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Graph Tracer – Simultaneous Vessel Identification to Detect the Retinal Crossover Points

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Abstract

Retinal vessel morphology is highly related with hypertension, coronary heart disease, and stroke and the changes in retinal vessel identification are considered as earlier diagnosis of the cardiovascular disease. However, there is a difficulty in quantifying changes in retinal vessels. Accurate measurement of vessel diameters on retinal images plays an important part in diagnosing cardiovascular diseases. In order to diagnose the diseases correctly, a method of vessel diameter measurement has been developed with a tracking technique for simultaneous identification of true vessels. Hence post processing step vascular structure segmentation is introduced for identifying the true vessels. So the vessel segment graph is constructed and formulated as the problem of finding optimal forest in the graph. Graph Tracer Algorithm computes the problem as constraint optimization problem (COP) to identify all the crossover points and segments. It represents the vessels in a binary tree and searches for an optimal forest. Thus simultaneous identification of vessels gives good diagnosis. Proposed work includes cup and OD segmentation for glaucoma assessment which prevents from visual loss with earlier treatment.

Keywords: Vascular structure, Crossover segments, Vessel Segment Graph, COP, Optimal Forest, Glaucoma detection Cup and OD Segmentation.

Introduction

Retinal images obtained using Adaptive Optics have the potential to facilitate early detection of retinal pathologies. The retina is the only location where blood vessels can be directly visualized. Increasing technology leading to the development of digital imaging systems over the past two decades has revolutionized fundal imaging. Whilst digital imaging does not still have the resolution of conventional photography, modern digital imaging systems offer very high-resolution images that are sufficient for most clinical scenarios. The retina is the only location where blood vessels can be directly visualized non-invasively in vivo.

The retina is a layered tissue lining the interior of the eye that enables the conversion of incoming light into a neural signal that is suitable for further processing in the visual cortex of the brain. A number of systemic diseases also affect the retina. Complications of such systemic diseases include diabetic retinopathy from diabetes, the second most common cause of blindness in the developed world, hypertensive retinopathy [5] from cardiovascular disease, and multiple sclerosis. Thus, on the one hand, the retina is vulnerable to organ-specific and systemic diseases, while on the other hand, imaging the retina allows diseases of the eye proper, as well as complications of diabetes, hypertension and other cardiovascular diseases, to be detected, diagnosed and managed [2][3][4].

Method

The method for finding all the true vessels includes a novel technique that performs the vessel segmentation using the fuzzy segmentation and uses the median filter to remove noise before segmentation. After segmentation it implements the graph tracer algorithm to identify true vessels by tracking all the crossover points in the vessel and applies CRAE and CRVE measurements to the six large arteries for cardio – vascular disease.

Graph Tracer - In this method vessels are arranged in a binary tree and it identifies all the crossovers and optimal forest [1] is searched from the binary tree

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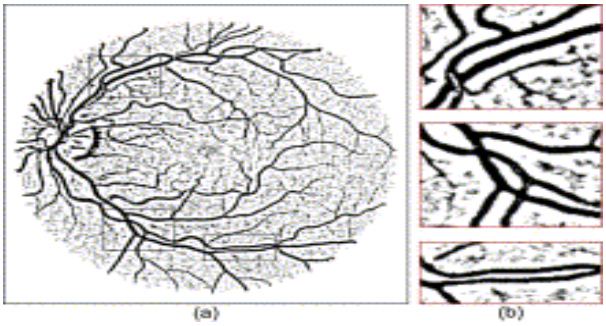

Fig. 1 Vessel Structure Extraction

Fuzzy Segmentation

Image segmentation is an important and challenging problem and a necessary first step in image analysis as well as in high-level image interpretation and understanding such as robot vision, object recognition, and medical imaging. In order to identify the true vessels this technique segments all true vessels from the retinal image and form a binary tree. It then extracts the vessels using the line image from the zone of interest as in Fig 2.

