Optimal partitioning methods for image segmentation

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Abstract: The importance of image processing is increasing in the digitally connected world due to its numerous applications in various fields of medical science, astronomy, weather prediction and video surveillance systems etc. The latest research and development in this field has helped the authors to obtain finer details of a particular image under study. The image segmentation technique, a part of digital image processing, helps to obtain meaningful information of the object. This study discusses the three widely used important image segmentation techniques: namely, split and merge, image growing and thresholding and their effects on a sample image. The authors results thus depict a significant difference in the segmented image by split and merge, image growing and thresholding. Split and merge is the optimal method of image segmentation as compared with the other two techniques mentioned above. The choice of the method varies with type of image, its colour, intensity and noise level.

1 Introduction

Image segmentation forms an extremely vital part of digital image processing (DIP) as it helps in analysing and at times improving the quality of the image being processed. Image segmentation is a branch of DIP where the purpose is to divide the image at hand into subparts for the purpose of better detection or a more defined study of that particular image. Enhancing the details of the part of the image which the user is interested in and reducing the part which is irrelevant or of less importance is the idea behind the technique of image segmentation [1]. To be more precise, we assign certain values to every pixel in the image such that the pixels with the same values have the same characteristics. It finds many real-world applications such as content-based image retrieval, medical applications (medical imaging of tumours [2], diagnosis of anatomical structure [3]) and object detection (face detection and satellite imaging) [4]. It also is used vastly in recognition systems [5] and video surveillance systems.

There are two major ways in which image segmentation can be done: (i) by analysis of the basic properties such as checking intensity values, i.e. their discontinuity and similarities. (ii) By partitioning the image according to the abrupt changes in the image, making use of predefined criteria.

This paper deals with the second category/method of image segmentation particularly. Three different techniques have been used to perform segmentation of sample images. These techniques include: (i) splitting and merging of the image, (ii) image growing and (iii) thresholding.

This paper is organised as the application of splitting and merging on a sample image of scatter pebbles is discussed in Section 2. Section 3 demonstrates image growing on a sample image of a heart. The techniques of thresholding and related details are given in Section 4. On the basis of these experiments the derived conclusions are given in Section 5.

2 Splitting and merging

In this section, we use the split and merge technique on an image of scattered pebbles shown in Fig. 1*a* and outcome is shown in Fig. 1*b*.

In this method, the image is subdivided into smaller regions for detailed analysis. The information related to the division of these regions is stored in a data structure such as the quadtree, i.e. a tree in which a node can have exactly four child nodes [6]. It is also called as quad splitting the image. The algorithm of this technique initially assumes the entire image to be a single homogenous region. It calculates the values of the adjacent pixels to check for TRUE and FALSE values. Depending on the values, the image undergoes segmentation. Region adjacency graph can also be used to store the related information of the neighbouring pixels. If the pixels are as represented in Fig. 2*a*, then the corresponding quadtree can be represented as shown in Fig. 2*b*.

Splitting leads to the formation of many subparts of the image which possess the same characteristics. Thus the merge operation is necessary to group the similar subparts together to get a clearer perspective of the required image. This entire process is based on the principle of divide and rule. The process of merging the split regions continues until no further merges are possible [7]. Care has been taken while designing the merge algorithm that the pixels with dissimilar properties do not overlap, i.e. the merge operation must update the parent node if a mismatch is found in its child node. The time complexity of this algorithm is $O(n \log n)$ [8].

The equations related to the split and merge algorithm are as below.

Let Q be a logical predicate defined over a particular region in the image. Then

$$Q = \begin{cases} \text{True}, & \text{if } \sigma > a \text{ and } 0 < m < b \\ \text{False}, & \text{otherwise} \end{cases} \tag{1}$$

where m and σ are the mean and standard deviation of the pixels in the region where the region is subdivided into quad regions, and a and b are constants [9].

The homogeneity of each region can be calculated by statistical analysis of σ where

$$\sigma = \frac{1}{n-1} \sum_{j=0}^{n} (x_j - \dot{x}) \tag{2}$$

where $\dot{x}$ is the mean intensity of n pixel in that particular region. On the application of split and merge on Fig. 1 (a picture of scattered marbles) it can be seen that the intensity and the curvatures of the image affect the image while performing the segmentation. As we can see in the original image, the intensity is varying from black to white for the same region. Thus on applying the split and merge operation the edges of the marbles seem to be highlighted.

