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A Survey of Image Segmentation by the Classical Method and Resonance Algorithm

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1. Introduction

Computer vision and recognition plays more important role on intelligent control (Chen & Hwang, 1998). For an intelligent system, it is necessary to acquire the information of the external world by sensors, to recognize its position and the surrounding situation. Camera is one of the most important sensors for computer vision. That is to say, the intelligent system endeavours to find out what is in an image taken by the camera: traffic signs, obstacles or guidelines.

For image analysis, image segmentation is needed, which means to partition an image into several regions that have homogeneous texture feature. This process is usually realized by the region-based, boundary- based or edge-based method (Castleman, 1998). And from the viewpoint of clustering, it is divided into supervised and unsupervised texture segmentation.

Since before segmentation, the intelligent control system seldom knows the feature of the image, e.g. which type and how many types of textures exist in an image, thus the unsupervised segmentation algorithm is always needed, although it is more difficult than the supervised method (Dai, Zhao & Zhao, 2007).

In this chapter, the classical method (Agui & Nagao, 2000) and the resonance theory (Heins & Tauritz, 1995; He & Chen, 2000) are proposed respectively for image segmentation. The classical method is simple but practicable, which will be introduced in section 2. But for some situations, it is not suitable for complex image segmentation (e.g., the gradient variations of intensity in an image).

We know that human vision can recognize the same texture that has gradient variations of intensity. And many image segmentation methods are proposed based on the change of intensity (Nakamura & Ogasawara, 1999; Deguchi & Takahashi, 1999). But they always fail to handle the wide-ranged gradations in intensity (Jähne, 1995). It is usually difficult to give a suitable threshold for pixel-based image processing methods to deal with this gradation.

Resonance algorithm is an unsupervised method to generate the region (or feature space) from similar pixels (or feature vectors) in an image. It tolerates gradual changes of texture to some extent for image segmentation. The purpose of section 3 is to propose the resonance-theory-based method for image segmentation, which means that the same texture in an image will be resonated into one region by seed pixels. This method assumes that the

differences of feature between adjacent pixels of the same texture must be within a tolerable range. Thus the selection of feature distance to segment them is important.

In this chapter, Section 2 introduces the classical method. Section 3 gives the resonance theory and the algorithm for image segmentation. Section 4 is the conclusion.

2. The classical method

2.1 The principle

This section introduces the classical method for image segmentation, and the example is to recognize the simple characters (the digit and letter). Recognizing the whole word needs to segment it into the characters 0 to 9, a to z, or A to Z firstly. The principle (Agui, Nakajima & Kimi, 1990; Tanaka, 1989) and a result of segmentation is shown in Fig. 1. This section is simple but is the original meaning of image segmentation, which is useful when the reader wants to understand image segmentation clearly.
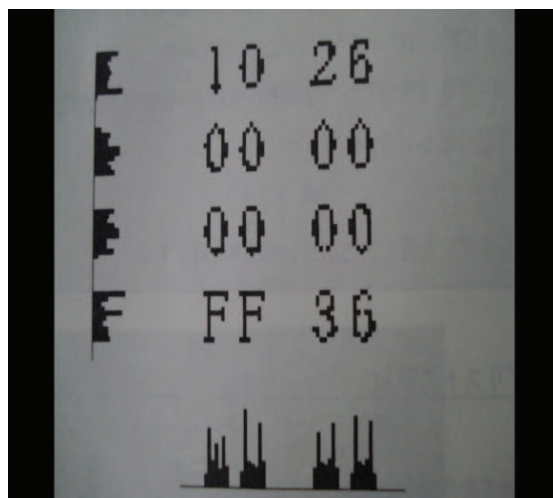

Fig. 1. The principle of segmentation

Fig. 1. gives the example of the digit segmentation. In the image there are some digits but as the image style, not the character. If the computer or intelligent system wants to recognize these digits autonomously, first image segmentation is needed to search and locate each digit, and then recognize them.

The method is that it calculates the values of the pixels by searching the X-axis and Y-axis to find the neighboring distribution of the digits (looking for the break of the character).

For each line (row and column) where there is a character, it appears that the values of pixels is not 0. If there are blanks, it means that they are the space between one character and another. Thus it gives the position of the break of the characters. In Fig. 1, there are four rows and four columns of digits.

