A Comparative Analysis of Various Image Segmentation Techniques

Poonam Jaglan, Rajeshwar Dass and Manoj Duhan

Abstract In this ascension era of technology, Magnetic resonance imaging (MRI) emerges as the utmost clinically acceptable imaging modality for detection and diagnosis of tumors. The Breast tumor is leading scrupulous diseases among women. In last two decades, image segmentation has got a high boost and attention from the researchers across the globe. To represent the image in such a way which is easy to analyze and more meaningful, the process of segmentation is used. It is the primal step in processing images of different types. Therefore, the image is sectioned into desirable building blocks. Basically, it provides the meaningful objects of the image. Literature provides a variety of image segmentation algorithms even though there is a requirement of an efficient segmentation technique which can work efficiently on all sorts of images. The key extract of an algorithm lies within the superiority of segmentation performed by a particular method. The availability of segmentation algorithms is quite large, so the analysis of these algorithms might be interesting to the researchers. This paper reviews segmentation techniques such as theory-based, region-based, thresholding, edge-based, Neural Network-based, Model-based, and Partial differential equation based on the basis of their functioning, utility, advantages, disadvantages, and applications.

Keywords Magnetic resonance imaging · Partial differential equation
Neural network · Markov random field · Fuzzy C-means

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1 Introduction

In the year 2016, approximately 1.5 lac new cases of breast cancer (over 10% of all cancers) have been registered in India [1]. Breast MRI becomes a clinically applicable imaging modality for breast cancer screening due to its high sensitivity and moderate specificity as compared to others [2]. MRI proves excellent at surgical implants imaging or the augmented breast [3]. Medical investigation of breast cancer is well recognized but finding out the proper technique for early detection is still the challenging one [4]. Initially, preprocessing should be considered for contrast enhancement before further processing [5]. Thus, the next step in image analysis is segmentation. Patterns color, shapes, and texture are the basic features to segment the complex image into the simple objects in the human vision; the image segmentation follow the same process for the computer vision. The process to part the image into distinct regions is so-called image segmentation. By and large, the image representation is so refined that the image outcomes are more functional for ongoing researches. This paper is further categorized as: In Sect. 1 introduction is presented, Sect. 2 gives a brief description of image segmentation, Sect. 3 explains the subsisting techniques of segmentation and Sect. 4 demonstrates the conclusion and future scope.

2 Image Segmentation

This process gets the higher attention in medical image processing. It aspires to section a digital image into a set of regions where each pixel is uniform as well as visually distinct with respect to characteristics like boundary, intensity, texture and color, etc., to identify objects/boundaries in an image. This partitioning is domain independent. It provides the significant information which can be easily analyzed.

From last many years, this area of research is speeded up at an extent. The researchers came up with enormous segmentation algorithms time to time because of its prodigious significance. Thus, an algorithm created for a particular image's type may generally not acceptable by the other class of images, as each doing the segmentation but not in the same way as another [6]. So from this point of view, there is a need to develop a specific algorithm which may fulfill every objective and must be effectively applicable to each kind of digital image. The process selection depends upon the problem formulation, type of image and output required. The field of image segmentation deserves the tremendous researches and hence a protean image segmentation technique needs to be developed on fast pace.

3 Image Segmentation Techniques

A distinct number of segmentation methods are proposed by the researches carried out in this field in the past decades. Segmentation techniques are initially classified as object, layer and block-based methods [7]. Where object based methods segment an image into regions in which the exact boundaries of the object are found. The object can be any text, photo or a graphical object, etc. Many researchers found this technique quite complex than the others. Layer Based method divides the image into layers, i.e., foreground, back ground, and mask layers. The mask layer decides the reconstruction of the final image from the other two layers. Object-based- and layer-based techniques are not much applicable to medical imaging so did not explain in detail. Whereas in the block-based approaches partition the image into rectangular blocks based on various image attributes, i.e., histogram, color, gradient, wavelet coefficients, etc. It is the most simplified segmentation technique. The hybridization of the above three categories also developed by the researchers. Block-Based Segmentation approach is further divided into two types as per the fundamental traits of pixels: Discontinuity and Similarity are as follows [8]:

a. **Boundary-based detection methods**

These methods rely on some discontinuity feature of the pixel. The images are segmented into regions by the unforeseen changes in the gray level/intensity of the image. Generally, it can identify various corners, edges, points as well as lines in the image. Pixel misclassification error is the prominent limitation. Edge detection technique is the main example of this type.

