DICTA2002: Digital Image Computing Techniques and Applications, 21--22 January 2002, Melbourne, Australia.

Speedup Method for Real-Time Thinning Algorithm

Ming Yin, Seinosuke Narita
Narita Laboratory, Graduate School of Science and Engineering
of Waseda University, Japan
Tel:81(3)52863179 fax:81(3)32029940
email:yin@narita.elec.waseda.ac.jp

Abstract

Thinning algorithms are widely used as a useful method of pre-processing in image process. In this paper, a high-speed method for real-time thinning algorithm is proposed. This method can be used by any thinning algorithms for speeding real-time process without any changes of thinning algorithms. The Hilditch thinning algorithm is adopted to verify the proposed method. With a 3×3 mask image in the Hilditch thinning algorithm, the result of process output can be saved to a memory "table". The output results of all different 3×3 masks are saved to this "table" at the beginning of starting application. When an image will be processed, the thinning results of every 3×3 masks in the image can be extracted by the method of "looking for table". Thus the thinning result is same but the process speed is high. The possibility of this method has been proofed using different configured computers to process a same image and the result is satisfied.

1. Introduction

In many computer vision applications, the skeleton of one object in a scene is paid more attentions such as recognizing handwriting or printed characters. The generation of a digital skeleton is often one of the first processing steps taken by a computer vision system when attempting to extract features from an object in an image.

In such situations, the thickness of the pattern strokes will not contribute to the recognition process. So many techniques are used to reduce the thickness of the pattern strokes. Thinning is the process of deleting pixels in a pattern image as many as possible without affecting the general shape of the pattern. In other words, a skeleton is left after thinning which can represent the shape of the object in a relatively small number of pixels.

Various algorithms have been proposed to produce the skeleton of a digital binary pattern. Hilditch proposed an algorithm [1] to obtain the skeleton of one object in an image and widely used by computer vision researchers. There are two versions for this algorithm, one using 4×4 mask and the other one using 3×3 mask. Another algorithm [2] was proposed by Chen, Y. and Hsu, W. in order to improve the process speed. However it is not satisfied when the size of image is very big and a lot of time costs even if the process result is perfect. It can not be applied very well in industrial inspection or medical inspection.

Recently, with the development of computer manufacture techniques, it becomes possible to provide much more memories in one computer. Now programmers do not worry about the short of the memory, occupy much more memory as they hope. It suggests that memory can be used to improve the speed of image process. In this paper, a method of improving speed of thinning process is proposed according to the usage of computer memory. This method can also be used by other image process not only by thinning process.

2. Hilditch Thinning Algorithm

Hilditch thinning algorithm is widely used as a useful method of pre-processing in image process. There are two versions for Hilditch's algorithm, one using a 4x4 window and the other one using a 3x3 window. In this paper, the 3x3 window version is considered and the algorithm is described below.

At first, consider the following 8-neighbourhood of one pixel p_0 defined in a binary digital image shown in figure 1.

P_4	P_3	P_2
P_5	P_0	P_1
P_6	P_7	P_8

Figure 1. a pixel of 8-neighbourhood

A set of 8-neighbourhood of a pixel p_0 is defined and the notation is shown as below.

$$N_8 \equiv \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8\}$$

$$N_{odd} \equiv \{p_1, p_3, p_5, p_7\}$$

For the pixel p_0, the aim of thinning algorithm is to decide whether to keep it as part of the result skeleton or delete it from the image. For this purpose, the 8 neighbors of pixel p_0 must be investigated, when pixel p_0 is part of a skeleton, pixel p_0 will be deleted or not deleted according to the 5 conditions described below, the 5 conditions must be considered together. But during one path process, the value of pixel p_0 should be set to another value such as –1 according to the Hilditch's algorithm, it will be set to 0 until all pixels in the image have been investigated during this path. Then this process is repeated until no changes are made.

Before introduce the five conditions mentioned above, supposed for every pixel p_i here i is from 1 to 8, its value of one pixel is represented by $B(p_i)$. The five conditions are described as below.

