International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 2– No.3, May 2012 – www.ijais.org

An Order-Independent two-pass Parallel Algorithm for Binary Image Thinning

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ABSTRACT

This paper addresses an order-independent rule-based parallel thinning algorithm. In this algorithm, thinning rules are formulated based on the weight-values of the input image. The weight-value of a non-zero pixel is evaluated by analyzing neighboring pixels. This weight-value is used to separate the conditions into rules. This process of transforming conditions into rules makes the thinning process faster and efficient. The experimental results are compared to the other parallel thinning algorithms and their relative performance is assessed. The proposed algorithm is shown to be computationally more efficient in terms of thinning and preserving the connectivity.

Keywords

Thinning, parallel, order-independent, rule-based, weight-value

1. INTRODUCTION

Binary image thinning is becoming a valid and fundamental approach to thinning and skeletonization, due to the ever increasing growth of availability of parallel processors (architectures) and the real possibility of realizing machine vision systems. Recently, its interest has also increased both in design and objective standpoint; this has lead to parallel thinning algorithms. The parallel thinning algorithms are characterized by the representation of a simultaneous deletion process of all the "deletable"contour points; to be efficient, the number of repetitions or iterations should be ideally equally to half of the maximum width of the figures present in. Of course, the less time-units and iterations the algorithm spends the more it is efficient under the constraint of remaining the 8-connected as perfect as possible and preventing excessive erosion. To deal with the later processing each iteration of the parallel thinning algorithm is subdivided into n-iterations. The stefanelli and rosenfeld indicated [1]. In parallel thinning, all the pixels in an image can be processed simultaneously and the operation on each pixel depends on the values of its neighbors. Parallel thinning algorithms with a 1-iteration have the disadvantage that they may yield no connected or even empty medial lines for connected figures; the case where a two-pixels-wide straight stroke is entirely eliminated by a single iteration is widely known [2]. Based on these considerations and computational requirements, we propose a thinning algorithm with 2-iteration which is able to

1) Reduce the number of sub-iterations and the time complexity of the each iteration

2) Produce a perfect 8-connected thinned image

3) Prevent the excessive noise and excessive erosion.

The meaning of these objectives will be clarified in the next sections. According to the algorithm, describe in section 3, a pixel is deletable by analyzing the values of its neighboring pixel with in the area of (3 X 3) pixels in the first iteration and an area of (3 X 3) in the second iteration. The algorithm is characterized by the fact that the first iteration is used to remove boundary elements of an object in all directions, while the second iteration is used to remove corners and diagonal boundary elements in the North East, North West, South West, and South East directions. The isotropic behavior allows the generation of more regular skeletons and better qualitative results. Experimental results in terms of degree of 8-connectedness, degree of erosion, stability under rotation, boundary noise sensitivity are also discussed in this paper.

2. REVIEW OF PARALLEL THINNING ALGORITHMS

The study of thinning has been improved until lately. The well-proved thinning algorithms in the literature are, Parallel algorithm [2], Rotation invariant [3] Rotation invariant rule based [4] Order independent [5] algorithm. ZS algorithm has a problem that the slanting lines are erased [3]. LW algorithm has the problem which slanting lines with two pixel width were remained [2]. We can find that ZS algorithm makes one-pixel line but loses connectivity in some images. LW algorithm have the same problem, however the proposed algorithm can settle the problem and make perfect slim line of 1-pixel with 8-neighbour connectivity even for the two pixel width images.

2.1 ZS algorithm

ZS parallel thinning algorithm performs sub-iterations step wise.

The first step

The pixels satisfied with the following conditions are erased.

1) $2 \leq B(Pi) \leq 6$
2) $A(Pi) = 1$
3) $P2 * P4 * P6 = 0$
4) $P4 * P6 * P8 = 0$

The Second step

Condition 3 and 4 in the first step are replaced with the following condition.

3) $P2 * P4 * P8 = 0$
4) $P2 * P6 * P8 = 0$

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2.2 LW algorithm

To solve the problem with slanting lines with 2-pixel width are erased, LU and Wang replaced the condition-1 ($2 \leq B$ (Pi) ≤ 6) in ZS algorithm with the following condition [6] ($3 \leq B$ (Pi) ≤ 6). Using the modified condition, the slanting lines do not disappeared, however the algorithm can not make 1-pixel with 8-neighbour connectivity [7]. In the discussions below, it is understood that a pixel Pi examined for deletion is a black pixel, and the pixels in its(3 X 3) neighborhood are labeled as X i =1…8, as shown in Fig-1 (a).