b. **Region-based detection methods**

These depend on similarity properties like lines, points and edges. The segmentation is done on the premise of similitude in intensity levels in according to a set of prerequisite criterion. Algorithms like region merging and splitting, thresholding, and region growing, etc., comes under this category.

Figure 1 shows the categorization of segmentation algorithms on the basis of various image attributes and Table 1 gives the relative comparison of different segmentation algorithms.

3.1 Region-Based

In this, the object's related pixels are grouped for segmentation. An image is segmented into the homogenous regions. In this, grouping of regions typically based on their anatomical or functional roles. The detected area for segmentation should be closed. It can also be termed as "Continuity Based". The patterns with same intensities inside the cluster formed by neighboring pixels make different sub-regions of the input image. There must be a pixel relevant to region at every step and that particular

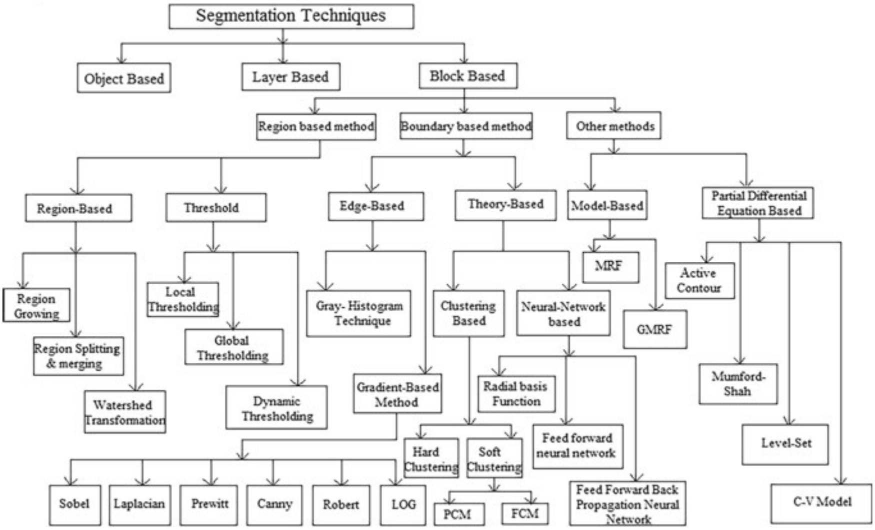

Fig. 1 Classification of image segmentation techniques

Table 1 Comparative analysis of various image segmentation techniques

S. no.	Segmentation techniques	Description	Types	Advantages	Disadvantages	Applications
1	Region-based	Sub-regions formation based on the patterns having same intensity values within a cluster of neighboring pixels	1. Region growing 2. Region splitting or merging 3. Watershed transformation	Simple and more immune to noise	It requires lots of computational time	Pixel aggregation, piecewise constant radiance, 3D reconstruction
2	Edge-based	Detection of pixels having abrupt intensity transition is done and then the extracted ones are joined altogether to form the closed object boundaries	1. Gray histogram technique 2. Gradient-based method	It can retrieve the information even through weak boundaries. Upgrade the positional accuracy	Image with too many edges is problematic. Less immune to noise than other techniques	Face identification, medical image processing, biometrics

(continued)

Table 1 (continued)

