method [29], [30]. The number of partitions in this algorithm are basically predefined. For clusters that have previously been defined, the cluster centers are initialized arbitrarily. After that, each data point is assigned to one of the closest clusters. Next, a new centroid is determined and the cluster centers are essentially re-estimated. This method is repeated until a significant change in the cluster center is not achieved [31]. Advantages: a) The algorithm is fast, robust and very easy to understand. b) The algorithm is systematic or relatively well-organized. c) The algorithm yields the most accurate results when the data set is discrete.

Although it has certain advantages and is easy to implement, the k-means algorithm has its drawbacks. In this algorithm, the final segmentation results depend highly on how we initially choose the cluster centroid.

4.4.2. Fuzzy C–means (FCM) algorithm

The Fuzzy-C-Means algorithm, commonly referred to as FCM, is essentially an iterative algorithm that uses the concept of fuzzy membership to help identify clusters in data. On each cluster, each pixel can have a unique membership value instead of assigning a pixel value to a single cluster. Fuzzy partitioning is used by the FCM to allow a data point to belong to any group with a membership grade between 0 and 1. FCM allows a single data to be a part of two or more clusters. We are able to preserve data set information by using FCM. The most common application of this method, which was enhanced by Bezdek in 1981 after being created by Dunn in 1973, is pattern recognition. FCM is among the most popular and commonly used technique of soft clustering approach [32]. Advantages: a) FCM algorithm is unsupervised and b) The algorithm converges.

However, the FCM suffers from certain limitations. The computation takes longer time and is more sensitive to noise. As for the outliers (noisy points), one expects low membership degree. Tongbram *et al.* [33] presented a novel image segmentation approach which is a hybrid of K-means clustering technique and a modified version of subtractive clustering method. This approach is based on the relative distance between clusters centers and the data points. For segmentation, the K-means algorithm used cluster centers acquired from the modified subtractive clustering method. Parameters such as MSE and PSNR values obtained from the designed algorithm has been compared with the traditional methods of segmentation. Results obtained from the experiment indicates that the designed approach is better than the conventional clustering techniques.

Ajala *et al.* [34] applied the clustering methods for segmentation of medical image. They have used MRI images of the human brain. They have successfully combined fuzzy C-means algorithm and K-means algorithm to obtain fuzzy K-C-means algorithm which is a novel method. Their algorithm performs better than other algorithms with regard to time utilization.

Sampathkumar and Rajeswari [35] designed a novel approach for identification of diseases in rice and apple tree. To identify the suspicious regions in these crops, CAD system-based process is employed. Denoising of the crop image is performed by using the cross central filter (CCF) technique. The disease affected regions are differentiated from the normal region by cognitive fuzzy C-means (CFCM) image segmentation algorithm. The evaluation of the results indicates that CFCM algorithm achieves higher performance in terms of sensitivity = 74.54%, accuracy = 83.47% and precision = 87.27% as compared to FCM algorithm.

Khrissi *et al.* [36] have developed an approach by incorporated clustering technique of image segmentation with sine cosine algorithm (SCA). SCA is a popular optimization method whereby optimal solutions are obtained by utilizing sine and cosine functions. The problem of initializing the cluster centers in conventional clustering technique has been solved in this approach. Results obtained from the designed algorithm has been compared with the existing clustering techniques and other meta-heuristic methods. The analysis of the results obtained indicates that the presented approach is more efficient and reliable and more rapid with respect to other approaches.

Munsarif and Saman [37] designed a methodology using k-means clustering technique and spatial filter for improving the quality of handwritten images. Mean and median spatial filters were employed to improve the image quality. The best result of segmentation was obtained with a median filter of kernel size 3x3 with a value of k=2 which yields the value of silhouette coefficient to be 99.22%.

4.5. Watershed based segmentation

The watershed segmentation method is among the oldest segmentation methods proposed initially by Beucher and Lantuejoul [38]. This method considers gray level images as topographic surface which consists of valleys, hills and peaks. Higher intensities are used to model the hills and peaks while lower intensities are used to model the valleys. The basic idea is relatively simple. The whole topography is flooded from below by punching a hole in the local minima and water is allowed to rise through the holes at a uniform rate. When the local water bodies are about to merge due to the rising water level, a dam is constructed that will prevent the merging of the water bodies. As the flooding continues, the whole image is partitioned into distinct catchment basins [39], [40]. Eventually the flooding will come to a stage where only the upper portion of the dams can be seen above the water line. The boundaries of these dams represent the divide lines which is called the watershed lines. Extraction of these connected boundaries are done by watershed segmentation algorithms. Thus, the main objective of watershed segmentation algorithms is to detect the watershed lines. Apart from image segmentation, watershed algorithm finds application in the preprocessing of digital images [41].