P_1	P_2	P_3
P_8	P_i	P_4
P_7	P_6	P_5

(a)

1	1→	↓0
1	P_i	1
1	1	1

(b)

Figure-1: Representation of Zero-to-One and One-to Zero Patterns

2.3 KNP algorithm

In 2009, Gabor Nemeth and Kalman Palagyi proposed [1] a topology preserving algorithm based on Ronse's sufficient conditions [8]. Ronse proposed three definitions for endpoints. Han proposed an order among these definitions from more restrictive to less restrictive. The definitions are as follows:

Exactly one 8-neighbor foreground point (BP = 1).

Two pixels in 8-neighbor and two pixels are 4-connected

(BP = 1 and AP = 1)

Two pixels in 8-neighbor and two pixels are 8-connected

(BP = 1 and CP = 1)

These algorithms produce spurs but are having less impact on later processing steps of the application.

3. THE PROPOSED ALGORITHM

3.1 Basic Definition

The binary images have black and white pixels. In this paper, the black pixel is represented as 1 and the white pixel is represented as 0. The proposed algorithm uses 3x3 masks as shown in figure-1(a). P1, P2, P3, P4, P5, P6, P7 and P8 are the 8-neighbours of the candidate pixel (Pi). The weight value, is defined as the number of black pixels in the 8-neighbourhood of Pi. We define P1, P3, P5 and P7 pixels are four connected, representing the background and P2, P4, P6 and P8 pixels are eight connected, representing the object. The number of one - to-zero or zero-to-one patterns (P2, P3, …, P8, P1) and the non-zero neighbors of candidate pixel Pi are computed [5]. For example, in figure 1(b), there is one one-to-zero transition and one zero-to-one transition.

3.2 Principal followed in the Algorithm

The Proposed algorithm is a two-pass iterative parallel thinning algorithm. In this we adopt a two-stage thinning procedure which checks whether any black pixel can be removed (made to be white) safely or not. In the proposed algorithm, there are two passes. In pass-1, we propose a 23 rule procedure and in pass-2, we propose a 4-rule procedure. In pass-1, as a first step, it counts the number of non-zero neighbors and one–to-zero or zero-to-one transition around the candidate pixel Pi. We derive the thinning rules from the masks shown in figure-2, which satisfy the rule -1 and rule-2 of pass-1 as shown in figure-2. The proposed rules are derived by rotating each mask by one bit (circular rotation) from left to right or right to left for one complete rotation to achieve the thinning rules. The rule-3 to rule-23 in pass-1 and rule-3 and rule-4 in pass-2 are nothing but the exhaustive list of alternatives possible based on rule-1 and rule-2 of pass-1

1	1	0
0	P_i	0
0	0	0

(a)

1	1	1
0	P_i	0
0	0	0

(b)

1	1	1
0	P_i	1
0	0	0

(c)

1	1	1
0	P_i	1
0	1	1

(d)

1	1	1
0	P_i	1
0	0	1

(e)

Figure-2: Masks used to derive thinning rules

If this number is in the range of two-to-six (rule-1) and either zero-to-one or one-to-zero transition is exactly one (rule-2), then it will check for the rule 3 to 23 as listed in figure-3. If one of the rules from 3 to 23 is satisfied then the pixel under consideration is deleted.

This process is repeated until no ore changes occur in pass-1. At the end of the pass-1, the out put image posses 2-pixel wide skeleton.

In pass-2, we initially check for two rules namely, whether the non-zero neighbors are in the range of 3 to 6 (rule-1) and the number of transitions from one-to-zero or zero-to-one is exactly one (rule-2). If these two conditions are satisfied, then we check for the rules 3 and 4 as listed in figure-4. If match is found then the 2-pixel wide lines (if any) in the provisional skeleton produced by the pass-1, will be further thinned to one pixel wide skeleton, without compromising the connectivity of the skeleton. Transitions from one-to-zero or zero-to-one are exactly one (rule-2). If these two conditions are satisfied, then we check for the rules 3 and 4 as listed in figure-4. If match is found then the 2-pixel wide lines (if any) in the provisional skeleton produced by the pass-1, will be further thinned to one pixel wide skeleton, without compromising the connectivity of the skeleton.

Rule-1: All pixels of value 1 whose number in eight neighbor pixels is in the range of two to six.

Rule-2: The number either zero-to-one or one-to-zero patterns in eight neighbor pixels is exactly one.