S. no.	Segmentation techniques	Description	Types	Advantages	Disadvantages	Applications
3	Thresholding based	It comes with a threshold value *T* which sectioned the entire image into only two intensities so-called binary image	1. Global thresholding 2. Local thresholding 3. Dynamic thresholding	Fewer computations. Easily understandable. Intrinsic and simple	Noise-sensitive. Not suitable for complex images. Not for multi-channel images	Locate cysts, tumors and distinct pathologies, medical image analysis
4	Theory-based	The derivatives from different regions taken into consideration in this technique	1. Clustering based 2. Neural network-based	Straightforward for classification. Implementation is quite simple	Computation time is high. Features are often image dependent. Feature selection criterion is uncertain. Spatial information is less utilized	Volume of tissues is accurately measured
5	Model-based	For object reproduction, specific learning regarding the geometrical state must be compared with the local information. Works well only when precise shape of the object is known	1. Markov random field 2. Gaussian Markov random field	Minimizes the number of misclassified pixels. Faster convergence. Fewer tendencies to be trapped in local minima	Hard to calculate. Expensive. Large storage required	Remote sensing and texture segmentation
6	PDE-based	Particularly the models are designed to solve problems where the approximate shape of the boundary is known. Active-contour model or snakes is the prominent one	1. Active contour 2. Level set 3. Mumford-shah model 4. C. V Model	Fast and efficient. Implicit, geometric characteristics of the evolving structures are straightway reckoned. Intrinsic	Highly immune to noise. Computational complexity is high	Computer vision and medical image analysis, stereo reconstruction, object extraction and tracking

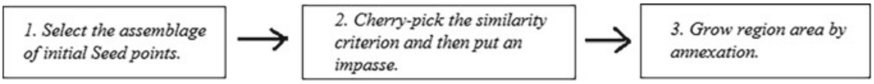

Fig. 2 Process of region growing

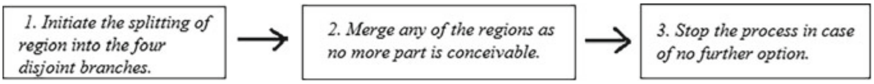

Fig. 3 Three steps of region splitting and merging

pixel is considered. These techniques are regularly utilized for intuitive methods for segmentation because of their high computational efficiency [9] but at the cost of high computational time [10]. Further classification is as below.

3.1.1 Region Growing

The accumulation process of pixels with comparable properties is done for the formation of a region. It bunches the pixels of the whole image into subparts or huge areas based on some standard criterion for growth. Region growing can be processed as shown in Fig. 2 [11].

3.1.2 Region Splitting and Merging

First the image is partitioned into a set of random detached regions and then merging and/or splitting can be done to satisfy some specific conditions. In fact, splitting has more impact on the overall process. The specific one can be accessible in the form of quad-trees as the name suggests that each node has exactly four branches. This technique is complex and time-consuming. For this the steps are as shown in Fig. 3 [12].

3.1.3 Watershed Transformation

It basically done the intensity-based assemblage of pixels as each pixel contains a different intensity value. It is a mathematical morphological operation reckoned imperative to solve formidable problems of image segmentation specifically breast images [13, 14]. Its textured patterns sometimes cause over-segmentation so researchers still finding the remedy. This is a puissant segmentation technique due to its processing speed, simplicity and entire image partition [13].

3.2 Edge-Based

Techniques based on finding discontinuities in the gray scale values are simply known as edge or boundary-based methods. Edges can be defined as the discontinuity of gray level intensity value at the boundaries [15]. The basic types of edges are step, point and line edges out of which step and line edges are infrequent for real-time images as sharp changes rarely subsist in the real images [16]. All kinds of edges can be detected mainly by spatial masks. It detects first and then extracting the objects that have a quick transition in the gray value. And finally these objects are joined to form the closed object boundaries. However, it may be classified as.

3.2.1 Gray Histogram Technique

This method is quite efficient comparatively. First, a histogram is formed on the basis of intensity level of each pixel so that edges and valleys are easily located in the image. If significant edges and valleys were identified, it is difficult to use this method. The specific value of threshold T gives the proper result, and to find out the limits of gray level intensity is quite difficult because the impact of noise on gray histogram is uneven.

3.2.2 Gradient-Based Method

Gradient can be considered as the first derivative of an image. This method responds well at points having rapid transition among two regions. These points also called edge pixels have high value of gradient and must be joined to build closed boundaries. Typically, gradient operators convolve with the image.