2.2 Image segmentation

If there are several targets in an image, image segmentation is necessary: locating and isolating the targets in an image and then identifying them. Once isolated, the targets can be measured and classified. The general image segmentation algorithm (Agui, Nakajima & Kimi, 1990) is shown in Fig. 2a. And Fig. 2b is the result of segmentation for the word 'R05'. Table 1 gives the segmented result. The steps for character segmentation are divided into 2 steps:
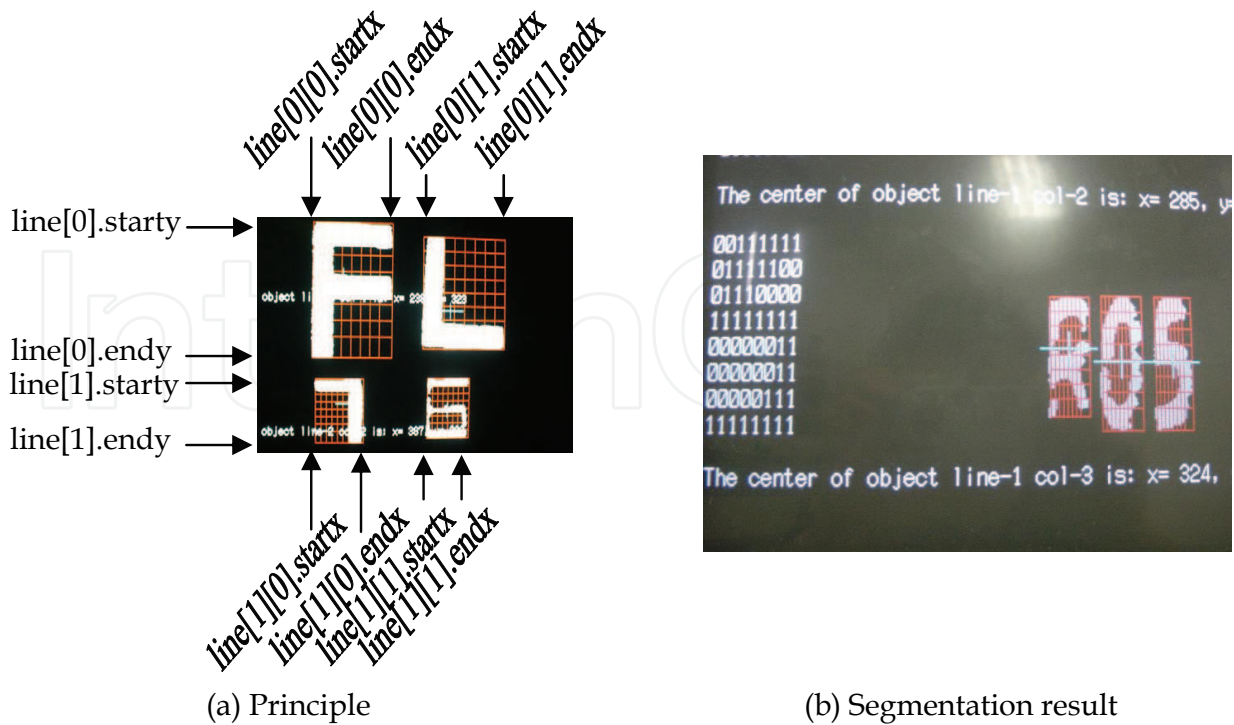
(a) Principle   (b) Segmentation result

Fig. 2. The classical image segmentation algorithm

Result for Fig. 2a		Result for Fig. 2b		
There are two rows. row-0 has two targets, row-1 has two targets.		There is One row. row-0 has three target.		
(top, bottom, left, right) is		(top, bottom, left, right) is		
row-0, col-0: *F* (line[0].starty, line[0].endy, line[0][0].startx, line[0][0].endx)	row-0, col-1: *L* (line[0].starty, line[0].endy, line[0][1].startx, line[0][1].endx)	row-0, col-0: *R* (line[0].starty, line[0].endy, line[0][0].startx, line[0][0].endx)	row-0, col-1: *0* (line[0].starty, line[0].endy, line[0][1].startx, line[0][1].endx)	row-0, col-2: *5* (line[0].starty, line[0].endy, line[0][2].startx, line[0][2].endx)
row-1, col-0: *7* (line[1].starty, line[1].endy, line[1][0].startx, line[1][0].endx)	row-1, col-1: *6* (line[1].starty, line[1].endy, line[1][1].startx, line[1][1].endx)			

Table 1. Segmented result of Fig. 2a, b

1. Search the screen from top to bottom line-by-line horizontally to find the start and the end line that contains how many rows of characters: the variables are line[0].starty, line[0].endy, line[1].starty and line[1].endy in Fig. 2a, which means that the image contains two rows of characters. The horizontal location of the first row of characters is from line[0].starty to line[0].endy, the second is from line[1].starty to line[1].endy, respectively.
2. For each row of characters, search the image from left to right vertically to locate and calculate how many characters in each row. For example, in Fig. 2a for characters within

line[0].starty and line[0].endy, there are two letters in this row. They are the letter 'F' from line[0][0].startx to line[0][0].endx, and 'L' from line[0][1].startx to line[0][1].endx. Thus each character (letter or digit) can be segmented.