2.1 Condition 1

The pixel p_0 is part of a skeleton.

$$\sum_{i\in N_{odd}} \{1-|B(p_i)|\} \geq 1$$

2.2 Condition 2

It will not be deleted when pixel p_0 is boundary of one skeleton.

$$\sum_{i\in N_8} |B(p_i)| \geq 2$$

2.3 Condition 3

It will not be deleted when pixel p_0 is isolate pixel.

$$\sum_{i\in N_8} C_i \geq 1$$

Here $C_k = \begin{cases} 1 & for \quad B(p_i)=1 \\ 0 & for \quad B(p_i)\neq 1 \end{cases}$

2.4 Condition 4

It will not be deleted when pixel p_0 is a connective pixel.

$$N_c^8(p_0)=1$$

Here $N_c^8(p_0)$ is

$$\sum_{i\in N_{odd}} \{D(p_i) - D(p_i)\times D(p_{i+1})\times D(p_{i+2})\}$$

The value of $D(p_i)$ is

$$\begin{array}{lll} 1 & for \quad |B(p_i)|=1 & \\ 0 & for \quad |B(p_i)|\neq 1 & i\in N_8 \end{array}$$

2.5 Condition 5

Only one side will be deleted when the width of skeleton is two pixels. The condition can be represented using two equations.

$$B(p_i)\neq -1 \qquad (i\in N_8)$$

$$N_C^8(p_0)=1 \qquad when \qquad B(p_i)=0$$

It must be paid some attentions that this algorithm is a parallel-sequential algorithm. At one pass all pixels are checked at the same time and decisions are made whether to delete each of the checked pixels. The process will be repeated several times until no more changes are done.

3. Proposed Method

During thinning process, it is very clear that the output result of one pixel in a image has two possibilities: changed or not changed. In program, the output result of Hildtch's algorithm is 0, 1 or –1, here –1 represents the pixel will be deleted without changing the shape of skeleton. But it must be kept until one path completes. From this algorithm, one pixel can be decided by a 3×3 mask as shown as Sec 2 figure 1(one pixel of 8-neighbourhood). The different type number of all 3×3 masks is 3^9 –1. For each 3×3 mask has only one output result during the process. Some examples of output result are:

$$\begin{bmatrix} 0&0&0\\0&0&0\\0&0&0 \end{bmatrix}\rightarrow[0] \quad \begin{bmatrix} 1&0&0\\0&0&0\\0&0&0 \end{bmatrix}\rightarrow[0]$$

$$\begin{bmatrix} 0&0&0\\0&0&0\\0&0&1 \end{bmatrix}\rightarrow[0] \quad \begin{bmatrix} -1&0&0\\0&0&0\\0&0&0 \end{bmatrix}\rightarrow[0]$$

In this case, the pixel is not part of a skeleton, so no need to process it.

$$\begin{bmatrix} 0&0&0\\0&1&0\\0&0&0 \end{bmatrix}\rightarrow[1] \quad \begin{bmatrix} 1&0&0\\0&1&0\\0&0&0 \end{bmatrix}\rightarrow[1]$$

$$\begin{bmatrix} -1&0&0\\0&1&0\\0&0&0 \end{bmatrix}\rightarrow[1] \quad \begin{bmatrix} 1&0&0\\0&-1&0\\0&0&0 \end{bmatrix}\rightarrow[1]$$

$$\begin{bmatrix} 0&0&0\\1&1&0\\0&0&0 \end{bmatrix}\rightarrow[-1] \quad \begin{bmatrix} 0&0&0\\-1&1&0\\0&0&0 \end{bmatrix}\rightarrow[1]$$

In this case, the pixel is part of a skeleton, the decision can be made by comparing the 8-neighbourhood pixels according to the Hilditch's algorithm.

Now it is easy to give the thinning result when processing a image real-time only depending on the number of 3×3 mask. It means the lookup "table" can be derived as follows.

(1) The value of one pixel has three possibilities: 0, 1, -1.
(2) It can be represented as 0, 1, 2 respectively in program.
(3) The value of 3×3 mask can be computed as:

$$\sum_{i=0}^{8} 3^{n_i}$$

Where n_i is the value of a pixel in 3×3 mask obtained in Section 2. It represents

$$3^{n_0}+3^{n_1}+3^{n_2}+3^{n_3}+3^{n_4}+3^{n_5}+3^{n_6}+3^{n_7}+3^{n_8}$$

(4) The range of lookup table is from 0 to $3^9 - 1$.

Every different 3×3 mask has only one correspond output number: 0 or -1 or 1.

4. Program of Proposed Mehtod

The procedure of proposed method can be formed as below.

4.1 Creating Lookup Table

In starting program, every different 3×3 mask is processed using the Hilditch algorithm to generate the lookup table from 0 to $3^9 - 1$.

4.2 Look up "Table"

During the thinning procedure, look up table to decide the output result when one pixel is part of a skeleton.

4.3 Repeating Process

Repeat the process step 2 until no change is found.