Indriyani *et al.* [42] designed a novel watershed algorithm for segmentation of potholed roads. The watershed algorithm consists of six steps viz. smoothing the segmented image, calculation of the gradient value and the third step is the automatic determination of the minimum flooding value so as to find the watershed image efficiently. The fourth step combines the catchment basins. Next, the remaining watershed lines are erased and lastly a watershed curve is created to know the segmentation boundary. The proposed algorithm achieves an accuracy of 95.34%, specificity of 97.37% and sensitivity of 90.04% and is much better in comparison to other watershed algorithms.

Bora *et al.* [43] developed an efficient method for segmentation of color image. This approach was based on the classical method of watershed algorithm. Here, the RGB image has been first converted into HSV image. For segmentation of color images, the HSV-color-space is more suitable. Otsu's technique of thresholding is implemented on the HSV converted image. The output image thus obtained acts as an input for the watershed algorithm. Finally, the segmented image is obtained. The proposed method overcomes the issue of over segmentation. The high values of PSNR and the low values of MSE of the proposed method indicates that it can efficiently deal with segmentation of color images.

Algailani and Hamad [44] presented a novel watershed methodology for detection of sickle cell disease. The proposed technique suppresses the problem of over segmentation. On the input image, nonlocal means filter was used to reduce the problem of over segmentation. This filter acts as an efficient method for noise removal. Here, all the image details were preserved after removing noise. All the sickle cells of the test image were accurately detected. The algorithm performs well in terms of accuracy, sensitivity as well as specificity factors.

Xue *et al.* [45] proposed a watershed algorithm that has been designed for accurate extraction of cultivable land boundaries. The image used were high-resolution image obtained by remote sensing. In this method, contrast enhancement method has been used as the pre-improvement process. For the post-improvement procedure, the color distance of the CIE color space has been adopted as the similarity measure to merge the regions. The results demonstrated that the designed algorithm outperforms the RGB colour space region merging method. The proposed methodology exhibits excellent performance with respect to visual impact, time efficiency, and extraction accuracy.

4.6. Artificial neural network (ANN) based segmentation

A neural network can be considered as a system that has been developed to mimic the human brain in performing a task as well as simulate the learning process. An artificial-neural-network is also otherwise known by the name of neural network or simply neural net. Parallel processing capability of ANN makes them applicable for real time processing. The ANN model was first proposed by McCulloch and Pitts [46] in the year 1943. Popular neural networks implemented for segmentation of images are Hopfield NN, back-propagation neural network (BPNN), feedforward neural network (FFNN), multilayer feedforward (MLFF), multilayer perceptron (MLP), Kohonen self-organizing map (SOM) and convolutional neural network (CNN).

However, in the recent years, deep learning (DL) models based on ANN architectures have become very popular and widely implemented by a large number of researchers. These models gave rise to the development of a new era of image segmentation models which shows incredible improvements in their performance. Some popular architectures of deep learning include convolutional neural networks (CNNs) [47], long short term memory (LSTM) [48], recurrent neural networks (RNNs) [49], encoder-decoders [50] and generative adversarial networks (GANs) [51]. The CNN architecture is shown in Figure 4. The architecture mainly consists of three types of layers: the convolution-layer, the pooling-layer, and the fully-connected-layers. Convolution of a kernel (or filter) along with the input image is performed in the convolution layer to extract image features. The main objective of the pooling layer is the reduction of the spatial dimensions of the feature maps. Fully-connected-layer is mostly used as final layers in classification problems. Some of the popular CNN architectures are: LeNet-5 [47], AlexNet [52], VGGNet [53], ResNet [54], (SENet) [55], GoogLeNet [56], MobileNet [57] and DenseNet [58]. With the development of transformer model [59], a breakthrough transformation has occured from CNN stage to transformer stage in the image segmentation domain.

The application scenarios of DL-based segmentation methods are extensive. Segmentation based on DL techniques has been widely used in medical imaging [60]. These methods have also been implemented successfully for segmentation of satellite images in the field of remote sensing [61]. Another domain where DL based segmentation has gained wide popularity is the surveillance systems [62]. Surveillance systems can be further extended to various fields of application such as object tracking [63], theft detection [64], searching [65], object detection [66] and so on. Biometric verification systems like iris [67], face [68], fingerprint [69] requires the segmentation of several informative regions in the image for efficient analysis.

