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1

Vessel detection in retinal images using Radon transform and genetic algorithm

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Abstract— *We propose a novel algorithm for vessel detection in retinal images. The proposed algorithm incorporates Radon Transform(RT) and Genetic Algorithm(GA) to detect vessels. We use RT because vessels could be approximated accurately by sets of lines. Since retinal images contain vessels of different size and width RT is performed locally. The local RT has parameters that should be set manually or automatically.We use GA to optimize the parameters of RT automatically. Our algorithm has been evaluated and compared with a similar algorithm using a standard dataset. The results show improvements in vessel detection.*

Keywords- Radon transform, Genetic algorithm, vessel detection, retinal images

1. Introduction

The study of vessel status is a common approach in medical diagnosis. In this study we tend to measure the width,color, tortuosity and abnormal branching of vessels. When the number of vessels in an image is large, or when a large number of images is acquired, manual extraction of vessel information becomes tedious or even impossible.

One of the diseases that vessels play a significant role in it's treatment is diabetic retinopathy. This disease is caused by diabetes. Diabetic retinopathy causes damage to the retinal vessels of eyes. This disease may lead to complete blindness. Diabetes is a disease that affects about 5.5% of the population worldwide. Almost 10% of all diabete patients have diabetic retinopathy too. Since this type of blindness can be prevented with treatment at an early stage, the WHO advises yearly ocular screening of patients. Automation will facilitate this screening. One of the automation done is vessel detection [1].

Vessel detection in retinal images is a well studied problem in computer vision and image processing. The previous algorithms could be categorized into four main classes. 1-model based , 2-tracking based,3-pattern recognition based,4-combinational methods. In model based methods, a model is considered for vessels and using this model we extract the vessels[2]. In tracking based methods the vessels are tracked. These methods are comprised of two steps which are specifying the vessel start points and tracking them[3]. In pattern recognition methods one approach is supervised classification. In this approach there are two main steps :1-feature extraction(vessels) ,2-classification[4,5].

We propose a new algorithm for vessel detection in retinal images. This algorithm is based on Radon Transform(RT) and genetic algorithm. We use RT because vessels could be approximated by a set of lines and RT is powerful for line detection[6]. Besides this genetic algorithm is used to optimize the parameters of RT. Since a retinal images has images with different size, orientation and width, RT is executed locally on the image.

The paper is organized as follows, section 2 explains the preprocessing method, in section 3 the algorithm is presented, section 4 explains the post processing method. In section 5 the experimental results are detailed and section 6 concludes the paper.

2. Preprocessing

Retinal images usually have low contrast therefore they should be first preprocessed for contrast enhancement. The algorithm used for this preprocessing is histogram equalization with limited contrast[10]. This algorithm starts with enhancing the contrast of equal sized regions after that bilinear interpolation is used to combine these regions and eliminate the false boundaries created (Figure 1).
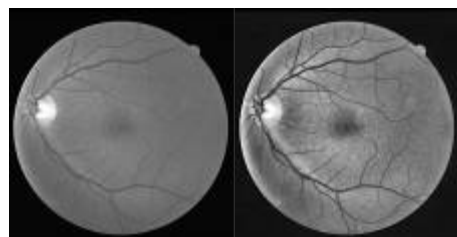
Figure 1.   Left image is the initial image,right image is the enhanced image

3. Algorithm

The proposed algorithm is a combination of Radon Transform(RT) and Genetic Algorithm(GA). The reson we use RT is that vessels are linear structures and could be accurately approximated by lines. On the other hand RT is a powerful line detector therefore it is suitable for vessel detection. Due to the existence of vessels with different size and width RT is performed locally. Since the proposed RT has same parameters, we use GA to optimize them.

The proposed algorithm has 6 steps that are listed below:

1- Scan the image with RT using a circular mask

2- Determine the maximum responses in each mask

3- Determine line validation coefficient

4- Determine line width

5- Threshold high response lines

6- Threshold to eliminate non vessel points

In the following sections we will explain the algorithm steps with more detail.

3.1 Local Radon transform using circular mask

Radon Transform(RT), transfers a function to a line parameter domain. To achieve this, RT computes the function's integral or sum on a set of lines. The RT of a function g(x,y) is

$$\check{g}(p,\tau) = \int_{-\infty}^{+\infty} g(x, px + \tau)dx \tag{1}$$

In equation (1) p is the slope of the lines and τ is the offset of the lines.

An image is a two dimensional signal therefore we could use RT to detect lines in images. If we input the whole image as a signal to RT, it would detect lines going through the whole image. Since a retinal image contains vessels with different size and width this approach is not appropriate. Therefore we perform RT for small regions to detect small lines. In other words we use local RT[7,8,9].