The FCM (Fuzzy C-Means) algorithm [6] attempts to partition a finite collection of n elements into a collection of c fuzzy clusters with respect to some given criterion. Given a finite set of data, the algorithm returns a list of c cluster centers and a partition matrix, where each element wij tells the degree to which element xi belongs to cluster cj. Like the k-means algorithm, the FCM aims to minimize an objective function. In fuzzy clustering, every point has a degree of belonging to clusters. Thus, points on the edge of a cluster may be in the cluster to a lesser degree than points in the center of cluster. The steps in fuzzy c-means algorithm are as follows: Choosing a number of clusters, Assigning randomly to each point, the coefficients for being in the clusters, Repeating the steps until the algorithm has converged (that is, the coefficients' change between two iterations is no more thanε, the given sensitivity threshold): Computing the centroid for each cluster, For each point, computing its coefficients of being in the clusters

Advantage: Fuzzy segmentation algorithm is the most popular method used in image segmentation because it has robust characteristics for ambiguity and can retain much more information than hard segmentation methods and the conventional fuzzy segmentation algorithm works well on most noise-free images.

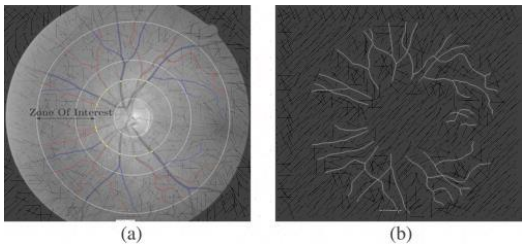

Fig. 2.a) Zone of interest b) Line Image

Graph Tracer

Graph Tracer Algorithm [1] aims to identify vessels from vessel segmentation and represented in binary trees for subsequent vessel measurements. It has two main steps:1) Identify crossovers 2) Search for the optimal forest set of vessel trees. Various Keys to identify crossovers are as follows.

A) Crossover segment: It occurs when two different vessels share a segment.

B) Crossover Point: Given the set of white pixels *P* in a line image, a junction $J \in JP$ is a crossover point if and only if the number of segments that are adjacent to *J* is than or equal to 4 cross (J) is true iff $|\{s \in SP\ |adj(s, J)\}| \geq 4$.

C) Directional Change Between Segments: The directional change between the two segments is given by the calculation, $\Delta D(sa,sb)=\cos{-1}(va \cdot vb)/(|va||vb|)$, where $\Delta D(sa,sb) \in [0^{\circ}, 180^{\circ}]$. When the directional change is minimal i.e., <30 degree it is considered as a bifurcation else it is considered as a crossover

Graph tracer algorithm models the segments as a segment graph and use constraint optimization to search for the best set of vessel trees from the graph. A binary tree is a natural representation of an actual blood vessel as it only bifurcates. Segment end points near the inner circle of the zone of interest are automatically identified as root pixels.

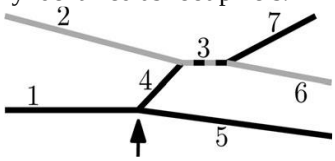

Fig. 3 Identification of crossover segments

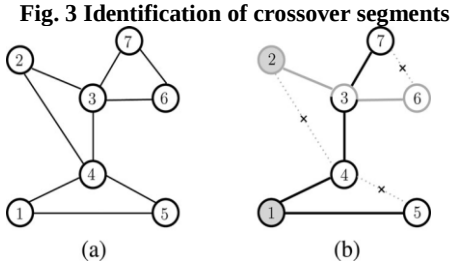

Fig. 4 Segment graph corresponding to the segments and forest of two binary trees

It formulates the problem of finding the optimal forest as a Constraint Optimization Problem (COP).

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Graph tracer algorithm as in Fig. 5 solves the COP by computing the minimum cost on the forest using the Lower bond cost. It performs as follows: 1) Checks whether the cost of the forest is minimum comparing the corresponding cost. 2) Updates the cost of the forest if it is minimal else goes to step 3. 3) If cost is not minimal it prunes the descendant forest. 4) It then finds the number of children and pushes the child nodes to the stack. 5) Once there are no children available it pops the tree and analyze the cost.

Proposed Work

Even though the graph tracer algorithm identifies vessels simultaneously there are certain limitations such as follows: It considers all the individual vessels for medical diagnosis, and it didn't consider glaucoma diagnosis which may result in wrong diagnosis of disease.