All the edge detection operators are listed below:

Sobel Operator

This is the most widely used technique introduced by Sobel in 1970 [6]. Edges can be finding out by the approximate sobel value to the derivative. The point with highest gradient value termed as edges. It is very much similar to the Roberts operator.

Prewitt Operator

It is introduced by Prewitt in 1970 [6] and most suitable to estimate the orientation as well as magnitude of an edge. It is very simple in operation as well as the edge detection and their orientation is quite easy. This operator is less precise and also sensitive to noise.

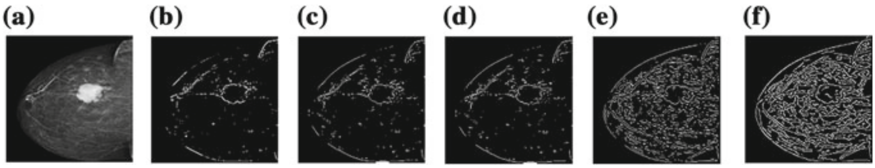

Fig. 4 Qualitative results of different edge detection operators. **a** Breast MR image [18]. **b** Robert. **c** Sobel. **d** Prewitt. **e** LOG. **f** Canny

LOG Operator

This can be termed as Marr-Hildreth edge detector. The pixels having gradient value at its maximum are considered as edges. At the zero-crossing, edge direction can prevail.

Canny Operator

It is one of the best edge detectors which possesses minimum error while detecting true edge points and also prevails good noise immunity. Also known as an optimal edge detector due to finding the edges optimally without emotive the features.

Laplacian Operator

In this, the second-order derivative expression is computed to detect the edges of the image as this particular expression has zero crossings at the prime edges within the image [17].

Robert Operator

Lawrence Roberts introduced this technique in 1965. It is quite simple and computes fast. The magnitude of the spatial gradient of the breast MR image at a particular point can be represented by pixel values at that point in the output. It accentuates the high spatial frequency regions considered as edges.

Figure 4a depicts the breast MR image [18] Fig. 4b–f shows the qualitative results of different edge detection operators. The Canny is most promising one as per the qualitative analysis shown in Fig. 4, yet it is comparatively time-consuming. Practically, it is necessary to maintain a balance in between accurate edge detection and noise reduction [6]. Some additional or fake edges will be detected in the case of high noise density. Hence, these techniques are effective for the noise-free images.

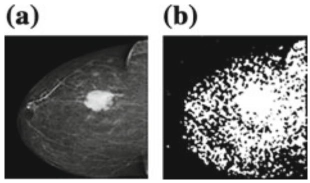

Fig. 5 **a** Breast MR image [18]. **b** Image after thresholding

3.3 Threshold

This is the easiest as well as efficient methodology for image segmentation based on the qualities of the picture. The values used as threshold must be acquired by the histogram of the input image's edges. So, the threshold gives an accurate value only if the edge detections are accurate. More logically, it converts a multi-level image into two-level image, i.e., only a specific threshold value T is selected first, any pixel having value equal or greater than T is considered as foreground and else pixel having value less than T is taken background [19]. Figure 5a shows the original breast MR image [18] and Fig. 5b shows the thresholded image. MRI images generally suffer from noise which corrupt the histogram of the image so that thresholding process also disrupts [20]. It does not perform well for complex images. The three thresholding strategies are.

3.3.1 Global Thresholding

If extremely large intensity distinction exists among the object's background and foreground, a sole value of threshold can essentially be utilized to differentiate both objects and this process is so-called Global thresholding. Hence, in this kind of thresholding, the threshold value estimation must depend solely on the property of picture intensity [21]. Otsu, entropy-based, object attribute-based thresholding are some examples of thresholding strategies [22].

3.3.2 Local Thresholding

This technique firstly segments the whole image into sub-regions and then assigns distinct threshold values to each one. Therefore, this type of thresholding process is called local thresholding. The filtering process should take place to remove spasmodic gray levels after thresholding. It takes more time for image segmentation in comparison to global thresholding. It is more applicable to images with varying backgrounds [21].