Though the quadtree is computationally efficient, it has certain shortcomings with respect to the image aesthetics and semantics. The process may lead to errors in segmentation and as a result

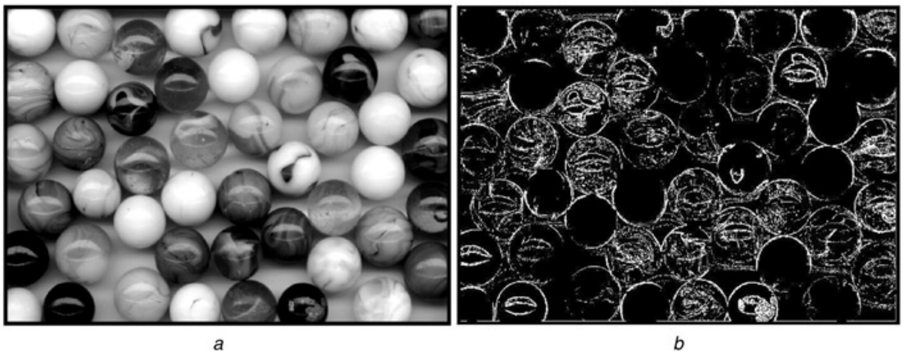

Fig. 1 *Split and merge technique on an image of scattered pebbles*
a Sample image of scattered pebbles
b Outcome of splitting and merging

affect the number of steps in the split and merge operations. To reduce this, the splitting can be done by an incremental Delaunay triangulation method [10]. Further details of Delaunay triangulation are documented by Gevers and Kajcovski [11].

3 Image growing

This section deals with application of image growing algorithm on a sample image of heart shown in Fig. 3*a*. The seed points are selected from the image to calculate the intensities of the neighbouring pixels with respect to the selected seed points. Furthermore, to increase the number of pixels being grouped at the time of segmentation on the basis of predefined parameters or conditions. In this method, we select a particular set of pixels which we call the 'seed points' from which we further grow the region by selecting the most suitable neighbouring pixels. These pixels are selected on the criteria that their properties or characteristics are similar to the seed points. This can be done both on the basis of intensity and on the basis of colour. The task at hand helps us analyse which approach is to be adopted [12].

Unlike other segmentation techniques, image segmentation is based on the connectivity between the pixels. Here, connectivity means the path between the selected pixels which is entirely made up of pixels. Image is grown on the basis of intensity of the grown region with respect to the seed points. It also depends on other factors such as the size and the shape of the grown image with respect to the original image or points, i.e. those neighbours whose characteristics are similar to the points being used. If they do satisfy the given set of conditions, then they are appended to the array of the previously selected pixels. This process is called recursively until the resulting image is sufficiently grown to the required amount. Here, we have to make sure that the points which are selected on the basis of similarity are connected to the seed pixels. To check similarities among the neighbouring pixels, we can make use of a threshold parameter T as a reference to the seed points.

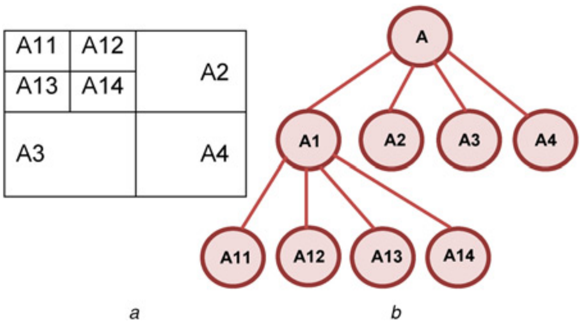

Fig. 2 *Pixels represented*
a Pixel representation
b Corresponding quadtree

Let R be a connected region for all points in $f(x, y)$, where R has a property that every pair of points is connected

$$g,\ \text{the entire image} = \bigcup_{k=1}^{m} R_k,\ \text{such that} \tag{3}$$

$$R_i \cap R_j = \oslash \text{ and } i \neq j \tag{4}$$

A set of regions satisfying (3) and (4) is known as a partition. Here, we use the image growing algorithm in each region by considering it as a homogeneous area.

Let $f(x, y)$ = array of pixels in the image

$$S(x, y) = \begin{cases} 1, & \forall x, y \in \quad \text{seed points} \\ 0, & \forall x, y \in \quad \text{non} - \text{seed points} \end{cases} \tag{5}$$

The following algorithm is based on eight connectivity principles:

(i) Create an image f_q such that $f_q(x, y) = 1$, for all inputs which belong to the predicate q.
(ii) Let g be the image created by appending to all seed points in S the values of pixels which satisfy $f_q = 1$. Care must be taken that these pixels are eight connected to the seed points [9].

4 Thresholding

We apply variable thresholding also commonly known as local thresholding a more commonly used technique, to perform the thresholding operation. Using variable thresholding, we divide the image into rectangles which are small enough to take care of the factors such as uniformity of illumination and reflectance of the particular image. The global thresholding [9] generally works when the region of interest of the image is of comparable size with respect to the image. This method however fails when the image consists only of the object pixels or the background pixels. Hence, variable thresholding starts playing a major role when it comes to applying segmentation on the particular image using thresholding operation.

The value of the local threshold is calculated on the basis of its neighbourhood pixels. This is traditionally done using statistical analysis, i.e. by calculating the mean deviation of the corresponding pixel with respect to the current pixel.

