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Thinning of Binary Images Using Neural Network Based System

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Abstract*— Image thinning plays a very significant task in analysis of images and also in applications of pattern recognition. Thinning reduces any thick digital object in an image to a thin one. It is the most commonly employed pre- processing methods for analyzing any digital image. There are numerous thinning algorithms available in the literature. In this paper, we have proposed different neural network based systems for thinning of binary images and thus generating skeletons. We have presented back propagation neural network based systems that implement thinning algorithms such as ZS thinning algorithm and hybrid thinning algorithm. The parameters chosen for evaluation of algorithms are thinning rate, mean square error (MSE) and peak signal to noise ratio (PSNR).

***Index Terms*— Parallel Thinning Algorithms, Neural Network, Thinning rate, Zhang and Suen Thinning Algorithm.**

I. INTRODUCTION

For analysing any type of image, the most commonly used pre-processing method is thinning. Thinning performs the function of reducing any object to the least size required for the processing of that object. It basically aims at reducing a thick pattern into a thin one. The output image as a result of thinning is known as skeleton. A binary image is composed of foreground and background pixels. So, thinning deletes the chosen foreground pixels from the image while preserving the topology of the image. The concept of skeleton was given in 1962 by Blum [1]. This concept was based on grass fire. He explained that if we consider a field of grass as an object and set its border on fire then the fire will begin spreading inside the field and then the fire will vanish when the fire fronts will meet and this meeting point form the skeleton of that object. An example of a thinning of an alphabet is shown in Fig. 1.

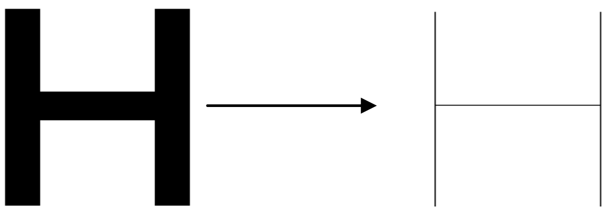

Fig. 1: Thinning of alphabet 'H'

Thinning of an image is very useful in the following ways:

• When an image is thinned, the quantity of data to transmitted over network or to be processed is reduced

• Also, the speed of analysis of a thinned object is increased

• Automatic analysis of shape of thinned image can be done much easily

• When an image is thinned, then the not so important features and the image noise can be reduced

Thinning has been useful in a variety of applications like analysis of medical images [2] [3], text and handwriting recognition and analysis, bubble chamber negatives [4] (a device for viewing microscopic particles), biometric authentication, fingerprint classification, signature verification and printed circuit boards. This broad range of applications depicts the importance of converting thick objects to thin line images.

Thinning algorithms are broadly categorized into two classes as iterative thinning algorithms and non-iterative thinning algorithms. This is shown in Fig. 2.

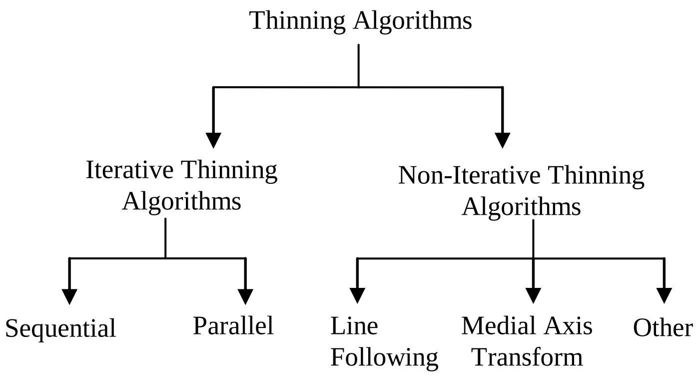

Fig. 2: Categorization of Thinning Algorithms

Iterative thinning algorithms process every pixel and then remove layers of pixels along the edges of the image until a skeleton is produced [5]. These algorithms are further categorized as sequential and parallel thinning algorithms based on the way the pixels are examined [6].

In a sequential algorithm, the unwanted pixels are removed in identifying the desired pixels in every iteration. In a parallel algorithm, the whole unwanted pixels are erased after identifying all the wanted pixels. These parallel algorithms are further classified into three categories as directional approach, sub-field approach and the fully parallel approach. In directional approach, each iteration is broken down into several sub-iterations and thinning is done on the basis of directions (North, West, East, South). All the simple pixels belonging to the similar direction are removed in a parallel manner. In the subfield approach a pattern is broken down into sub-fields based on some condition and in this way the simple pixels belonging to the same sub-field are removed in

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parallel. There is no sub-iteration or subfield in the case of fully parallel approach and it uses the same thinning operator for every iteration.