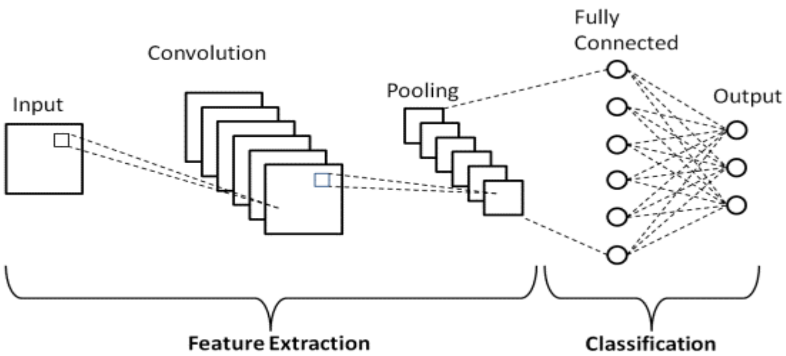

Figure 4. CNN architecture

Liu *et al.* [70] proposed a novel deep learning architecture named DeepCrack for crack segmentation. In this model, multilevel and multiscale features are learnt and then aggregation is done from the convolutional layers in the lower level to the-convolutional layers in the higher-level. The Deepcrack architecture consists of the Deeply-Supervised-Nets and extended FCN. Refinement of the final results are done by applying guided filtering and Conditional Random Fields, CRFs. The results demonstrate that the guided filtering method is faster and more efficient than CRF.

Yuan *et al.* [71] proposed a novel methodology MC-WBDN for detection of water bodies from satellite images. The use of NIR and SWIR wavelength bands results in improved segmentation. Experiments have been performed on Sentinel-2 satellite dataset. The designed model is robust against weather and light variations. MC-WBDN model gives an average mIoU of 73.56 and outperforms other models in water body detection.

Pereira *et al.* [72] developed a novel CNN-based automatic segmentation approach for segmentation of brain tumor. Small kernels of size of 3x3 are applied. In the pre-processing step, intensity normalization has been performed. Along with this, the data augmentation procedure performed during their experiment proved to be very efficient in brain tumor detection of MRI images. They have used MRI images of 274 gliomas (an aggressive type of brain tumor) for training the data. The computation time for their model was reduced by tenfold in comparison with the best generative model. They obtained first position in the BRATS 2013 challenge, as well as second position in the 2015 BRATS challenge.

Shah *et al.* [73] presented a comprehensive review on the use of ANN and CNN for detection of skin cancer at the early stages. Their study addressed that CNN models perform better as compared to ANN models. The classification of image data using CNN is more accurate compared to other neural networks. The paper also discussed the importance of developing more accurate and efficient algorithms for early diagnosis of skin cancer which will eventually help in improving the outcomes of those patients suffering from skin cancer.

5. COMPARISON AND ANALYSIS

Image segmentation has been divided into different types on the basis of constraint selected for segmentation such as intensity of the pixel, homogeneity, discontinuity, cluster data, and topology. The choice of segmentation method depends on the quality of segmentation required as well as the scale of information required at the output. Thus, till date, no single algorithm exists that is applicable to all types of images and nature of problem. This is so because image segmentation is affected by several factors such as image type, color of the image, intensity level, and noise level. Each approach has its own pros and cons. Table 1 presents a brief description of various segmentation techniques with their advantages and disadvantages.

Table 1. Comparison of various image segmentation techniques

Segmentation technique	Method description	Advantages	Disadvantages
Threshold Based Segmentation	It is the oldest and simplest method based on the information of peaks histogram of an image.	1. Prior knowledge about the image is not needed. 2. The computational complexity is less. 3. Good for grayscale images.	1. It is not suitable for an image that does not possess distinct peaks or images with wide and flat valleys. 2. Sensitive to noise. 3. The method fails in situations where the object area is smaller compared to the area of the background.
Region Based Segmentation	This technique forms regions having pixels with similar characteristics like texture, color and intensity into homogeneous regions.	It is more immune to noise and hence gives remarkable results on noisy images.	It is quite expensive method with respect to computational time and memory.
Edge Based Segmentation	The method detects discontinuity in an image thereby locating points that show abrupt changes in intensity level.	1. The technique is suitable for images with good contrast between regions. 2. Mostly suitable for grayscale images.	1. Not suitable for images whose edges are improperly defined or have a large number of edges. 2. Less immunity to noise.
Clustering Based Segmentation	In this method, pixels with similar characteristics form clusters.	Pixels selection is done with the help of a function. This makes the process more accurate and efficient.	1. Determining the membership function is not an easy task. 2. The efficiency of clustering functions is affected by the presence of noise.
Watershed Based Segmentation	In this method, an image is modelled to a topographic surface consisting of valleys and hills depending on the pixel's intensity details.	1. The results obtained are more stable and highly accurate. 2. The detected boundaries are continuous.	1. The computation is complex and time consuming. 2. It is highly sensitive to noise.
ANN Based Segmentation	This method uses neural networks to simulate human learning process for classification task.	The need to write complex programs has been avoided.	More time is wasted in training the data.

