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The Comparative Research on Image Segmentation Algorithms

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***Abstract*—As the premise of feature extraction and pattern recognition, image segmentation is one of the fundamental approaches of digital image processing. This paper enumerates and reviews main image segmentation algorithms, then presents basic evaluation methods for them, finally discusses the prospect of image segmentation. Some valuable characteristics of image segmentation come out after a large number of comparative experiments.**

Keywords-Image segmentation, edge detection, thresholding techniques, the evaluation of image segmentation.

I. INTRODUCTION

Image segmentation is the foundation of object recognition and computer vision. In general, image noise should be eliminated through image preprocessing. And there is some specifically-given work (such as region extraction and image marking) to do after the main operation of image segmentation for the sake of getting better visual effect [1].

In image preprocessing, firstly, various color spaces should be transformed into specifically-given color space [2]. Then some techniques such as Gaussian filter are used to smooth image to diminish the influence of noise. As the main body of image segmentation system, image segmentation algorithm determines the result of image segmentation. After that, region merging and region extraction are used to combine unreasonably discontinuous regions. All the efforts above can ensure a satisfying image segmentation result.

In this paper, firstly, main image segmentation algorithms are classified and reviewed; then evaluation and comparison of image segmentation algorithms are discussed in depth based on the reason that evaluation of image segmentation is essential in the aspect of comparing the segmentation algorithm and providing advice for improvement.; at last, evaluation results of typical segmentation algorithms in MATLAB environment are summarized and presented.

II. CLASSIFICATION OF IMAGE SEGMENTATION ALGORITHMS

Image segmentation is generally defined as the basic image processing that subdivides a digital image $f(x,y)$ into its continuous, disconnect and nonempty subset $f_1, f_2, f_3, \cdots f_n$, which provides convenience to extraction of attribute [3]. In general, Image segmentation algorithms are based on two basic principles [4]: the trait of pixels and the information in nearby regions. Most of segmentation algorithms are based on two characters of pixels gray level: discontinuity around edges and similarity in the same region. As is shown in Table I, there are three main categories in image segmentation [5]: *A*. edge-based segmentation; *B*. region-based segmentation; *C*. special-theory-based segmentation. And some sub-classes are included in the main categories too.

TABLE I. CLASSIFICATION OF IMAGE SEGMENTATION

Main categories	Sub-classes		Interpretation
Edge-based segmentation	Gray-histogram technique		Partition an image through detecting edge among different regions.
	Gradient--based method	Differential coefficient technique	
		Laplacian of a Gaussian(LoG)	
		Canny technique	
Region-based segmentation	Threshol-ding	Otsu	Exact the objects from the background by setting reasonable gray threshold Ts for image pixels.
		Optimal thresholding	
		Thresholding image	
		…	
	Region operating	Region growing	Partition an image into regions that are similar according to given criteria, such as gray character, color character or texture character and so on.
		Region splitting and merging	
		Image matching	

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Special theory based segmentation	Fuzzy clustering segmentation	Introduce Fuzzy Set Theory into image segmentation
	Neural networks based segmentation	It is a learning algorithm imitating the working pattern of neural networks.
	Physically-based segmentation	Utilizing the physical characters of images to partition.
	…	

III. EDGE-BASED SEGMENTATION

Understandably, an edge is a set of linked pixels lying on the boundary between different regions, where there are intense discontinuities such as gray change, color distinctness, texture variety and so on [6]. An image can be segmented by detecting those discontinuities. Based on this theory, there are two main edge-based segmentations methods: gray-histogram method and Gradient--based method.

The key to a satisfactory segmentation result lies in keeping a balance between detecting accuracy and noise immunity [7]. If the level of detecting accuracy is too high, noise may bring in fake edges making the outline of images unreasonable; otherwise, some parts of image outline may get undetected and the position of objects may be mistaken if the degree of noise immunity is excessive.

A. *Gray-histogram technique [8]*

The quality of edge detection depends greatly on the fitness of threshold T .However; it is really difficult to search for the maximum and minimum gray value, because gray-histogram is uneven for the impact of noise. In this case, we can approximatively substitute the curves of object and background with two conic Gaussian curves, whose intersection is the valley of histogram. Threshold T is the gray value of the point at that valley.

B. *Gradient-based method*

Gradient is the first derivative for image $f(x,y)$. When the change of gray value near edge is intense enough and there is little image noise, Gradient-based method works well, and segmentation result is adaptive to the direction of gradient. There are three most commonly used Gradient-based methods [9]: differential coefficient technique, Laplacian of Gaussian (LoG), and Canny technique. Among them Canny technique is the most representative one. Canny proposed three criteria for edge detection: optimal detection result, optimal position outcome, and low repeating response. Based on these criteria, he invented “optimal linear filter”, which is the first derivative of Gaussian function [3].