The non-iterative thinning algorithms do not examine each pixel. They are faster than iterative algorithms but the results produced are not always accurate. Some popular methods for this are medial axis transform, distance transform and centerline determination by line following.

For a thinning algorithm to be effective, it should possess some properties. Following are the properties that a good thinning algorithm should have

- Skeleton produced should be of unit thickness
- Topological and geometric properties of the image should be preserved which means that connectivity should be preserved and there should not be any extra end points
- It should be rotation invariant i.e. the skeleton produced should be same no matter in which way the original image is being rotated
- No excessive erosion should take place
- It should be very efficient and execute as fast as possible

The remaining paper is arranged as follows: the ZS algorithm for image thinning is given in section 2. Section 3 explains the hybrid thinning algorithm. Section 4 presents the proposed neural network based systems using ZS and Hybrid thinning algorithm with back propagation as learning algorithm. The results are shown in section 5 and finally, the conclusion is presented in section 6.

II. ZS THINNING ALGORITHM

This algorithm is proposed by Zhang and Suen in 1984 [7]. It a parallel thinning algorithm and uses a 3 x 3 window. This 3 x 3 window is shown in Fig. 3. It is based on directional approach and each iteration is divided into two sub-iterations. One iteration is based on removing the south-east boundary points and the north-west corner points and the second iteration is based on removing the north-west boundary points and the south-east corner points. It aims at deleting all the contour pixels, leaving the ones that are part of the skeleton.

p_9 (i-1 , j-1)	p_2 (i-1 , j)	p_3 (i-1 , j+1)
p_8 (i , j-1)	p_1 (i , j)	p_4 (i , j+1)
p_7 (i+1 , j-1)	p_6 (i+1 , j)	p_5 (i+1 , j+1)

Fig. 3: The nine pixels in a 3 x 3 mask [7]

In the first sub-iteration, the contour pixel p1 is removed if the conditions listed below are satisfied.

Sub-iteration 1:

(1) $2 \leq B(p1) \leq 6$ where B(p1) gives the number of neighbours of p1 which are not zero

(2) A(p1) = 1 where A(p1) defines the number of transitions from 0-1 in the neighborhood of p1 along the ordered set as defined in the 3 x 3 window

(3) p2 * p4 * p6 = 0

(4) p4 * p6 * p8 = 0

The conditions (3) and (4) state that if p1 is deleted then it means that p1 is a south or east boundary pixel or a north-west corner pixel i.e. p4 = 0 or p6 = 0 or both p2 and p8 are equal to zero.

In the second sub-iteration, the contour pixel p1 is removed if the conditions listed below are satisfied.

Sub-iteration 2:

(1) $2 \leq B(p1) \leq 6$ where B(p1) gives the number of neighbours of p1 which are not zero

(2) A(p1) = 1 where A(p1) defines the number of transitions from 0-1 in the neighborhood of p1 along the ordered set as defined in the 3 x 3 window

(3) p2 * p4 * p8 = 0

(4) p2 * p6 * p8 = 0

The conditions (3) and (4) state that if p1 is deleted then it means that p1 is a north or west boundary pixel or a south-east corner pixel i.e. p2 = 0 or p8 = 0 or both p4 and p6 are equal to zero.

The iterations keep on executing till no more pixels can be deleted. But there are some problems in ZS thinning algorithm. In case of 2 x 2 square pattern, loss of connectivity occurs because of disappearance of the pattern and thus the topological property is not preserved. Also, the skeleton produced is not of unit thickness. It also faces the problem of excessive erosion of diagonal lines.

III. HYBRID THINNING ALGORITHM

It is proposed by Lynda Ben Boudaoud, Abderrahmane Sider and Abdelkamel Tari in 2015 [5]. It solves the problems of ZS thinning algorithm and produces better skeletons. This thinning algorithm is based on a combination of directional approach of ZS thinning algorithm and the sub-field approach. The sub-field approach divided a pattern into two sub-fields and the two sub-fields are defined on the basis of parity of pixels. The first sub-field is composed of the set of odd pixels and the second one consists of the set of even pixels.

In the first sub-iteration, the contour pixel p1 is removed if the conditions listed below are satisfied.