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0	0	1		0	0	1		0	1	1
0	P_i	1		0	P_i	1		0	P_i	1
0	0	0		0	1	1		0	0	1
Rule-3				Rule-4				Rule-5		
1	1	1		0	0	0		0	0	0
1	P_i	0		0	P_i	1		0	P_i	1
0	0	0		0	0	1		1	1	1
Rule-6				Rule-7				Rule-8		
1	1	1		0	1	0		0	0	0
0	P_i	1		x	P_i	0		0	P_i	0
0	0	0		0	0	0		1	1	0
Rule-9				Rule-10				Rule-11		
0	0	0		0	0	0		0	0	0
0	P_i	1		1	P_i	0		1	P_i	x
0	0	x		1	1	1		0	0	0
Rule-12				Rule-13				Rule-14		
0	0	0		0	0	x		1	0	0
0	P_i	0		0	P_i	0		1	P_i	0
0	1	1		0	1	0		1	1	0
Rule-15				Rule-16				Rule-17		
1	1	0		1	0	0		0	0	0
1	P_i	0		1	P_i	0		1	P_i	0
1	0	0		0	0	0		1	0	0
Rule-18				Rule-19				Rule-20		
1	1	0		0	1	1		1	1	1
0	P_i	0		0	P_i	0		1	P_i	1
0	0	0		0	0	0		x	1	x
Rule-21				Rule-22				Rule-23		

Figure-3: Thinning rules for pass-1
Where x=1||0

3.3 Steps followed in the Algorithm

Pass-1:

Step-1: If Rule-1 and Rule-2, are satisfied then, check the Rule-3 to 23, if match found then process the pixel under consideration.

Step-2: Repeat the step-1 until no more change take place in pass-1, else go to pass-2.

	0	1	OR	1	1	1	OR	1	1	1
1	P_i	1		x	P_i	0		x	P_i	1
1	x	1		1	1	1		1	0	1
Rule-3										
x	1	1	OR	1	1	1	OR	1	1	1
1	P_i	0		1	P_i	x		0	P_i	1
1	1	1		1	0	1		1	x	1
Rule-4										

Figure-4: Thinning rules for pass-2

Pass-2:

Step-3: If Rule-1 and Rule-2 are satisfied then, check the Rule-3 and Rule-4. If both the rules are satisfied then process the pixel under consideration.

Step-4: Repeat the step-3 until no more change; take place in pass-2. Else stop thinning process.

4. AN ORDER INDEPENDENCE PROPERTY OF THE PROPOSED ALGORITHM

To establish the robustness of the proposed thinning algorithm to rotation, an original image has been rotated by 90 degrees, 180 degrees 270 degrees. The resulting images have been thinned using proposed thinning algorithm. The proposed algorithm can produce size and translation invariance for different rotations as demonstrated in figure-5. All these thinned images preserve their connectivity and the thinned patterns have one pixel thickness.

The image topology is also maintained although the shape and geometry of the image may differ marginally in very few image examples. The order independence property of the algorithm is achieved by rotating the thinning mask into all the directions and these masks are converted into the rules. These rules are used to thin the image from all the directions without leaving any part of the image is un-thinned. Moreover there are no two pixels thick lines as shown in figure-5.

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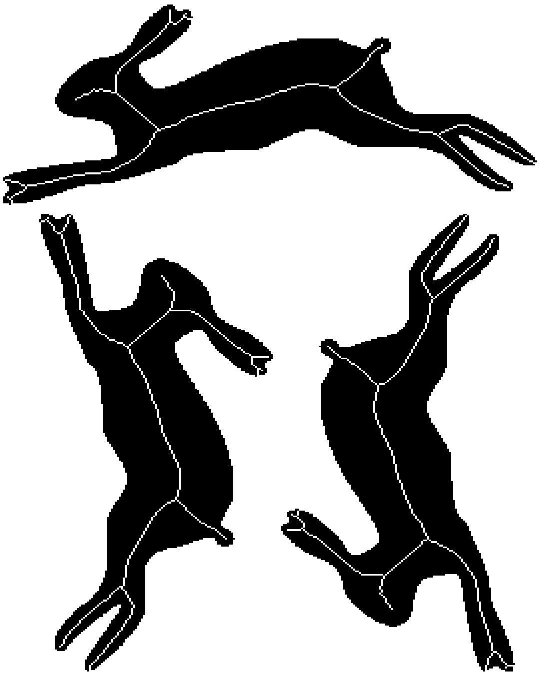
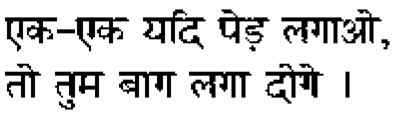


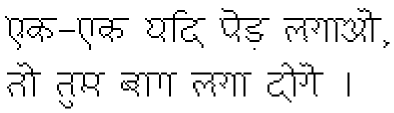
Figure-5: An order independent property of the proposed algorithm

5. RESULTS AND COMPARISONS

Image thinning has been performed on a few sample images using order independent thinning algorithm (KNP) and parallel thinning algorithm (ZS) and LW. The results show that KNP algorithm is not able to thin the image comprehensively; which means that it is leaving some parts of the image. In most of the cases, the edges and the corner points are not processed. In ZS algorithm there is excessive erosion and discontinuities in the thinned pattern are observed, where as proposed algorithm is processing the entire image and producing the exact skeleton for the given input image. These observations are illustrated as in figure-9 A unique advantage of the proposed algorithm is that this algorithm does not change the topological properties of the connectivity and the shape of the thinned image as compared to the other existing algorithm.