5. Result of Experiments

The performance of the proposed method is evaluated by comparing the time expensive of the Hilditch algorithm and new proposed real-time method. The cost time is recorded when the program runs on different computers. The selected computers have different type cpu or memory. The time expensive of the two methods is also compared when processing different size images. It must be pointed that when the size of an image is too small, there is no difference between the two methods. All experiments are done on Windows 2000 professional version. From the experiment result, it can be conclude that the proposed method is good at real-time thinning process for one times speedup.

In result images, the result of thinning process is merged with the source image. The black lines in the image represent process output.

When the image size is 300×300 (pixels), the results of two thinning method are shown in figure 2 and figure 3 below.

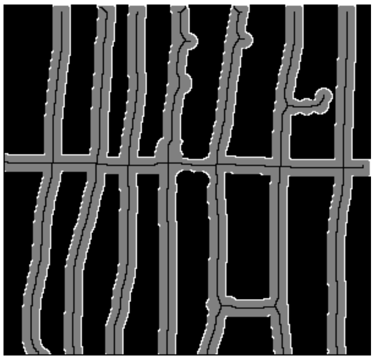

Figure 2. Result of Hilditch Algorithm

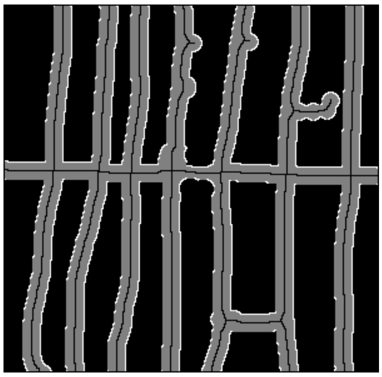

Figure 3. Result of Real-Time Method

The time expensive(ms) of two method is show in table 1 when image size is 300×300 (pixels).

In table 1, F represents Cpu frequency and M represents size of memory.

Computer Type	Hilditch	Real-Time
F:300 M: 64M	641	301
F: 300 M: 128M	640	300
F: 300 M: 256 M	640	299
F: 500 M: 64 M	401	190
F: 500 M: 128 M	391	189
F: 500 M: 256 M	380	180
F: 1000 M: 256M	200	90
F: 1000 M: 512M	190	90

Table 1. Time Expensive of 300×300 (pixels) image

From figure 2 and figure 3, it is very clear that the results of two method are same but from table 1, the time expensive of new proposed real-time method is less than Hilditch's method. It can also be known that the time expensive is almost same when computers have same cpu but different size of memory.

The experiment is also done when the image size is 600×600 (pixels), the results of tow thinning are shown in figure 4 and figure 5 below and the time expensive(ms) of two method is show in table 2. Also in table 2, F represents Cpu frequency and M represents size of memory.

Figure 4. Result of Hilditch Algorithm

Figure 5. Result of Real-Time Method

6. Conclusion

A method of real-time thinning process based on Hildtch algorithm is proposed and demonstrated. The Hilditch algorithm is used to generate the lookup table of all 3×3 masks before the thinning process. The relationship between one 3×3 mask and it's output result is single correspondence, it is easily located during the real-time thinning process. The proposed method has improved the speed about one times comparing the Hilditch method from experiment result. This proposed method can also be used by other thinning algorithms to overcome the shortcoming that need much time in applications.

Computer Type	Hilditch	Real-Time
F: 300 M: 64M	2003	1192
F: 300 M: 128M	1982	1152
F: 300 M: 256M	1943	1151
F: 500 M: 64M	1211	721
F: 500 M: 128M	1210	701
F: 500 M: 256 M	1182	701
F: 1000 M: 256M	651	401
F: 1000 M: 512M	641	395

Table 2. Time Expensive of 600×600 (pixels) image

7. Acknowledgement

The author wishes to thank the Yoshida Scholarship Foundation in Japan for supporting this research work.

8. References

[1]. Hilditch, C.J., Linear Skeletons From Square Cupboards, in Machine Intelligence IV (B. Meltzer and D. Mitchie eds), University Press, Edinburgh, 1969. 403-420. 17, 2, 1970. 339.
[2]. Chen, Y. and Hsu, W., An Interpretive Model Of Line Continuation In Human Visual Perception, Pattern Recognition, Vol. 22 No. 5, 1989. 619-639.
[3] Anil K.Jain, Fundamentals of Digital Image Processing, Prentice-Hall, Inc. 1989.
[4] Parker, J.R. and Jennings, C., Defining The Digital Skeleton, SPIE Conf. on Vision Geometry, Boston, Nov. 1992.
[5] T. Agui, T. Nagao, Entrance of Image Processing using C Language, Shokodo Press.