Sub-iteration 1:

(1) (i + j) mod2 = 0 which defines that this iteration consists of even pixels

(2) C(p1) = 1 which means that p1 is a simple pixel and its removal will not disconnect the object

(3) $2 \leq B(p1) \leq 7$ where B(p1) gives the number of neighbours of p1 which are not zero and it lies between 2 and 7 which means that a bigger set of border points are considered here than the ZS algorithm

(4) p2 * p4 * p6 = 0

(5) p4 * p6 * p8 = 0

In the second sub-iteration, the contour pixel p1 is removed if the conditions listed below are satisfied.

Sub-iteration 2:

(1) (i + j)mod2 ≠ 0 which defines that this iteration consists of odd pixels

(2) C(p1) = 1 which means that p1 is a simple pixel and its removal will not disconnect the object

(3) 2 ≤ B(p1) ≤ 7 where B(p1) gives the number of neighbours of p1 which are not zero and it lies between 2 and 7 which means that a bigger set of border points are considered here than the ZS algorithm

(4) p2 * p4 * p8 = 0

(5) p2 * p6 * p8 = 0

The iterations keep on executing till no more pixels can be deleted.

IV. NEURAL NETWORK BASED SYSTEMS

ZS thinning algorithm is the most commonly used algorithm for image thinning. But when the thinning algorithms are applied for image thinning, some pixels cannot be processed and thus the efficiency of the algorithm is reduced. Thus for this purpose neural networks are used. In this paper, we have proposed neural network based approaches for image thinning. We have proposed two neural network based systems, one is neural network based system using ZS thinning algorithm and the other is neural network based system using hybrid thinning algorithm. Both these algorithms use back propagation as the learning algorithm. Firstly, both the neural networks are trained and also the initial network parameters are determined.

The proposed algorithm of neural network based system using ZS thinning algorithm is given below:

Algorithm 1

Input: Binary image

Output: Binary Image

Step 1: Consider a set of input images for the system

Step 2: Determine the neural network factors

(a) Number of input layers

(b) Number of hidden layers

(c) Number of output layers

(d) Learning rate

(e) Error criteria

(f) Initial weights

Step 3: Train the neural network using back propagation with ZS as thinning algorithm while propagating from input layer to hidden layer and then hidden layer to output layer and then adjusting the weights and calculating the error at each neuron

Step 4: Simulate the network

Step 5: If the image is thinned Display the thinned image else

Again feed it to the network.

The proposed algorithm of neural network based system using hybrid thinning algorithm is given below:

Algorithm 2

Input: Binary image

Output: Binary Image

Step 1: Consider a set of input images for the system

Step 2: Determine the neural network factors

(a) Number of input layers

(b) Number of hidden layers

(c) Number of output layers

(d) Learning rate

(e) Error criteria

(f) Initial weights

Step 3: Train the neural network using back propagation with hybird thinning algorithm while propagating from input layer to hidden layer and then hidden layer to output layer and then adjusting the weights and calculating the error at each neuron

Step 4: Simulate the network

Step 5: If the image is thinned Display the thinned image else

Again feed it to the network.

Both the proposed algorithms accepts input image as binary image because all the thinning algorithms works only on binary images. However, if colored images are to be thinned then they have to be firstly converted to binary image and then thinning can be performed. In case of neural network based systems for thinning, firstly the network parameters are to be evaluated. The network parameters include number of input layers, output layers and hidden layers,

V. IMPLEMENTATION AND RESULTS

For implementation purpose, 10 sample images are taken as input images. Then the network parameters are evaluated. The number of input and output nodes is determined depending upon the size of the image. The number of hidden nodes is chosen as 2 and the initial weights are set to 0.5. The input nodes are connected to nodes of hidden layer and these are further linked to output nodes. Also the network is trained with the training data. The error criterion is set to 0.02 for termination and the learning rate is set to 0.08. The set of input images with description is shown in Table 1. The input images considered here for implementation purpose are not taken from any standard database. Also, the input images are not shown here in their actual size, they are shown in small size for reference purpose only. After training the neural network based systems, the outputs generated are shown in Fig. 4.

Table 1: Input images

Input Images	Image Name	Image Format	Dimensions	Size (Kb)
	Image 1	.bmp	173 x 175	31. 1