6. RESULTS AND DISCUSSION

Although many achievements have been made by researchers in the field of image segmentation, there still exists many challenges such as feature representation, design of the model and optimization. Also, through research, it has been demonstrated that hybrid model of different segmentation techniques yields optimized results as compared to model designed using a single technique. The introduction of DL architectures has led to tremendous advancement in the domain of image segmentation. Although deep learning has brought many benefits to image segmentation tasks in a large scale, it still faces many challenges such as the requirement of large-scale image datasets for training the model.

Table 2 (appendix) presents a brief summary of the various research papers being reviewed in this study. Through this study, we draw conclusion on various facts regarding image segmentation. First, image segmentation is an important step of image understanding/processing tasks. Secondly, the role of image segmentation in real world applications such as in computer vision tasks, pattern recognition, satellite imaging, medical imaging, autonomous vehicles, surveillance, object detection and recognition, forensics, feature extraction, and plant disease detection. has become tremendously important in today's rapidly advancing technology. Moreover, the analysis of results in these applications extensively depends on the accuracy of the segmentation process. Thirdly, the choice of any image segmentation technique depends on the input image and the problem domain. There exists no universally accepted segmentation technique for the different types of images.

Indeed, conducting a review on image segmentation would provide a valuable source of reference for enthusiastic researchers who seek to gain a better knowledge regarding the contributions of image segmentation models in diverse fields. Such a review would enable the identification of existing models, their characteristics and working methodology. Also, in future, it would contribute in promoting the improvement of existing models of image segmentation and the discovery of novel models for varied applications.

7. CONCLUSION

In this study, a review of different image segmentation techniques has been presented. The findings of the publications related to image segmentation techniques has been addressed in this manuscript. Applications of image segmentation in various domains has been highlighted. A relative comparison of the different segmentation techniques along with their advantages and disadvantages has been demonstrated. Even after extensive research for over many years, image segmentation still remains as a challenging task in image processing. This is so because each method has its pros and cons. So, a single segmentation technique cannot be applied to all kinds of images and not all techniques can suit a particular type of image. Consequently, till date, researchers have not been successful in finding an unanimously supported image segmentation method which is suitable for all types of images. Due to these reasons, it still remains as a challenging task in image processing. However, among the various segmentation methods presented in this study, ANN model-based algorithms tend to give segmentation results that are most desirable. The ANN segmentation algorithms are not only robust but also compatible with imaging in real-time and segmentation procedure. Image segmentation algorithms designed based on deep learning models will revolutionize the image segmentation applications by providing more accurate results. Our study will provide some insightful knowledge regarding recent trends in image segmentation to those researchers willing to pursue further research in this field. This will eventually help them in designing improved algorithms with enhanced performance. Our future work will focus on using machine learning techniques for design of image segmentation algorithms that will deliver an enhanced performance compared to the existing algorithms.

APPENDIX

Table 2. Summary of literature review

Reference	Image type/Dataset	Method/Algorithm	Findings
Devanathan and Venkatachalapathy K [6]	Grayscale image (brain MRI image, kaggle dataset)	Multi-level thresholding and ABC algorithm	Sensitivity=97.90%, specificity = 97.91%, and accuracy =97.56% is achieved.
Al-Amri and Kalyankar. [7]	Grayscale and color image	Mean thresholding method, P-Tile, EMT, HDT, Visual method	HDT and EMT produce the best results among various methods.
Rahaman *et al.* [8]	Color image (satellite image)	ACS with Otsu and Tsallis entropy	Levy flight is used to obtain the best value of threshold in less time. Better PSNR, MSE, SSIM, FSIM and computational time.
Jiang *et al.* [9]	Grayscale image (Lena image and food image)	Multilevel thresholding	Maximum entropy of the segmented image can be higher by the proposed approach. The rate of convergence is faster.
Reddy *et al.* [15]	Color image (skin image)	Region growing segmentation and autoencoder for classification	Achieves an enhanced performance of 6.78% than CNN, 7.2% compared to RNN and 3.68% compared to LSTM models.
Wang *et al.* [16]	Color image (SPOT 5 and Satellite Quickbird image)	RISA based on k-means clustering	Good for segmenting linear features the kappa co-efficient of RISA is higher than other algorithms. Object-based classification is better than pixel-based method.
Cigla and Alatan [17]	Grayscale and color image (mosaic and cow image)	Region based segmentation via graph cut	Yields minimum MSE and the execution time is decreased while increasing the reliability of segmentation.

