Gray-scale thinning by using a pseudo-distance map

A.Nedzved*, S. Uchida**, S. Ablameyko*

**United Institute of Informatics Problems of the National Academy of Sciences, Surganova 6, Minsk, 220012 Belarus. e-mail: {nedzveda, abl}@newman.bas-net.by*

***Dept. of Intelligent Systems, Kyushu University, Fukuoka-shi, 812-8581 Japan. e-mail: uchida@is.kyushu-u.ac.jp*

Abstract

In this paper, the algorithm for thinning of grey-scale images is proposed that is based on a pseudo-distance map (PDM). The PDM is a simplified distance map of gray-scale image and uses only that features of image and objects that are necessary to build a skeleton. The algorithm works fast for large gray-scale images and allows constructing a high quality skeleton.

1. Introduction

One of the most significant operations in image processing is thinning, which is transformation of original “thick” object into lines of one-pixel thickness, called skeleton. Skeleton usually has the following basic properties:

•It preserves a topology of an original object;

•It is located in an object area and desirably in an object center;

•All pixels of a skeleton are connected with each other;

•Isotropy – skeleton is preserved after image rotation (at least for an angle that is divisible by $\pi/2$;

•It has a width that is equal to 1 pixel.

The thinning algorithms for binary images are very well developed and have been used for description of topological properties of the objects in the images. They are often classified by methods of neighborhoods testing: operated by mathematical morphology methods [1], distance transform [4-6], hit or miss transformation [10], watershed [2], and others [8]. Among them, distance transform is the most popular method because it provides high-quality skeleton for binary images. Generally, thinning by distance transform includes the following steps:

•construction of distance map;

•detecting pixels of skeleton;

•postprocessing (pruning).

During last decades, there appeared papers with algorithms for thinning of grey-scale images and many of them are based on using distance transform. Conventional distance transform-based algorithms for gray-scale images, however, require huge computations and thus the algorithms are slow.

In this paper, a novel algorithm of gray-scale thinning is proposed. The proposed algorithm is based on *pseudo-distance map* (PDM), which is a simplified distance map of gray-scale image and uses only that features of image and objects that are necessary to build a skeleton. The algorithm is faster than ordinary raster-based gray-scale thinning algorithms.

2. Building a pseudo-distance map

2.1 Principles of PDM building

Distance transform (DT) is defined as replica of the region of image where pixels are labeled with their distance from a reference pixels set of object [12]. For gray-scale image, reference set for such region is constituted by different gray-scale. The union of DTs of regions of all gray-scale is the DT of gray-scale image. When computing the DT of a region with gray-scale k, adjacent regions with the levels greater than k are obstacles for the propagation of distance information. Thus, distance transform of a region with value k may require more than one pair of forward and backward scans of the image [13].

The result of thinning operation is a skeleton. For gray thinning algorithm, it is necessary to build special distance map, which includes all necessary properties of a skeleton. Skeleton reflects the following topological properties of an object:

•Skeleton must cross pixels of local maximum. These pixels have no neighbors with greater gray-scale in their neighborhood.

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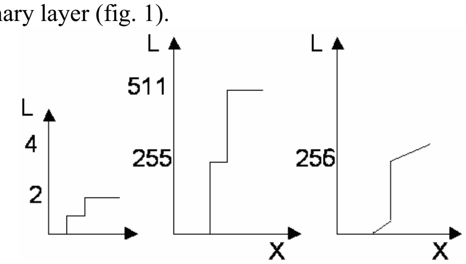
•Skeleton must cross node pixels. These pixels connect more then three neighbors with higher value by a sole way.

•Skeleton must finish at the end pixels. These pixels have only one pixel with greater or equal value.

•Skeleton should not cross pixels of local minimum. These pixels have no pixel with lower level.

Let us build a PDM that preserves all these properties and can be built in a more effective and easier way.

For construction of a PDM, a gray-scale image is described as a collection of binary layers where every lower layer includes pixels from a higher layer [7]. Distance map of one binary layer is constructed by increasing pixels depth for reflecting distance properties of pixels. Mostly gray-scale image has 256 levels. In this way, if every binary layer is raised to 256 levels (with zero level), then we will have enough depth of gray value for construction of a distance map for every binary layer (fig. 1).



a) b) c)

Fig. 1 Profile (L – pixels value, x – pixels coordinate) of a) gray values in an original gray-scale image b) gray values multiplied by 256, and c) a pseudo-distance map.