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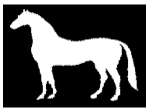
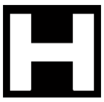
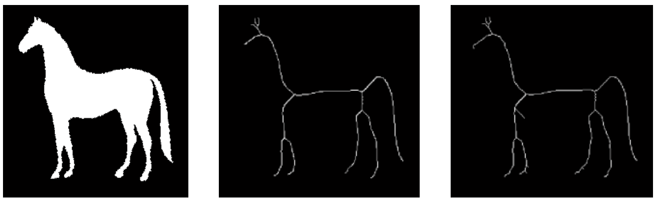
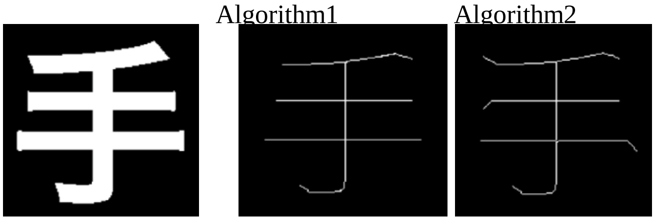
	Image 2	.bmp	216 x 101	22.3
	Image 3	.bmp	339 x 336	112
	Image 4	.bmp	220 x 229	50.2
	Image 5	.bmp	254 x 223	56.8
	Image 6	.bmp	220 x 220	48.3
	Image 7	.bmp	295 x 268	78.5
	Image 8	.bmp	237 x 213	50.9
	Image 9	.bmp	254 x 298	75.5
	Image 10	.bmp	309 x 344	105



Input Image　Output of Proposed Algorithm1　Output of Proposed Algorithm2



Input Image　Output of Proposed Algorithm1　Output of Proposed Algorithm2

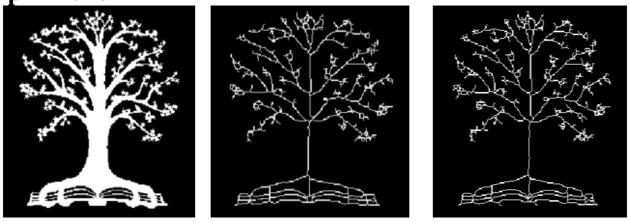


Fig. 4: Resultant skeletons for proposed algorithms

The parameters chosen for evaluation of the algorithms are thinning rate, mean square error (MSE) and the peak signal to noise ratio (PSNR). The performance evaluation of neural network based system using ZS thinning algorithm and hybrid thinning algorithm with back propagation as learning algorithm is shown in Table 2 and Table 3 respectively.

Table 2: Performance evaluation of neural network based system using ZS thinning algorithm with back propagation as learning algorithm

Input Images	Thinning Rate	Mean Square Error (MSE)	Peak Signal to Noise Ratio (PSNR)
Image 1	0.82	123.25	27.26
Image 2	0.83	116.53	27.50
Image 3	0.74	111.25	27.70
Image 4	0.51	109.97	27.75
Image 5	0.48	98.39	28.24
Image 6	0.47	100.11	28.16
Image 7	0.63	119.03	27.41
Image 8	0.48	97.53	28.27
Image 9	0.49	99.13	28.20
Image 10	0.51	99.10	27.21

Table 3: Performance evaluation of neural network based system using hybrid thinning algorithm with back propagation as learning algorithm.

Input Images	Thinning Rate	Mean Square Error (MSE)	Peak Signal to Noise Ratio (PSNR)
Image 1	0.82	84.14	28.91
Image 2	0.83	80.75	29.09
Image 3	0.74	74.83	29.42
Image 4	0.51	73.38	29.51

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Image 5	0.48	66.14	29.96
Image 6	0.47	67.51	29.87
Image 7	0.63	79.92	29.14
Image 8	0.48	65.64	29.99
Image 9	0.49	66.95	29.91
Image 10	0.51	65.35	30.01

It is shown from the Table 2 and Table 3 that the values of thinning rate are the same. This was shown in [5] where the results of ZS thinning algorithm and hybrid thinning algorithm are compared. The hybrid thinning algorithm was proposed to overcome the shortcomings of ZS thinning algorithm but it does not improve the thinning rate to a great extent. The values of thinning rate remain almost the same. So same is the case as in case of the proposed neural network based system using ZS thinning algorithm and hybrid thinning algorithm. The values of mean square error is less in case of neural network based system using hybrid thinning algorithm and the values of peak signal to noise ratio are better in case of neural network based system using hybrid thinning algorithm as compared to neural network based system using ZS thinning algorithm. A comparison of the proposed neural network based systems using ZS thinning algorithm with the existing ZS thinning algorithm is given in Table 4. Also a comparison of the proposed neural network based systems using hybrid thinning algorithm with the existing hybrid thinning algorithm is given in Table 5.