IV. REGION-BASED SEGMENTATION

Edge-based segmentation partitions an image based on abrupt changes in intensity near the edges whereas region-based segmentation partitions an image into regions that are similar according to a set of predefined criteria. Thresholding, region growing, region splitting and merging are the main examples of techniques in this category [10].

A. *Thresholding Methods*

Thresholding techniques are image segmentations based on image-space regions. The fundamental principle of thresholding techniques is based on the characteristics of the image [11]. It chooses proper thresholds T_n to divide image pixels into several classes and separate the objects from background. When there is only a single threshold T , any point (x,y) for which $f(x,y)>T$ is called an object point; and a point (x,y) is called a background point if $f(x,y)<T$.

According to the aforementioned discussion, thresholding can be viewed as an operation to gain threshold T in the following equation:

$$T = M[x, y, p(x, y), f(x, y)] \quad (1)$$

In this equation, T stands for the threshold; $f(x,y)$ is the gray value of point (x,y) and $p(x,y)$ denotes some local property of the point—such as the average gray value of the neighborhood centered on point (x,y) . Based on (1), thresholding techniques can be mainly divided into global, local, and dynamic thresholding techniques.

1) Global thresholding: When T depends only on $f(x,y)$ (in other words, only on gray-level values) and the value of T solely relates to the character of pixels, this thresholding technique is called global thresholding technique [5]. There are a number of global thresholding techniques such as: minimum thresholding, Otsu, optimal thresholding, histogram concave analysis, iterative thresholding, entropy-based thresholding, MoM-keeping thresholding and so on.

2) Local thresholding: If threshold T depends on both $f(x,y)$ and $p(x,y)$, this thresholding is called local thresholding [5]. This method divides an original image into several sub regions, and chooses various thresholds T_S for each sub region reasonably. After thresholding, discontinuous gray levels among sub images must be eliminated by gray level filtering technique. Main local thresholding techniques are simple statistical thresholding, 2-D entropy-based thresholding, histogram-transformation thresholding etc.

3) Dynamic thresholding: If, in an image, there are several objects taking up different gray level regions, the image should be partitioned with vary dynamic thresholds(T_1、 T_2、 …T_n) [5] , depending on $f(x,y)$, $p(x,y)$ and the spatial coordinates x and y. In general, dynamic thresholding techniques include thresholding image, Watershed, interpolatory thresholding and so on.

B. Region operating [12]

The objective of image segmentation is to segment an image into rational regions. In Section III this problem is solved by finding fit boundaries between regions based on discontinuities in gray levels, whereas in Section IV.A the segmentation is accomplished by thresholds based on the distribution of pixel properties, such as gray values and color. In this section, we introduce region operating segmentation techniques based on finding the aim regions directly [13]. This type of segmentation techniques is a kind of iterative algorithms. So its drawback is that it requires lots of computation time.

1) Region growing: As is suggested by its name, region growing is a process that groups pixels or sub regions into larger regions based on predefined criteria [14]. This approach goes on like this: firstly, set a group of "seed" points in original image; then grow regions by appending each seed to those neighboring pixels that have similar properties of the seed (such as gray level or color). Based on this rationale, region growing can be processed in three steps: *a)* choose the right "seed" points; *b)* select a set of similarity criteria; *c)* set up a stopping rule.

2) Region splitting and merging: Rather than choosing seed points, users can divide an image into a set of arbitrary, unconnected regions and then merge and/or split the regions in an attempt to satisfy the conditions of reasonable image segmentation. Region splitting and merging is usually implemented with theory based on quadtree data [15].

V. SPECIAL-THEORY BASED SEGMENTATION

Numerous special-theory based segmentation algorithms derive from other fields of knowledge such as wavelet transformation, morphology, fuzzy mathematics, genetic algorithm, artificial intelligence and so on.

A. Fuzzy clustering segmentation

In image segmentation, analysis, recognization and other levels of image processing, uncertainty is a key factor that leads to unfavorable results for fixed algorithms [14]. Going further, the result of preceding processing will influence the performance of subsequent processing, which asks for certain degree of flexibility (fuzzy characteristic) in image processing algorithms. Fuzzy Set Theory can be used in clustering and it allows fuzzy boundaries to exist between different clusterings. The main drawback of this algorithm is that it is difficult to confirm the attribute of fuzzy members and it is complicated for calculating in this algorithm [11].

B. Neural Network-based segmentation

Neural network based segmentation is totally different from conventional segmentation algorithms. In this algorithm, an image is firstly mapped into a neural network where every neuron stands for a pixel. Then, we extract image edges by using dynamic equations to direct the state of every neuron towards minimum energy defined by neural network [13].