Table 2. Summary of literature review *(Continue)*

Reference	Image type/Dataset	Method/Algorithm	Findings
Qiao *et al.* [18]	Grayscale image (abdominal CT image)	Region growing	Automatic selection of seed points for region growing. Segmentation errors are reduced and the segmented image has fewer holes and smooth edges.
Shah *et al.* [24]	Grayscale image	Sobel, Roberts, Prewitt, LoG, Canny	Canny detector is the most efficient as compared to other detectors. Though most efficient, it takes more computational time.
Roy *et al.* [25]	Color image (H&E stained histopathology images)	Edge detection based on local standard deviation	The F1 score value is close to 1 indicating that it can effectively and accurately achieve nuclei segmentation. Insensitive to noise.
G. E. Rani *et al.* [26]	Color image (SEM image)	Sobel, Laplacian and Hough transform	Laplacian detector gives better accuracy and higher execution speed.
Awalludin *et al.* [27]	Color image (coral reef dataset)	Sobel, Roberts, Prewitt, LoG, Canny	Canny yields the highest sensitivity of approx. 96%.
Tongbram *et al.* [33]	Grayscale image (Berkeley dataset)	k-means and modified subtractive clustering	Achieves PSNR= 62.35dB and MSE=1.07 on synthetic images and PSNR= 45.52dB and MSE= 6.25 for real images, outperforms conventional techniques.
Ajala Funmilola *et al.* [34]	Color image (MRI images of human brain)	Fuzzy k-c means	Delivers the highest iteration value with segmentation performed within the shortest time period with highest accuracy.
Sampathkumar *et al.* [35]	Color image (apple scab and rice crop image)	Cognitive fuzzy c- means (CFCM)	Achieves a sensitivity of 74.54%, precision of 87.27%, accuracy of 83.47% compared to conventional FCM.
Khrissi *et al.* [36]	Color image (Berkeley dataset)	Clustering based on sine cosine algorithm	Execution time is saved by 37% in comparison to clustering algorithm by GA and 20% compared to that of clustering algorithm by PSO.
Munsarif *et al.* [37]	Grayscale image (handwritten image)	k-means clustering with spatial filters	Delivers the most significant segmentation result reaching 99.22% with a median filter of size 3x3 and value of k=2.
Indriyani *et al.* [42]	Grayscale image (Kaggle dataset)	New watershed algorithm	Produces an accuracy of 95.34%, Sensitivity of 90.04%, Specificity of 97.37% compared to other algorithms.
D. J. Bora *et al.* [43]	Color image (Berkeley dataset)	An efficient watershed algorithm	Over-segmentation problem is solved. Yields low MSE and high PSNR values resulting in high efficiency of color image segmentation.
H. Algailani and Hamad [44]	Color image (blood smear image with sickle cell anaemia)	Improved watershed segmentation	Reduces over-segmentation and produces a segmentation accuracy of 93.21% compared to other algorithms.
Xue *et al.* [45]	Color image (GF-2 remote sensing image)	Region merging watershed algorithm	Higher time efficiency and segmentation accuracy is achieved.
Liu *et al.* [70]	Color image (custom dataset consisting of 537 images)	Deepcrack	Integrated direct supervision for multi-level feature learning is achieved. F-score = 86.5, mI/U=85.9, Recall= 86.9, Precision = 86.8 is achieved.
Yuan *et al.* [71]	Color image (Sentinel-2 satellite dataset)	MC-WBDN	Produces mIoU of 73.56. The inclusion of NIR and SWIR bands gives better water detection results.
Pereira *et al.* [72]	Grayscale image (BRATS 2013 and 2015 database)	Automatic segmentation based on CNN	Small kernels felicitate the design of deeper architectures giving a positive effect against overfitting. Computation time is reduced by tenfold.

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