2.3 An experimental result
Fig. 3 shows an experiment (including the image sampling, processing, segmentation and recognition), which is to segment the image and then recognize each character one by one.
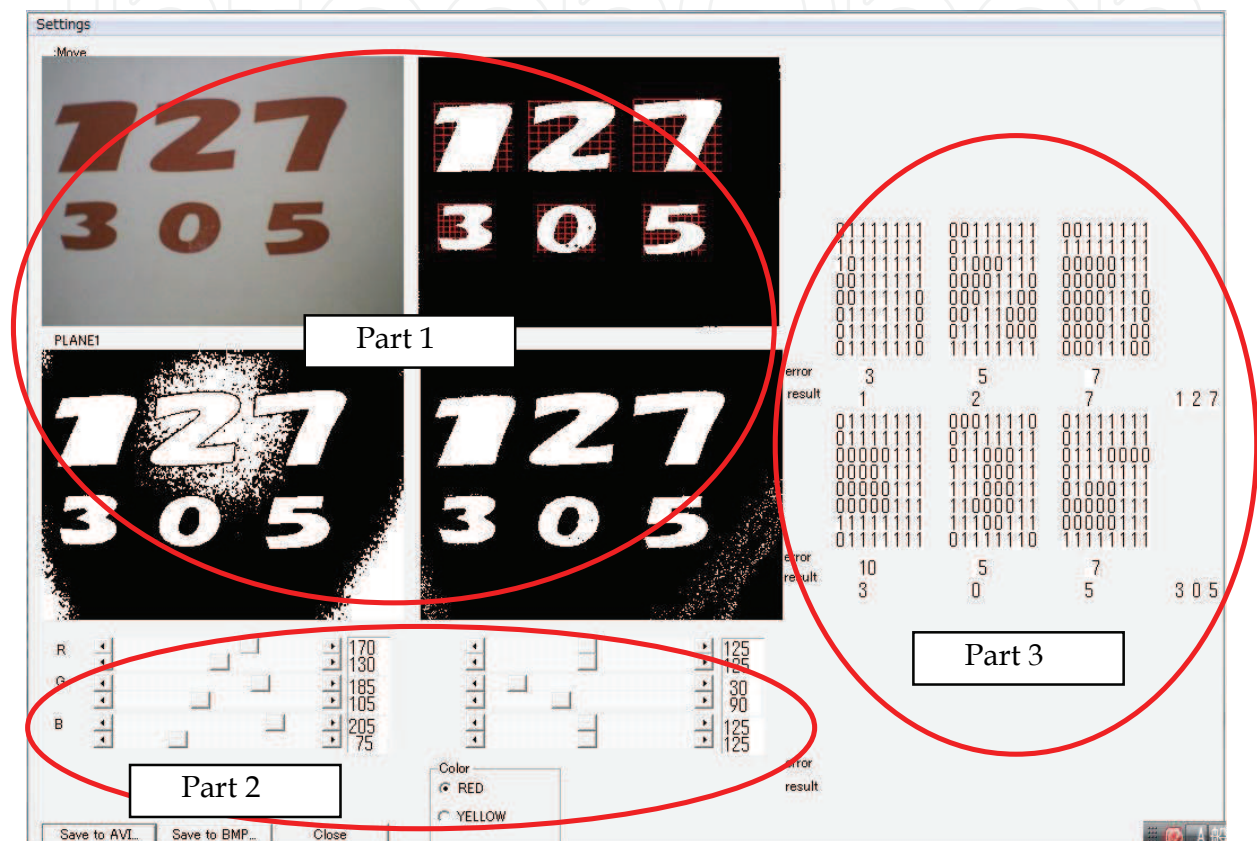

Fig. 3. An example of the classical image segmentation

In Fig. 3, part 1 is the image sampling and segmentation. The top-left window in part 1 gives the image sampled directly from the camera. After image processing, the segmented result is shown in the top-right window (Dai, Shimogaki & Fujihara, 2008).

Part 2 in Fig. 3 shows some parameters for image processing. These parameters can be adjusted based on environment in real time, so that the result of image processing is good enough to segmentation.

Part 3 is the process for character recognition. The feature vector of each segmented character is extracted and then matches it to the templates. By the template matching method (Snyder & Qi, 2004), each digit or letter can be recognized respectively, and then the whole meaning of the word can be understood by combination of the meaning of each character.

2.4 Problem of the classical method
From the above explanation, we see that the classical method is really simple but practicable. It can segment the characters in an image by locating and calculating how many rows of characters, and how many characters in each row.