On the base of obtained image with increased pixels value, distance map is built for every layer. The set of PDMs of all binary layers results to a pseudo-distance map with topological properties. In the result, we have a set of 256 image layers with 256 gray values for each layer.

2.2 PDM building algorithm

The PDM building algorithm contains two-scans.

	11		11	
11	7	5	7	11
	5	0	5	
11	7	5	7	11
	11		11	

Fig 2. Chamfer metrics mask.

The first scan is realized in the direction from top to bottom and from left to right. For constructing PDM in this direction, every pixel is changed by the following condition:

$$p = \begin{cases} (p_i + f_i), & if \quad (p_i + f_i < p)\, and (p_i + f_i \ge L(p)),\, i = 0,\dots,n \\ L(p), & if \quad (p_i + f_i < L(p)),\, i = 0,\dots,n \\ p, & another \;\; case \end{cases}$$

where:

p - is a pixel value,

L(p) – level of binary layer in image,

p_i – value of pixels from a neighborhood,

f_i – value of corresponding point from mask-table for Chamfer metrics (fig. 2),

i – index of element in mask-table,

n - number of elements in mask-table.

The Chamfer metrics is employed above for the best compromise between computational complexity and quality.

The second scan is realized by the similar condition with direction from bottom to top and from right to left and it finalizes constructing PDM. This results to a pseudo-distance map with basic topological properties of an image (fig. 3). In this case, PDM corresponds to sets of layers of distance maps. Every layer starts from value, which multiples by 256. In the result, pixel value of PDM includes properties of gray-value and distance.

0	0	0	0	0	0	0	0
0	255	255	255	255	255	255	0
0	255	255	255	511	511	255	0
0	255	255	255	511	511	255	0
0	255	255	255	511	511	255	0
0	255	255	255	511	511	255	0
0	255	255	255	255	255	255	0
0	0	0	0	0	0	0	0

a)

0	0	0	0	0	0	0	0
0	1	1	1	1	1	1	0
0	1	2	2	256	256	1	0
0	1	2	3	256	256	1	0
0	1	2	3	256	256	1	0
0	1	2	2	256	256	1	0
0	1	1	1	1	1	1	0
0	0	0	0	0	0	0	0

b)

Fig. 3 Stages of pseudo-distance map construction a) A gray-scale image multiplied by 256, and b) its pseudo-distance map.

Example of pseudo-distance map is shown in fig.4.

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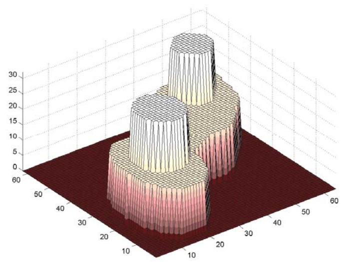
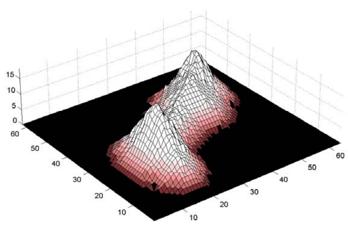
3. Detection of skeleton

The proposed pseudo-distance map allows to use binary-like thinning algorithm. Metrics of this algorithm has to be equal to metrics from PDM building.



a)



b)

Fig. 4. An original gray-scale surface (a) and its pseudo-distance map (b)

The algorithm for detection of skeleton pixels consists of two parts:

1) Detection of feature pixels (topological properties):

a) end pixels;
b) saddle pixels;
c) duplex of saddle pixels;
d) local maximum.

2) Determination of remaining elements of a skeleton.

Method of determination of these properties is described in Table 1.

All pixels with previous topological properties are marked as a maximal level on the pseudo distance map. They are starting pixels for growing skeleton. After detecting starting pixels, function for finding of maximum is recursively executed in neighborhood of a pixel. This function ignores starting pixels. In a result of this operation, found maximum is marked as next starting pixels. The skeleton grows until it does not reach other starting pixels or detects maximum. The obtained gray-scale skeleton is shown in fig.5.