3.3.3 Dynamic Thresholding

If there are several objects in the image having distinct intensity regions then some locally varying threshold values $(T_1, T_2, \ldots T_n)$ for each pixel should be used to partition the image which depends upon point values of gray level image.

3.4 Theory-Based

In this kind of segmentation technique, a number of algorithms were outgrowth by distinct works, which plays a vital role for segmentation approach. In general, they include algorithms based on wavelet, clustering, genetic and neural network.

3.4.1 Clustering Techniques

In this, a finite set of categories are identified and then clusters are formed by grouping them together. It is an unsupervised learning task. It relies on the basic principle to maximize the intra-class similarity as well as the inter-class similarity is minimized. The imaging traits, i.e., color, size, intensity, texture, etc., impinge the clustering algorithms. The similarity measures affect the outcomes. It is generally classified as:

Hard Clustering

Each pixel is related to only one cluster and each cluster differentiated by sharp boundary lines. *k*-means algorithm [23] is the prominent one. The number of pixels *p* is assigned to *k* different clusters as per the closeness measured by the Euclidian distance. Initially, the centroids must be chosen arbitrary. The mean must be recalculated of every cluster when each pixel is clustered and this is a repetitive process to get some significant results. The main drawback is that the different results occurred at every execution, the number of clusters must be determined [6]. The essential steps are [24]:

(i) The numbers of cluster are randomly selected.
(ii) Compute the histogram of pixel intensities and certain random pixels are chosen as centroids amongst the *k* pixels.
(iii) The mean of a certain region is considered as the centroid and there should be a huge gap between each centroid.
(iv) Now do the comparison of every pixel to each centroid and assigned it to the specified one.
(v) Then reconsider the mean of each cluster and also the location of every centroid is recalculated.

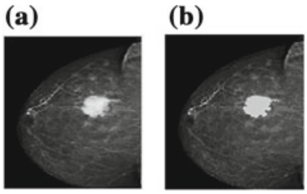

Fig. 6 **a** Breast MR image [18]. **b** K-means segmented image

(vi) Repeat step 4 and 5, until centroids stop moving. Therefore, Image separated into clusters.

Figure 6a depicts the breast MR image [18] and Fig. 6b shows the K-means segmented image.

Soft Clustering

It is the efficient algorithm because of its feature of maximum information preservation [25]. Recently, fuzzy clustering algorithms are integrated with object shape which can be considered as a unique feature [26]. Therefore, it is suggested to extract constant geometric contours to avoid the segmentation of random objects. It further categorized as Possibilistic c-means (PCM) and Fuzzy c-means (FCM), etc.

FCM: According to this, every pixel of the image assigned to more than one cluster as per some membership function. It may reproduce the brittle representation of the system's behavior. The outcome is restricted by spherical clusters even then it is the promising one [27]. Generally, it provides more flexibility than the corresponding hard clustering algorithm.

3.4.2 Neural Network-Based Segmentation

In this, first neural network mapping is done in which each neuron is identified as a pixel [28]. Then, by the use of dynamic equations, the image edges are extracted to command that every neuron must be stated towards minimum energy defined by neural network [29]. Generalization, learning ability and reminiscence are the three basic properties of neural network [30]. Generally, neural networks are processed in layers. A large number of interconnected "nodes" containing an "activation function" forms the layers. The "input layer" transfers the particular patterns to the "hidden layer" where the real processing is done by the weighted connections network. [30]. Then, a connection must be formed in between "hidden layer" and "output layer". It is basically classified as:

Radial Basic Function

It is one of the techniques of the neural network. The preprocessed image is required to upgrade the training process. This method gives highly accurate results as well as the time complexity is less [31].

Feed Forward Neural Network

The information flow is unidirectional starts from the input layer and reaching the output layer via hidden layer without following any cycles [32]. The main examples are Hebb, Perceptron, Ada-line and Madaline networks.