But this method cannot segment the characters in Fig. 4 correctly. Since the classical method cannot correctly divide the image into two rows of character (the numbers "127" and "305") by any horizontal line (the dashed lines), the wrong result is appeared: all the characters in the image are recognized into one row. Of cause the correct number cannot be gotten.
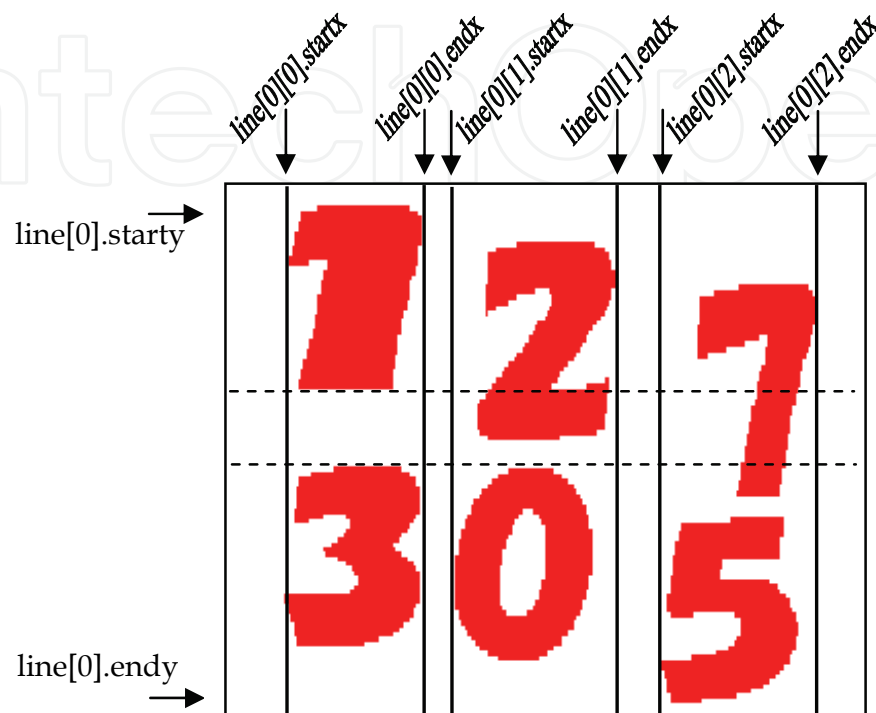

Fig. 4. An example for wrong segmentation by the classical method

3. Resonance theory and algorithm

3.1 Resonance theory

The resonance theory (He & Chen, 2000) can be expressed in Fig. 5. Assumes that in a scene of space, each point has a mass m. These points are not isolated from each other but inter-connected by inter-force. In Fig. 5, two points (a) and (b) are given and the distance between them is d.
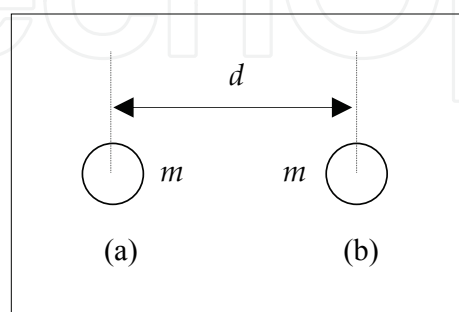

Fig. 5. Resonance theory

If an externally sinusoidal force F adds to the point (a), the movement of the point (a) can be expressed by

$$m\,\ddot{y} + b\,\dot{y} + ky = F\cos wt \tag{1}$$

b, *k* are the parameters of the system and point, the values of which are not important to the following explanation. $\dot{y}$ and $\ddot{y}$ means the first and second-order derivatives with respect to the time *t* for the motive distance *y*. The frequency of force *F* is *w*. Its stable solution is

$$y(t) = A\sin(wt + \theta) \tag{2}$$

where

$$A = F / \sqrt{m^2(w^2 - w_0^2)^2 + b^2 w^2} \tag{3}$$

is the oscillating amplitude. θ is the initial phase, $w_0 = \sqrt{k/m}$ is called the natural frequency.

From Eq. (3), if the frequency of the external force *F* (to the point (a)) is equal to the natural frequency w_0, the amplitude *A* has the maximal value, and this case is called the resonance between the external force and the point (a).

Since we have assumed that the points are not isolated, the motion of the point (a) will result in the spreading of its effect to other points that are around it. This is the resonance among the points, which is the theory for image segmentation proposed in section 3.2 to 3.4. From the analysis of the resonance mechanics (He & Chen, 2000), the amplitude of point (b) with the distance of *d* from (a) has the feature of

$$A_{(\text{distance}=d)} \propto A_{(\text{point a})} / \sqrt{d} \tag{4}$$

From the above analysis, if we assume that point (a) is the source to resonate and another point (b) can be largely affected, then the difference between the external frequency and the natural frequency, and the distance *d* between those two points should be small sufficiently. These two conditions can be satisfied by:

1.   A threshold is set to ensure the difference of external frequency from the natural frequency is small enough.
2.   The resonance algorithm is used within the adjacent points (in image segmentation) to ensure the distance between them is small enough.

3.2 Resonance algorithm

By the spreading of the resonance, the adjacent points that have the same or similar feature (e.g. texture in an image) are clustered into one region. It seems like the general region growing algorithm (Castleman, 1998; Jähne, 1995), but they are essentially different.

Region growing method partitions an image by the threshold directly: in an image, defining the maximum and minimum thresholds for each region to segment them. If an image contains complex color (or gray level) gradation, the selection of threshold is difficult.

Differently, the resonance algorithm emphasizes the similarity between the adjacent points, not the threshold for global usage. And the resonance can be spread from point to point. Thus the problem caused by gradation in intensity can be solved. Only the sudden change of features between adjacent points can be regarded as the boundary of different regions.