To perform RT locally we should use filters or masks. Here we use circular masks. The reason we use circular masks is that if we use square masks RT may produce unreal peaks at the lines moving across the square mask's diameters, causing to have false lines detected. In circular masks all of the lines moving across the center point have the same size so we wouldn't have false detected lines.

Before we perform RT on the circular mask we invert the gray levels of the image under the mask so that the vessels have lighter gray levels than background. This issue causes to

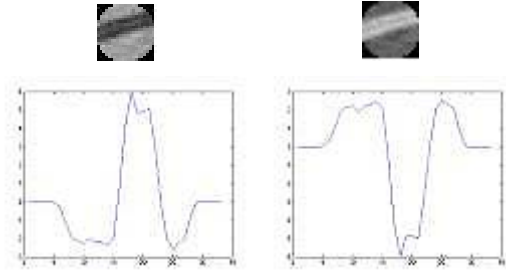deal with maximum coefficients instead of minimum coefficients(Figure 2).

Figure 2.   Retinal images under circular mask and their corresponding Radon Transform

Another important issue is the step of the mask. In order to have a smooth line detection we move the circular mask with small steps. The smaller the steps the more the detected lines.

3.2 Determine the maximum response in each mask

In this step the highest coefficient of the RT in each region of the image is determined. This coefficient specifies the degree and the coefficient of the best line in the circular mask. To make the results robust to contrast changes, the coefficients of the lines vertical to the detected line are subtracted from the coefficients of the detected line and the lines that have the same degrees with it.

3.3 Determine line validation coefficient

In this step the validation coefficient is determined to be able to remove unwanted lines. This coefficient is determined using the following relation

$$\left. (\text{max radon coef})^2 \middle/ \text{average radon coef} \right. \tag{2}$$

In Table I we see some examples of the validation coefficient for certain regions of the image.

TABLE I.   LINE VALIDATION COEFFICIENT

Image regions		
Line validation coefficients	*3.47*	*8.91*

3.4 Determine line width

In order to determine the line width, we perform a thresholding on the coefficients of the lines that have the same degree with the best line detected.

TABLE II. LINE WIDTH OF A SAMPLE LINE

	Radon coefficient	Position of coefficient in matrix
Best line	*5.9452*	*18*
Best line before	*4.0912*	*17*
Best line after	*2.9417*	*22*

In MATLAB , RT returns a matrix in which the columns are line degrees and the rows specify the coefficients of lines with same degree. To determine the line width using the information given in Table II, we use the position of the best lines before and after the best lines detected and the line width is computed using the below equation.

$$LStrt = LStrt - fix(RR/2) + fix(R/2)$$
$$LEnd = LEnd - fix(RR/2) + fix(R/2)$$

(3)

In Equation (3) , R is the number of rows of the circular mask and RR is the number of lines with the same degree. The expression $-fix(RR/2) + fix(R/2)$ normalizes the results.

3.5 Thresholds for high response lines and eliminating non vessel points

In this step the lines with high responses are thresholded using a threshold obtained from GA. Besides this non-vessel points are eliminated from the mask using the detected line and the main image. To eliminate the non-vessel points we compute the average of the main image gray levels on the detected line and the background of the circular mask. Then we threshold non-vessel points using the below relation.

$$\text{(average of line points graylevel+average of non line points graylevel)}\big/ 2$$

(4)

Figure 3. Right image is the initial image and left image is the thresholded image

3.7 Genetic algorithm for parameter optimization

Genetic Algorithm(GA) is a suitable algorithm for optimization problems. This algorithm is an evolutionary, population based optimization. In this type of optimization a population of solutions is generated and then this population is evolved to optimal values using a fitness function[11].

There are two basic concepts in GA that are chromosomes and fitness function. Chromosomes represent the parameters we want to optimize and the fitness function is a function that specifies the fitness of a chromosome. This functions guides the evolutionary optimization process.

The proposed local RT has four parameters which are: mask size, line validation threshold, line width threshold,non vessel elimination threshold. Therefore each chromosome contains these four parameter values. The fitness function we use is the area under the ROC curve. The ROC curve specifies the relation between true positives and false positives. True positive and false positive are determined using the below equations

$$True\ positive\ rate = \frac{Number\ of\ true\ \det ected\ vessel\ pixels}{Number\ of\ all\ vessel\ pixels}$$

(5)

$$False\ positive\ rate = \frac{Number\ of\ false\ \det ected\ vessel\ pixels}{Number\ of\ all\ non\text{-}vessel\ pixels}$$

(6)

The genetic operators for selection,crossover and mutation are standard operations. In every GA the population of solutions should be initialized. Here we initialize the chromosomes using suitable ranges for each parameter.