Neural network based segmentation has three basic characteristics [14]: *1)* highly parallel ability and fast computing capability, which make it suitable for real-time application; *2)* unrestricted nonlinear degree and high interaction among processing units, which make this algorithm able to establish modeling for any process;*3)* satisfactory robustness making it insensitive to noise. However, there are some drawbacks of neural network based segmentation either, such as: *1)* some kinds of segmentation information should be known beforehand; *2)* initialization may influence the result of image segmentation; *3)* neural network should be trained using learning process beforehand, the period of training may be very long, and we should avoid overtraining at the same time [15].

VI. EVALUATION AND COMPARISON OF IMAGE SEGMENTATION ALGORITHMS

The research on evaluation of image segmentation can provide crucial reference for those segmentation algorithms, and so this research deserves wide attentions. Understandably, the basic requirements are as follows: universal use for evaluation algorithms, its simplification and reliability, and whether referent images or manual intervention is needed. Generally, two basic methods are applied to objective evaluation of image segmentation: analytical technique and experimental technique [16].

A. The analytical technique

The analytical technique evaluates an image segmentation algorithm by analyzing the principle of the algorithm, its complexity, the prior knowledge needed, accurate detecting probability, image resolution and so forth [15]. The analytical technique usually provides supplementary information and supports for other methods of segmentation evaluation and it is seldom used alone [17].

B. The experimental technique

The experimental technique, which is widely used, interprets and compares experiment results of image segmentation algorithms to make an evaluation. This technique can be subdivided into two distinct methods: superiority evaluation method and deviation evaluation method [18].

1) The superiority evaluation method: The superiority evaluation method evaluates an image segmentation algorithm by utilizing human visual trait [19]. It judges the quality of a segmentation algorithm by calculating certain measures based on image segmentation result. The commonly used measures are region uniformity, contrast of regions, region shape and synthetical measure based on ambiguity [19].

The evaluation method based on region uniformity characterizes segmentation result by quantizing uniformity within regions after segmentation. Suppose R_i stands for region i, then gray uniformity (UM) within regions can be expressed as follows [20]:

$$UM = 1 - \frac{1}{\beta}\sum_{i}\{\sum_{(m,n)\in R_i}[f(m,n) - \frac{1}{A_i}\sum_{(m,n)\in R_i} f(m,n)]^2\} \quad (2)$$

Where β is the normalized coefficient; A_i is the overall number of pixels in R_i.

2) The deviation evaluation method: In this method, firstly a standard segmentation image is provided for comparison criteria. Then the disparity between actual segmentation and ideal one can be calculated to evaluate the image segmentation algorithm [13]. With a comparing test, the deviation evaluation method is generally more effective than the superiority evaluation method [14]. Generally, this method executes evaluation via factors as follows: the probability of mistaken pixels, the position of mistaken pixels, the consistency for the number of regions and so on.

The evaluation method based on the consistency for the number of regions evaluates image segmentation in the manner like this: suppose that *N'* stands for the number of regions after image segmentation and *N* is the number of regions correctly partitioned. Reasonably, we can evaluate image segmentation algorithms by analyzing the difference between *N'* and *N*. One measure of consistency (*F*) is shown as below [16]:

$$F = \frac{1}{1 + p\,|\,N'\text{-}N\,|^{q}} \quad (3)$$

Where p and q are both scale parameters.

C. Examples

Based on region uniformity, literatures [19] evaluated the segmentation effects of common algorithms on three images, whose objects are a cameraman, a building and a model respectively. And the evaluation result shows that entropy-based thresholding, MoM-keeping thresholding and Otsu thresholding have advantages in the uniformity of image and the shape maintenance of objects. We actualized a myriad of commonly used segmentation algorithms in the environment of MATLAB. Moreover, we evaluated and compared those algorithms' performance through sufficient comparative experiments on image segmentation. And the result of our research is shown in the table below:

TABLE II. COMPARISON AND EVALUATION OF SEGMENTATION ALGORITHMS

Algorithms	Complexity & Processing rate	Suitable images	Segmentation effect	Flaw & Suggestions for improvement
Minimum thresholding	very low/ very fast	Big difference between objects and background	normal	Narrow in application
Iterative thresholding	normal/ normal	All images	good	Image details are fuzzy
Entropy-based thresholding	very low/ fast	Image with low contrast & complex background	normal	Sensitive to noise
Ostu thresholding	very high/ very slow	Gray histogram have three crests	good/ stable	Combine with other algorithms to improve its performance
Genetic algorithm	very low/ very fast	All images	normal/ stable	Optimize the adaptability function
Genetic algorithm combined with Ostu	low/ fast	All images	excellent	Segmentation speed can be increased by preprocess

VII. CONCLUSIONS AND PROSPECTS

In this paper, we classify and discuss main image segmentation algorithms; introduce the evaluation of image segmentation systemically; evaluate and compare basic, practical segmentation algorithms after a large number of comparative experiments. Based on this, we now discuss the prospect of image segmentation. As the basic technique of image processing and computer vision, image segmentation has a promising future and the universal segmentation algorithm has become the focus of contemporary research [4].