Define $P_\delta(a,b)$ as the path between the point *a* and *b* (*a* and *b* need not to be adjacent) under the threshold δ (the value to estimate the difference of features between two adjacent points). If there are sequences of adjacent points connecting between *a* and *b*, all of which

have the same features or have different features between the adjacent points but below δ, they form the connected path by the determination of the path between point a and b.

And if s is a point in an image, all points x_i that satisfies $P_\delta(s, x_i)$ will form the region $R_\delta(s)$. The point s is always called as seed (Dai, Zhao & Zhao, 2007; He & Chen, 2000). Remember that the region $R_\delta(s)$ is not centered by the point s, but refers to a region that all points in which have the same features to s, or the difference of features between adjacent points below δ.

Now the principle of the resonance algorithm for image segmentation is clear (in image processing, the point is called pixel): From one or some seed pixels, the adjacent pixels that belong to the same region under δ are clustered until all the pixels are searched.

From the above definitions and the transfer of resonance, we see that the selection of seeds does not influence the segmentation result in an image.

Fig. 6 gives the expression of the resonant process. In Fig. 6, a is the seed pixel, from which to resonate all the space in the image.
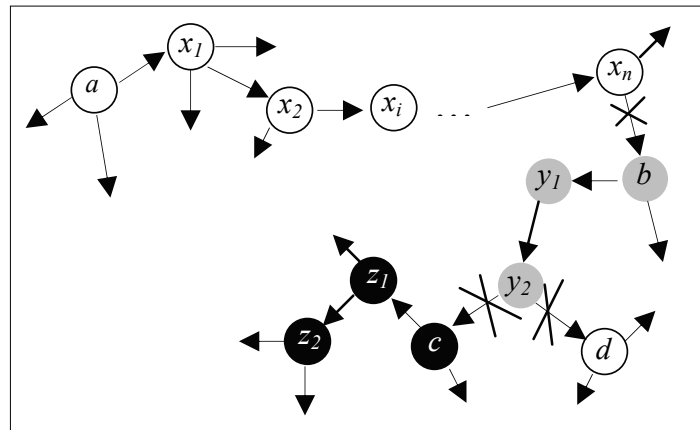

Fig. 6. Resonance process

By comparing with the difference of feature values between the point a and the adjacent pixels, all the pixels in $P_\delta(a, x_i)$ are labeled to belong to one region, e.g. $R_\delta(a)$ (Regin-1) = {a, x_i (i = 1,…,n)}. Next, from x_n to the pixel b, the difference between them is larger than δ, b is defined as a pixel belonging to a new region, e.g. $R_\delta(b)$ (Region-2) = {b, y_j (j = 1,…,m)}, all the pixels in which are $P_\delta(b, y_j)$. The same is to $R_\delta(c)$ (Region-3) = {c, z_k (k = 1,…,l)} that are $P_\delta(c, z_k)$ until all the pixels are labeled. The selection of seeds will not affect the result of segmentation.

From Fig. 6, although the pixel d has the same feature to Region-1, since it is far from Region-1 and is segmented by other regions, by the resonance theory, the pixel d cannot be resonated by any pixel in Region-1. Thus a new region creates from the point d. That is to say, the number of the segmented regions in an image does not absolutely equal to the number of real different texture types. In fact, this is not the weakness of the algorithm. Just as this case, it clearly shows that between Region-1 and the pixel d, there must exist some other textures.

Thus by the resonance theory, the resonance algorithm is determined by three important elements:

1. One or several seed points,
2. The features to determine the difference between points,
3. The parameter of the threshold δ.

And the steps of the resonance algorithm for image segmentation are:

1. Initialization. $R_\delta(0)$.
2. Segmentation. Find new region $R_\delta(i)$.
3. Termination after having searched all pixels.
4. Result. $R = \bigcup\limits_{i=0}^{M} R_\delta(i)$.