4. Post processing

The proposed algorithm outputs some unwanted regions in the final image. These anomalies should be removed by post processing methods. To eliminate these regions we propose a three step process. First we perform a morphologic erosion operation with a square structure element with seven pixel size on the mask image so that when we multiply the mask in the image the boundaries are removed(Figure 4).
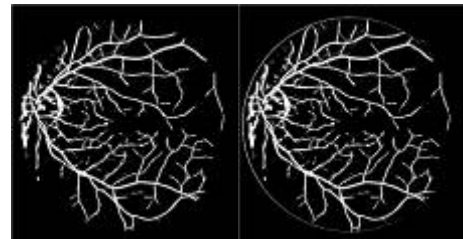

Figure 4. morphologic operation to remove boundaries

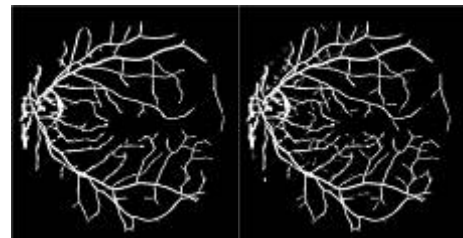Second we label the image and threshold the regions smaller than 100 pixels(Figure 5).

Figure 5. labeling and thresholding the image

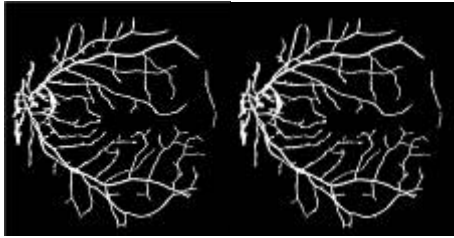At last we process the image with a mean filter(Figure 6).

Figure 6.   processing the image with a mean filter

With these three step of post processing almost all of the unwanted regions are eliminated.

4. Experimental results

The proposed algorithm was evaluated using the DRIVE database[12]. The experiments where performed using MATLAB 7 on a Pentium 4, 3GHz computer with 1GB RAM. Figure 7 shows a sample result. In Figure 8 we observe a the ROC curve for 20 images.
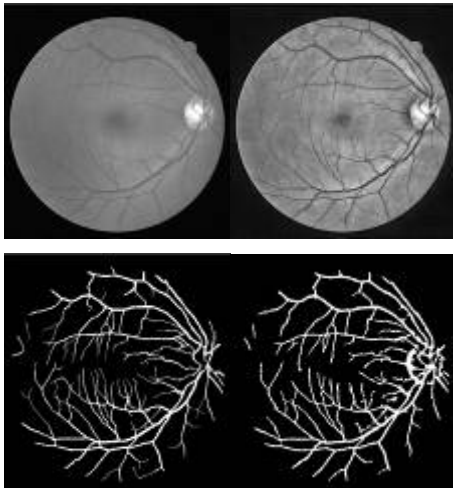

Figure 7.   first row, from left to right, main image preprocessed image.second row from left to right, manual image and algorithm result
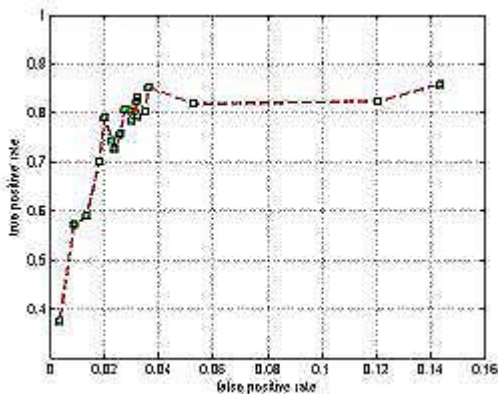

Figure 8.   ROC curve for 20 images from DRIVE database

The proposed algorithm was compared with Estabridis[7] in Table III. We compared our algorithm with Estabridis because this algorithm uses local Radon transform too. The main differences between our algorithm and Estabridis's algorithm are: 1- we use a single mask size opposed to [7] that uses multiple mask sizes for RT , 2- we use circular masks opposed to [7] that uses square masks, 3- the preprocessing and post processing procedures are different. As a whole our algorithm is simpler than [7].

The evaluation was done for the best results i.e. the best result of Estabridis was compared to our algorithm's best results.

TABLE III.   RESULT COMPARISON

Algorithm	Max TPR	FPR
Estabridis [7]	0.9200	0.0925
Our algorithm	0.8526	0.0317

As shown the proposed algorithm has better results compared to Estabridis's algorithm.

5. Conclusion

We proposed a new algorithm for vessel detection in retinal images. This algorithm is based on local Radon Transform(RT) and genetic algorithm. Since vessels could be approximated accurately with sets of lines, RT is an suitable algorithm for vessel detection. We performed RT locally because vessels have different size and widths and normal RT is not capable of detecting them. To perform RT locally we used circular masks which improved the results. The proposed local RT has some parameters. Genetic algorithm was used to optimize the parameters of local RT. We compared the proposed algorithm with a similar algorithm. The results show improvements.

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