Let σ_{xy} and m_{xy} be the standard deviation and the mean of a particular set of pixels contained in the neighbourhood of an image S_{xy}

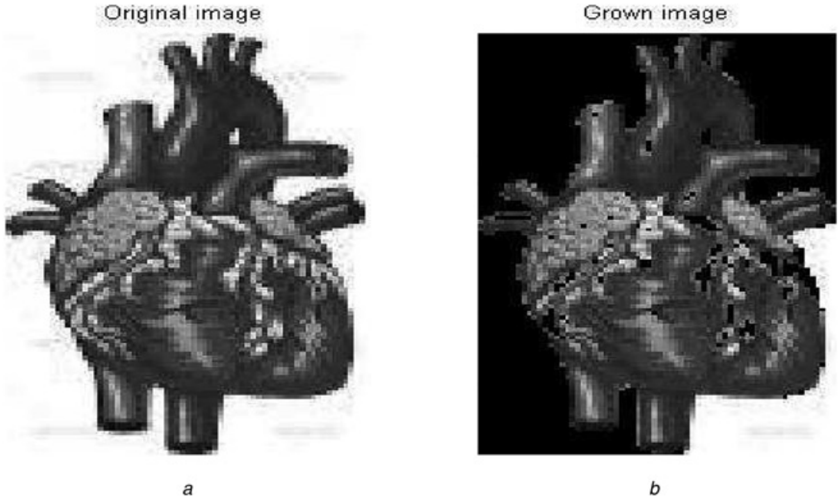

Fig. 3 *Application of image growing algorithm on a sample image of heart*
a Original image
b Image after application of image growing algorithm

with centre at (x, y). The following will denote the local thresholds

$$T_{xy} = a\sigma_{xy} + bm_{xy}$$

where a and b are non-negative constants

$$T_{xy} = a\sigma_{xy} + bm_{\rm G}$$

where $m_{\rm G}$ is the global mean

$$g(x, y) = \begin{cases} 1, & \text{if } f(x, y) > T_{xy} \\ 0, & \text{if } f(x, y) \leq T_{xy} \end{cases} \quad (6)$$

Equation (6) is then evaluated for all pixel locations in the image and at each location (x, y) a unique threshold value is computed [9]. The results of this computation are shown in Fig. 4.

5 Conclusions

This paper helps analyse three methods of image segmentation, i.e. split and merge, image growing and thresholding. On the basis of the analysis it can be concluded that:

(i) In split and merge the algorithm of traversing the quadtree, to create the image, helps segment the image better and faster with accurate details.
(ii) Image growing segments the image by differentiating the neighbouring pixels with respect to the seed points on the basis of their intensities/colour.

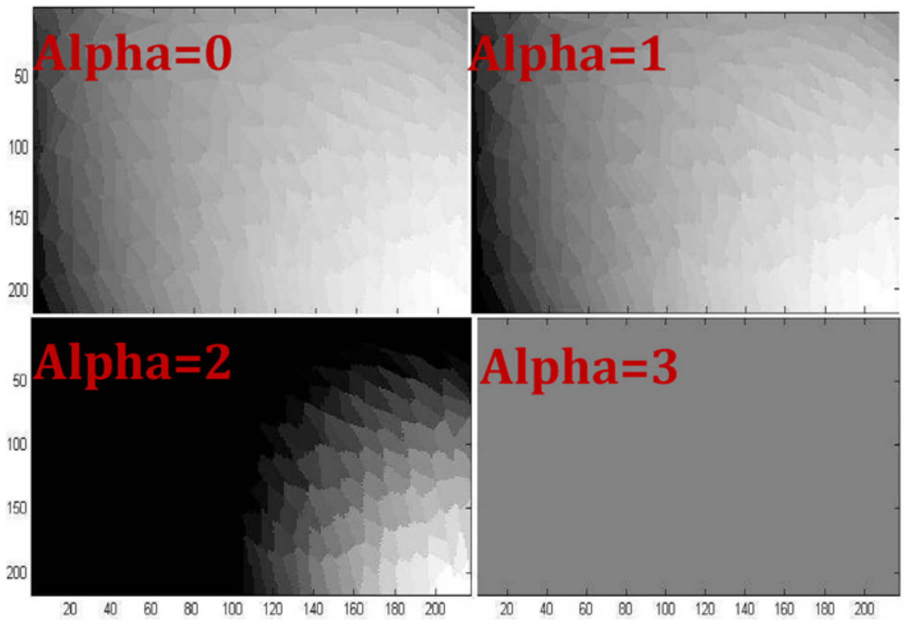

Fig. 4 *Images obtained by varying threshold parameter alpha*
a Alpha = 0
b Alpha = 1
c Alpha = 2
d Alpha = 3

(iii) The technique of thresholding carries out image segmentation by using the threshold as a parameter to distinguish among the pixels of interest and otherwise.

The analysis demonstrates that the split and merge technique is the most optimal when speed and accuracy are both considered for the purpose of segmentation. Considering the illumination, reflectance, intensity, colour and uniformity of the image, the choice of the method used to partition the image may vary. However, we can combine or modify any of the above methods to optimise the performance of the segmentation of the image at hand. We also propose the use of thresholding in combination with image growing to obtain better results. It is still a challenging task to obtain desirable results by the application of a single technique which requires further research.

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7 References

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