Thus we see that this method is to find a harmonious threshold within adjacent points, not to estimate a global value. Fig. 7 gives the flow chart of the resonance algorithm for image segmentation.
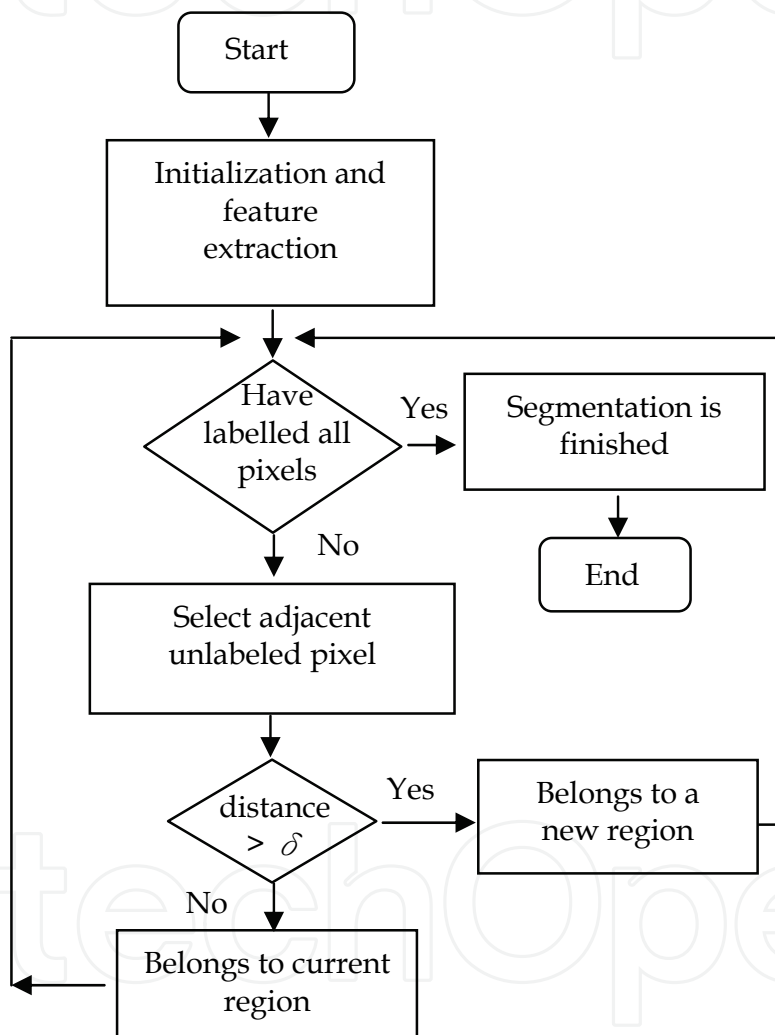

Fig. 7. Resonance algorithm

3.3 Selection of elements

Selection of the three elements of the resonance algorithm will be considered in this section. First, we see that from the resonance theory and the transfer of resonance, the initial place of the seed does not influence the segmentation result in an image. Thus the seed can be selected randomly.

The threshold δ is important in the resonance algorithm. Too large will include surplus regions into one while too small reject some points that belong to the same region. δ should

be larger than the distance in one region and less than the difference between two different regions. But different images, or different regions in one image, may have different thresholds. We propose an automatic selection method for δ.

Since δ is used to partition the different regions in an image, it is rather a range of values (determine the maximum and minimum values) than a fixed value to ensure the points have the same or similar features in one region.

If δ for different regions in an image are selected well, then all the regions are segmented stably. That is to say, when the correct δ varies by a small value, the change of regions in an image is not distinct. Other word is that if the selection of δ is incorrect, a small change of it may vary the area of region greatly. This is the influence of δ for the region segmentation, and comparatively, it can be used as criterion to estimate δ.

Since the suitable threshold should be selected to ensure greater than the intra-region feature difference and less than the inter-region feature differences (Castleman, 1998; He & Chen, 2000), from the initial seeds, the resonance begins from the current region to extend to other regions with the rise of δ.

Fig. 8 is an example. In a unit square, three different regions are in it: the black, the gray and white region. The area of black is $S_{\text{black}} = \dfrac{1}{2} \times \dfrac{1}{2} = \dfrac{1}{4} = 0.25$, the area of gray is $S_{\text{gray}} = \dfrac{3}{4} \times \dfrac{3}{4} - S_{\text{black}} = \dfrac{5}{16} = 0.3125$, and the white $S_{\text{white}} = 1 - \dfrac{3}{4} \times \dfrac{3}{4} = \dfrac{7}{16} = 0.4375$.
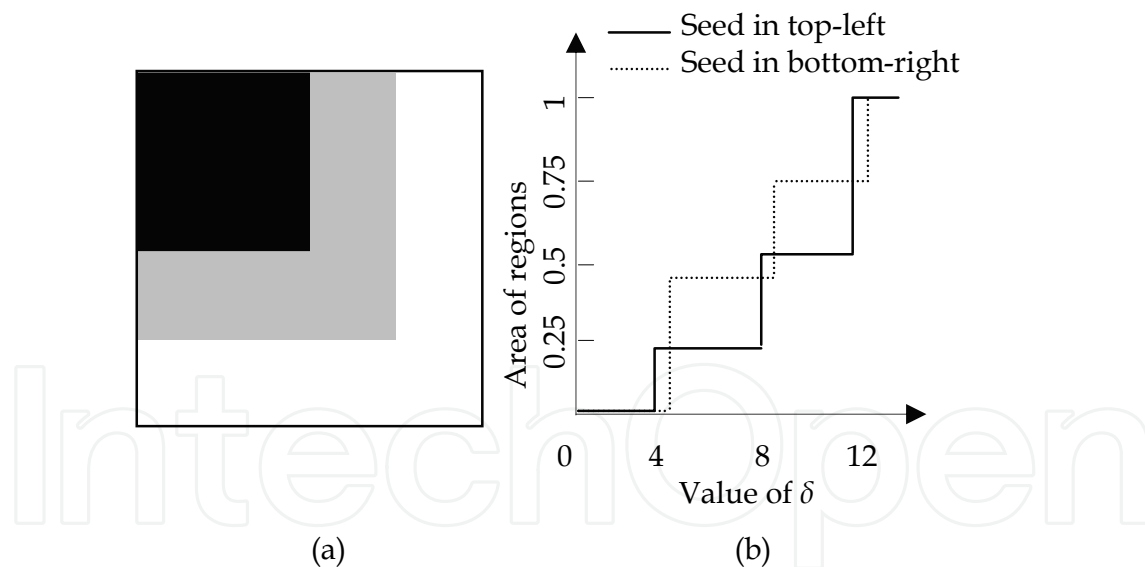