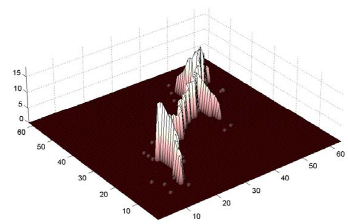


Fig.5. Gray-scale skeleton

Table 1. Conditions to detect feature pixels

End pixels (p):	$\Sigma(p_i \geq p)>0$
Saddle pixels	(c_4 and c_0 and not c_2 and not c_6) or (not c_4 and not c_0 and c_2 and c_6) or (c_1 and c_5 and not (c_2 and c_3 and c_4) and not (c_0 and c_7 and c_6)) or (c_3 and c_7 and not (c_2 and c_1 and c_0) and not (c_4 and c_5 and c_6))
Duplex of saddle pixels (two pixels p and p_i, when i – neighbour, that is tested by FindMax function)	(c_5 and n_1=p and not c_0 and not c_2) and (FindMax(1)>0 (c_1 and n_5=p and not c_6 and not c_4) and (FindMax(5)>0 (c_3 and n_7=p and not c_0 and not c_6) and (FindMax(7)>0 (c_7 and n_3=p and not c_2 and not c_4) and (FindMax(3)>0 (c_4 and n_0=p and not c_2 and not c_6) and (FindMax(0)>0 (c_0 and n_4=p *and not* c_2 and not c_6) and (FindMax(4)>0 (c_6 and n_2=p and not c_4 and not c_0) and (FindMax(2)>0 (c_2 and n_6=p and not c_4 and not c_0) and (FindMax(6)>0
Local maximum	$\Sigma(p_i>p)=0$

Where:
p – a current pixel,
p_i – neighbor,
c_i – condition (p_i>p),
and, or, not – logical operators: conjunction, disjunction, negation,

FindMax(i) – function for count of pixels with greater level from neighborhood i:

$$\text{FindMax}(i) = \sum_{j=0}^{n} \begin{cases} 1, if (p_i < p_{i,j}) \\ 0, \text{ in otherwise} \end{cases},$$

where $p_{i,j}$ – neighbor of p_i.

4. Conclusion and discussion

In this paper, the algorithm for thinning of gray-scale images has been proposed. It is based on building a pseudo-distance map and produces a high quality skeleton and is faster that ordinary raster-based algorithms.

The algorithm has been widely tested to thin biomedical vascular images. The fig. 6 shows result of thinning of biomedical image by our algorithm. As one can see, the algorithm correctly extracted all ridge pixels. There exist several open branches bounded by end and node pixels. However, they can be easily removed by pruning procedure [7].

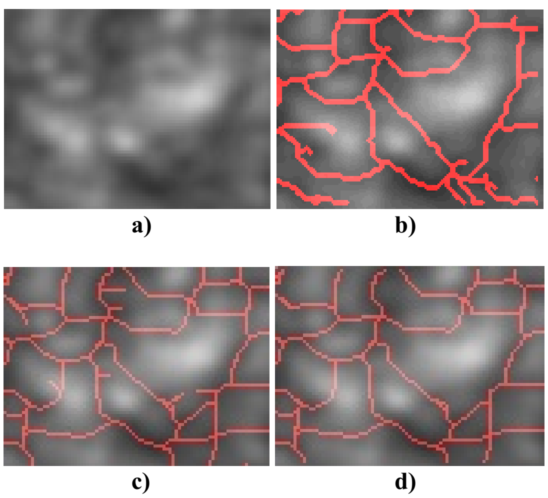


Fig. 6. Result of thinning: a) source image, b) Zhang-Suen method, c) algorithm by pseudodistance map, d) algorithm by pseudodistance map with prunning

Table 2. Comparison of several thinning algorithms

	Time of process (ms)	Relative time of process	Number of iterations
Our algorithm	51	0.08	8
Zhang-Suen [10]	480	0.76	70
Method [4]	630	1	120

From time-consumption point of view, the developed algorithm was compared with modified algorithm of Zhang-Suen [11] and raster thinning algorithm [7], on the image of vessels on computer with Celeron 1300 MHz. The processing time is shown in Table 2.

ACKNOWLEDGEMENT

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