Table 4: Comparative study of ZS thinning algorithm and the neural network based system using ZS thinning algorithm

Images	Mean Square Error (MSE)		Peak Signal to Noise Ratio (PSNR)	
	ZS Thinning Algorithm	Proposed Algorithm 1	ZS Thinning Algorithm	Proposed Algorithm 1
Image 1	6861.65	123.25	9.80	27.26
Image 2	4413.96	116.53	11.72	27.50
Image 3	1173.05	111.25	17.47	27.70
Image 4	111.75	109.97	27.68	27.75
Image 5	98.32	98.39	28.24	28.24
Image 6	99.66	100.11	28.18	28.16
Image 7	125.71	119.03	27.17	27.41
Image 8	97.55	97.53	28.27	28.27
Image 9	98.94	99.13	28.21	28.20
Image 10	98.92	99.10	28.21	27.21

Table 5: Comparative study of hybrid thinning algorithm and the neural network based system using hybrid thinning algorithm

Images	Mean Square Error (MSE)		Peak Signal to Noise Ratio (PSNR)	
	Hybird Thinning Algorithm	Proposed Algorithm 2	Hybird Thinning Algorithm	Proposed Algorithm 2
Image 1	6833.77	84.14	9.82	28.91
Image 2	4372.10	80.75	11.76	29.09
Image 3	1136.08	74.83	17.61	29.42
Image 4	73.26	73.38	29.52	29.51
Image 5	65.46	66.14	30.00	29.96
Image 6	69.28	67.51	29.76	29.87
Image 7	85.23	79.92	28.86	29.14
Image 8	65.03	65.64	30.03	29.99
Image 9	66.31	66.95	29.95	29.91
Image 10	65.34	65.35	30.01	30.01

From Table 4 and Table 5 it is shown that the values of MSE have decreased and also the values of PSNR has increased in case of the proposed algorithms as compared to the existing algorithms. So the results show that the algorithms proposed here are better than the existing ZS and hybrid thinning algorithms. This is also graphically shown in Fig 5 and Fig 6.

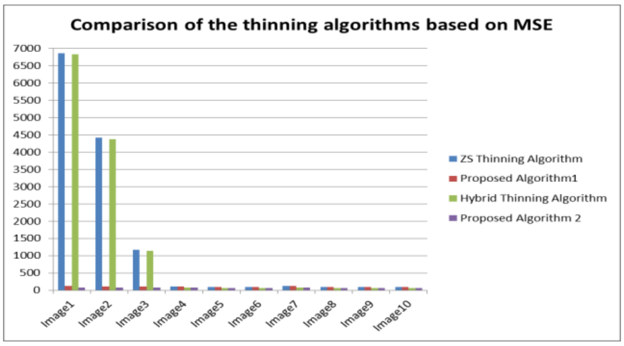

Fig 5: Comparison of the thinning algorithms based on MSE

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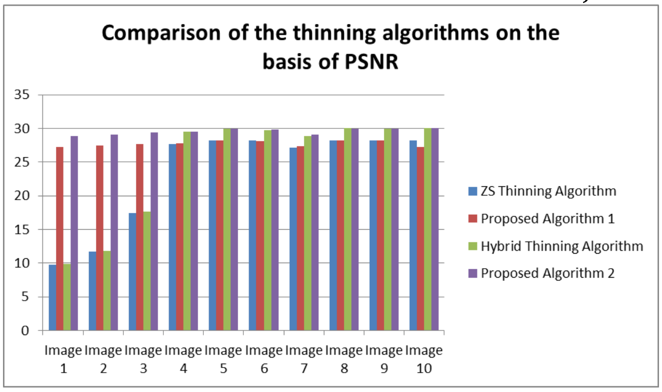

Fig 6: Comparison of the thinning algorithms based on PSNR

VI. CONCLUSION AND FUTURE SCOPE

In this paper, two algorithms are proposed. One is a neural network based system using ZS thinning algorithm and the other algorithm is a neural network based system using hybrid thinning algorithm. Both these algorithms use back propagation as learning algorithm. Results show that better skeletons are produced in case of neural network based system using ZS thinning algorithm. In case of neural network based system using hybrid thinning algorithm spurious branches are produced. Also it is shown that the values of thinning rate for both the proposed algorithms are the same. The main aim is to reduce the error produced and to increase the PSNR values. The results show that the values of MSE are decreased when the proposed algorithms are compared with the existing algorithms that are discussed here. Also the values of PSNR have increased when proposed algorithms are compared with the existing algorithms that are discussed here. Thus it can be deduced that the proposed algorithms i.e. neural network based systems using ZS and hybrid thinning algorithm with back propagation as learning algorithm produces better results than the existing ZS and hybrid thinning algorithm.

In future, other neural networks can also be used for thinning of binary images. Moreover, it can be tested on other datasets. Different parameters can also be considered for the evaluating the performance of the algorithms.

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