Fig. 8. δ - area curve

Fig.8b gives the δ-area curves of Fig.8a for the seed point selected in the top-left and bottom-right corner respectively, from which we see that the selection of seeds will affect the parameter δ, but not affect the segmentation result (He & Chen, 2000).

Another element for resonance is the selection of features to estimate whether the distance between two adjacent points is below δ or not. In fact, it can be chosen by any features of the image, and the different selection of features results to different threshold δ. In this chapter, the eight-connectivity is used to connect the pixels of the object.

3.4 Image segmentation

When there are multi-objects in an image, image segmentation is necessary: locating and isolating the objects from the image and then identifying them. Once isolated, the objects can be measured and classified. The correct segmentation should be that it divides the image S into several independent regions $\{S_1, S_2, …, S_n\}$, each region represents one kind of textures (Tanaka, 1989).

$$
\begin{align}
(1)\quad & S = \bigcup_{i=1}^{n} S_i \\
(2)\quad & S_i \cap S_j = \Phi \qquad \text{for all } i \neq j \\
(3)\quad & P_r(S_i) = 1 \qquad \text{for all } i
\end{align}
\tag{5}
$$

$P_r(x)$ is the probability of the existence of x and Φ is the null set.

Fig. 9a (a strong light is given behind the right hand of the black rectangle) is always used to compare the results among different image processing algorithms, which is the scene of setting the experiment. Fig. 9b is the original experimental image extracted from Fig. 9a.

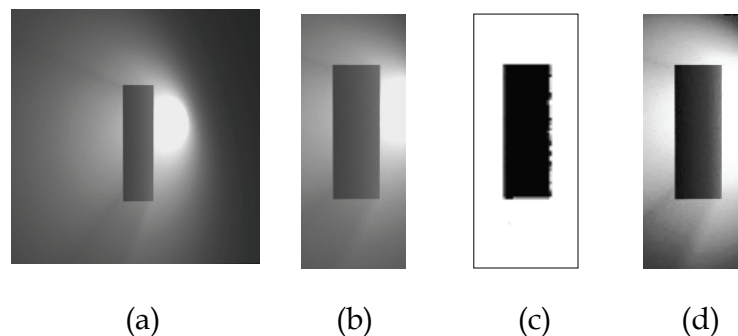   (a)   (b)   (c)   (d)

Fig. 9. Compared experiment

By using the resonance algorithm proposed in the chapter, the segmentation result is given in Fig. 9c, in which the effect of light is removed, so that the background is in one region. A compared result is given in Fig. 9d by the reinforcement histogram algorithm (Castleman, 1998), which shows that the background is difficult to be clustered into one region.

3.5 The experiment

In this section, compared to the conventional method, the natural image in real environment will be applied to analyze the resonance algorithm for image segmentation.

Fig. 10 shows the source image and the segmentation result (Dai, Fujihara & Sugisaka, 2008). In the original image of Fig. 10a, sky and trees are two main regions, while the color of the sky is varied gradually by clouds.