Although there are a myriad of segmentation algorithms designed day in and day out, none of them can apply to all types of images and actual segmentation techniques usually aim at certain application [17]. The result of image segmentation is affected by lots of factors, such as: homogeneity of images, spatial structure character of the image, continuity, texture, image content, physical visual character and so on [18]. A good image segmentation algorithm should take all-sided consideration on those factors. Based on the aforementioned statements, we can foresee the trend of image segmentation as follows:

1) Combination of multi-algorithms [15]: For example we can integrate the advantages of edge detection and region-based segmentation by combining those algorithms together and merging the segmentation results according to certain criteria.

2) The application of artificial intelligence [19]: Nowadays, although there are many existing image segmentation algorithms, almost each of them aims at a specific single application and only uses a fraction of image information, which limits their use to a great extent. Fortunately, this problem can be solved by introducing artificial intelligence into image segmentation.

3) The rise of manual alternating segmentation [20]: It is effortless for a human to partition and detect an image. The efficiency and effectiveness of human eyes on image processing is far beyond the level of any computer. The reason is clear and simple: we human use a lot of synthetical knowledge when we are observing an image. Based on this reality, it is optimistic that manual alternating segmentation can realize better segmentation results.

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REFERENCES

[1] Chen Tianhua, Digital Image Processing, Beijing: Tsinghua University Press, 2007,pp.48–61.

[2] Tan Zhiming, "Research on graph theory based image segmentation and its embedded application,"[D] Shanghai: Dissertation of Shanghai Jiao Tong University, 2007, pp.14–24.

[3] Rafael C., Gonzalez, and Richard E. Woods, Digital Image Processing, 2nd ed., Beijing: Publishing House of Electronics Industry, 2007.

[4] Liang Dong et al, A Method of Automatic Thresholding Based on Artificial Intelligence.Microelectronics & Computer, 1999, vol.l, pp.2–5.

[5] Liu Ping, "A survey on threshold selection of image segmentation," Journal of Image and Graphics, 2004, pp.86–92.

[6] Otsu N, Discriminant and Least Square Threshold Selection. In: Proc 4IJCPR, 1978, pp.592–596.

[7] Wang Kejun, Ding Yuhang, Zhuang Dayan and Wang Dazhen, "Threshold segmentation for hand vein image," Control Theory and Application, Beijing: Publishing House of Electronics Industry, 2005, pp.19–22.

[8] Kittler J. and Illingworth J., "On threshold selection using clustering criteria," IEEE Trans, 1985, SMC-15, pp.652–655.

[9] Liu He, Digital Image Processing and Application, Beijing: China Electric Power Press, 2006, pp.245–263.

[10] Shi J and Malik.J, "Normalized cuts and image segmentation," IEEE TransMachine Intell, 2000, vol.22, pp.888–905.

[11] Gao Xinbo, Fuzzy Cluster Analysis and Application [M], Sian: Xidian University Press, 2004,pp.124–130.

[12] Cattleman Kenneth R., Digital Image Processing, Prentice Hall, 1998, pp.432–459

[13] Wang Qiaoping, "One image segmentation technique based on wavelet analysis in the context of textur," Data Collection and Processing, 1998,vol.13, pp.1216.

[14] Alan Bovik, Handbook of Image and Video Processing (Second Edition), Beijing: Publishing House of Electronics Industry, 2006, pp.429–468.

[15] Claudio Rosito Jung, "Multiscale image segmentation using wavelets and watersheds," IEEE Symp.2003, Computer Graphics and Image Processing, SIBGRAPI XVI Brazilian Symposium, pp.278–284.

[16] Sharon E., Brandt A. and Basri. R., "Fast multiscale image segmentation," Proc of IEEE Conference on Computer Vision, 2000, vol.1, pp.70–77.

[17] Huang Daren and Sun Xin, Multi-band Wavelets Analysis, Hangzhou: Zhejiang University Press, 2001, pp.106–127.

[18] Brink A. D., "Thresholding of digital images using of two-dimensional entropies[J]," Pattern Recognition, 1992, vol.25(8), pp.803–808.

[19] Zhou Liping and Gao Xinbo, "Image segmentation via fast fuzzy c-means clustering[J]," Computer Engineering and Application, 2004, vol.40(8), pp.68–70.

[20] Eschrich T. and Ke Jingwei, "Fast fuzzy clustering of infrared images[C]," Proc of the 9th IFSA World Congress and 20th NAFIPS International Conference, 2001, pp.1–6.