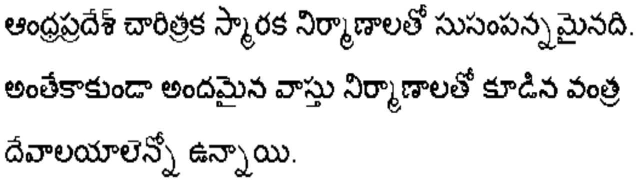


(a) Input Image

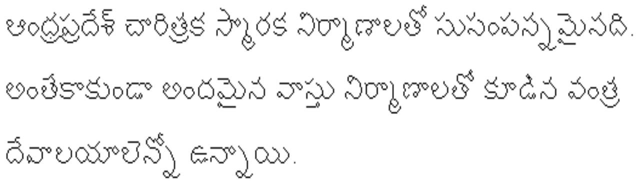


(b) Thinned Image

Figure-6: Thinning results produced by proposed algorithm



(a) Input Image



(b) Thinned Image

Figure-7: Thinning results produced by proposed algorithm

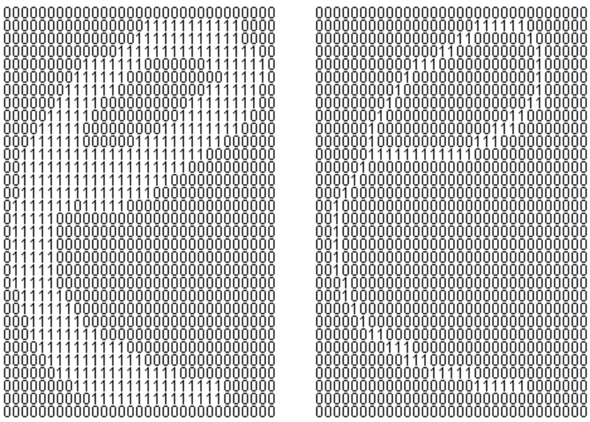
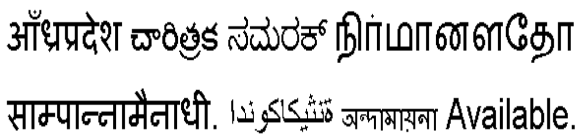
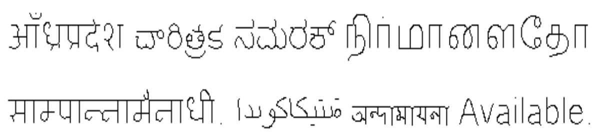


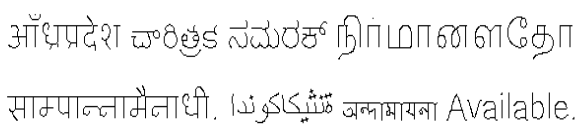
Figure-8: Thinning results of Printed Telugu characters



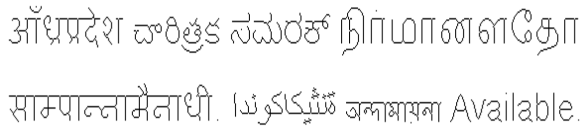
(a) Input Image



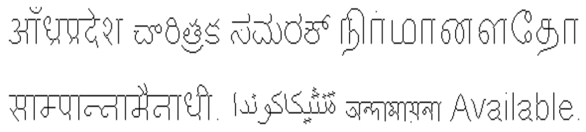
(b) ZS Algorithm



(c) LW Algorithm



(d) KNP Algorithm



(e) Proposed Algorithm

Figure 9. Thinning Results for Image consist of different Indic language characters 594X113(9183)

Table-1 Performance Comparison for Image consist of different Indic language characters shown in figure 9.

Characteristic	Algorithms			
	ZS	LW	KNP	Proposed
Object Points	9183	9183	9183	9183
Skeletal points	4078	4063	3075	3072
Thinning Ratio	66.46	62.7	66.48	66.58
Thinness	99.959	99.948	99.997	99.998
Execution Time	94ms	172ms	94ms	78ms

The results obtained by proposed algorithm for different indic language characters shown in figure 9(a) of sizes 594x113 are shown in table-1. The number of skeletal points, object points, thinness, and thinning ratio along with the time taken to produce the output skeletons for theses images are summarized in the table -1.

6. CONCLUSION

We have proposed an order independent parallel thinning algorithm. Implementation of this algorithm has been carried out for different kinds of images like printed and hand written images. We have evaluated thinning algorithm in terms of thinning time, thinning ratio, excessive erosion, connectivity, endpoint preservation, and visual quality. Results indicate that the proposed algorithm is very efficient and effective. The robustness of the proposed thinning algorithm has been established across heterogeneous image examples.

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