Feed Forward Back Propagation Neural Network

In this, a specific set of training data fed in the forward direction via the network for each training iteration. Then the error calculation is done at the output layer on the basis of some target information consequently the required changes of weights has been taken place which is then implemented throughout the network to begin the next iteration. Furthermore, repeat the entire procedure by the use of the next pattern of training [33].

The major issue in the case of breast MR image is to train the neural network model and only then one can identify the tumor as benign or malignant. All the three neural networks stated above gives the different accuracy even if trained on the same set of inputs. The back propagation neural network proves better in terms of accuracy as compared to the others [31].

3.5 Model-Based

Generally, local information is the essential one in each algorithm [34] while in this; the specific learning of the geometrical state of the object must have a contrast with the local information to make a representation of the objects. The exact shape of the object must be known to make this system pertinent.

3.5.1 Markov Random Field

MRF-based segmentation comes under this. To identify the edges accurately, MRF must be combined with edge detection [10]. The process performs in an iterative fashion as coarse resolution is segmented initially and finer resolution gets the secondary attention.

3.5.2 Gaussian Markov Random Field

Another method includes Gaussian Markov Random Field (GMRF) in which consideration of spatial dependencies between pixels takes place. In region growing, Gaussian Markov Model (GMM) based segmentation is taken into consideration. The GMM extended version also identifies the region, edge cues as well as feature space [35].

3.6 Partial Differential Equation Based

It is the finding of Kass et al. in 1987 [36]. Kass invented this for finding regions those are familiar even in the presence of noise and other uncertainty. PDE-based methods are mainly conveyed by snakes also called active-contour model. This model describes the approximate shape of the boundary. Other techniques are described below.

3.6.1 Active Contours

The basic idea behind this is to elaborate a curve, subject to refrainment from a given image for detecting objects. These are computer generated curves to find object boundaries under the influence of internal and external forces while moving within the image [37]. It has multiple advantages as compared to classical feature attraction techniques. They usually track dynamic objects while autonomously searching for the minimum state. Main drawbacks are noise sensitivity and high computational complexity [38]. Various improvements have been made by the researchers to the basic model, but still not overcome fundamentally.

3.6.2 Level Set Model

The method developed by Osher and Sethian was much influential [39]. This method easily follows shapes having topological changes. Therefore, it becomes a great tool for modeling time-varying objects. The problems of corner point producing, curve joining and breaking due to its topological irrelevancy and stability may be solved. The disadvantage lies with the fact that the image gradient is the fundamental rule for edge-stopping function [40] and the curve may pass the object boundaries as it never level at zero at the edges.

3.6.3 Mumford-Shah Model

The stopping criterion taken into consideration is global information of the entire image for segmentation purpose. This feature of globalization results in the best image segmentation [41].

3.6.4 C–V Model

In this, image must be partitioned into two regions out of which one can represents the objects needs to be detected and the other one shows the background. C–V model is not based on edge function, to stop the evolving curve on desired boundary [42]. It can detect objects even with smooth boundaries.

4 Conclusion

All the applicative techniques of image segmentation are briefed in this paper on the basis of their functioning utility, advantages, disadvantages, and applications. The description of every method shown in Table 1 helps in the selection of appropriate technique as per the various image attributes. Since a number of parameters like color, intensity, noise, etc., affect these algorithms, this emphasizes the necessity of appropriate image segmentation technique. Thresholding and region-based are less immune to noise; so least applicable to MR images. Theory-based techniques are time-consuming as it is required to train the data first. But FCM behaves well for medical imaging. Active-contour and level set methods finds their way in the field of MR images as it is fast enough as well as efficient. Still, application-based image segmentation algorithms developed on daily basis by the researchers but needs to come up with the protean one that is independent of the input image and accurate enough. Therefore, the researchers can come up with the hybrid approach of two or more segmentation techniques (as per the area of application given in Table 1) to give the better segmentation results. Also the researches may carried out by modify some of the existing techniques. Any optimization technique can be combined with the ongoing techniques of segmentation to present the good outcome [43]. Researchers still need to design a universal as well as effective algorithm for image segmentation.

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