Fig. 10b is the result after segmented by the proposed resonance algorithm. We adopt the gray level as the feature and the seed pixel is selected from the top-left corner of the image. The image is divided into three parts. The sky is separated into part-1 and 3 by a trunk of tree in the image. Part-2 is the region of trees. The influence of clouds is greatly eliminated because the resonance algorithm can handle gradual changes of intensity.
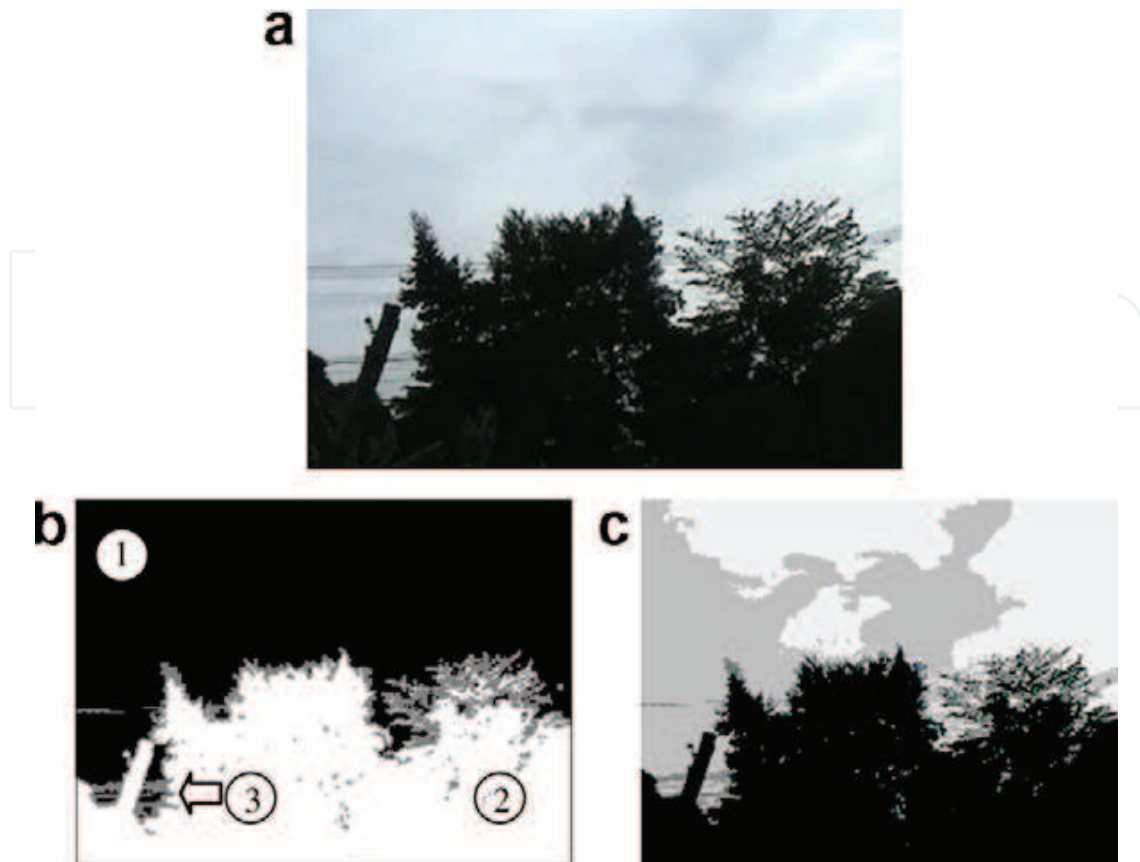
Fig. 10. Image segmentation: (a) color image, (b) by the resonance algorithm, (c) by the histogram analysis

Also if we do not satisfy that the sky is separated, the part-1 and 3 can be combined by the later processing easily, because the features of them are the same. The compared result is given by Fig. 10c, which is produced by the general histogram analysis method. It shows that the influence of the clouds cannot be ignored.

4. Conclusion

In this chapter, first the classical method for image segmentation is introduced. It is suitable for digit or letter segmentation and the program to realize the method is easy to be composed. But it still has some limitations.

In the second part of the chapter, the resonance theory and algorithm, and the three important elements of resonance are introduced.

The unsupervised resonance algorithm is proposed for complex image segmentation, which has the feature to eliminate the influence of gradual changes of texture in intensity to some extent.

The resonance algorithm for image segmentation is to search the same or similar texture pixels (among the adjacent pixels) so as to cluster them into one region: the resonance is spread among all the pixels within the image.

The compared result is also given and shows that the resonance algorithm emphasizes the similarity among the adjacent pixels rather than the global threshold values, and the segmentation result is satisfied. But there are some problems still existed to be solved:
1. How to select the parameter δ more correctly,
2. How to improve the program to fasten the algorithm.

5. Acknowledgment

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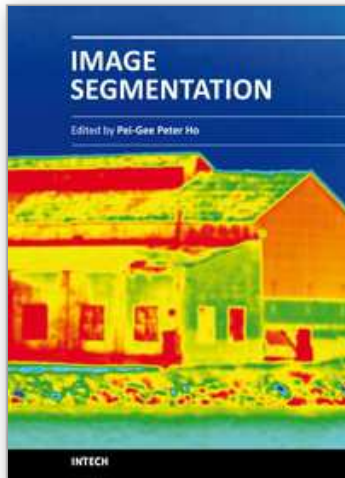
Image Segmentation

Edited by Dr. Pei-Gee Ho

It was estimated that 80% of the information received by human is visual. Image processing is evolving fast and continually. During the past 10 years, there has been a significant research increase in image segmentation. To study a specific object in an image, its boundary can be highlighted by an image segmentation procedure. The objective of the image segmentation is to simplify the representation of pictures into meaningful information by partitioning into image regions. Image segmentation is a technique to locate certain objects or boundaries within an image. There are many algorithms and techniques have been developed to solve image segmentation problems, the research topics in this book such as level set, active contour, AR time series image modeling, Support Vector Machines, Pixon based image segmentations, region similarity metric based technique, statistical ANN and JSEG algorithm were written in details. This book brings together many different aspects of the current research on several fields associated to digital image segmentation. Four parts allowed gathering the 27 chapters around the following topics: Survey of Image Segmentation Algorithms, Image Segmentation methods, Image Segmentation Applications and Hardware Implementation. The readers will find the contents in this book enjoyable and get many helpful ideas and overviews on their own study.

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