Hence in addition to finding the cardio–vascular diseases, a special technique will be introduced to find the glaucoma diseases that it helps in early detection of the eye related infections. It will use the special cup and OD (Optical Disk) segmentation using the cup boundary algorithm which uses the cup to disk ratio for assessment. Since enlargement of the cup with respect to OD is an important indicator of glaucoma progression, various parameters will be estimated and recorded to assess the glaucoma stage.

Algorithm GraphTracer
Input: $G_P = (S_P, E_P), S_{root}$
Output: F_{min}

1: $\mathcal{C} \leftarrow$ set of constraints (1)–(6) in COP formulation
2: $F[1..n] \leftarrow \langle$vessels of root nodes in $S_{root}\rangle$
3: $R[1..n] \leftarrow \langle root(F[T])\rangle$ for $T \in [1, n]$
4: $c_{min} \leftarrow \infty$; $F_{min} \leftarrow F[]$ # root node vessels
5: Trace$(1, F, R)$
6: **return** F_{min}

procedure Trace(i, F, R)
7: **if** $cost(F) < c_{min}$
$\wedge$ F cannot be grown without violating $\mathcal{C}$ **then**
8: $c_{min} \leftarrow cost(F)$; $F_{min} \leftarrow F$
9: **else if** $LB_{cost}(F) \leq c_{min}$ **then**
10: **for** $T = i$ to n **do**
11: **while** $R[T] \neq \emptyset$ **do**
12: $s_T \leftarrow$ Pop$(R[T])$
13: # valid children of s_T using forward checking
14: $N \leftarrow$ FindChildren(F, s_T) # left & right pairs
15: **for each** $(s_l, s_r) \in N$ **do**
16: $left(s_T) \leftarrow s_l$; $right(s_T) \leftarrow s_r$ # s_r may be $\emptyset$
17: Push$(R[T], s_l)$ # at least one child
18: **if** $s_r = \emptyset$ **then**
19: Trace(T, F, R)
20: **else**
21: Push$(R[T], s_r)$ # at most two
22: Trace(T, F, R)
23: Pop$(R[T])$ # pop s_r
24: **end if**
25: Pop$(R[T])$ # pop s_l
26: $left(s_T) \leftarrow \emptyset$; $right(s_T) \leftarrow \emptyset$
27: **end for**
28: **end while**
29: **end for**
30: **end if**

Fig. 5 Graph Tracer Algorithm

Experiments And Results

Crossover points are identified using parallel method by simultaneously tracing out the pixels as in Fig. 6.

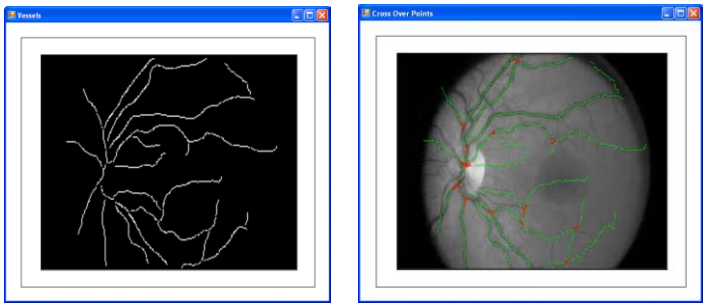

Fig.6 Crossover identification using parallel Method

According to the matched pixels method, it traces the crossover based on the crossover profile and marks the matched pixels as in Fig. 7.

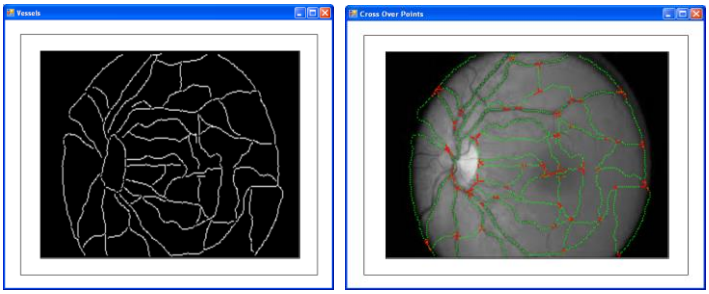

Fig.7 Crossover identification using matched pixels

The Traced co-ordinates for each crossover point is given by as follows in Fig.8.

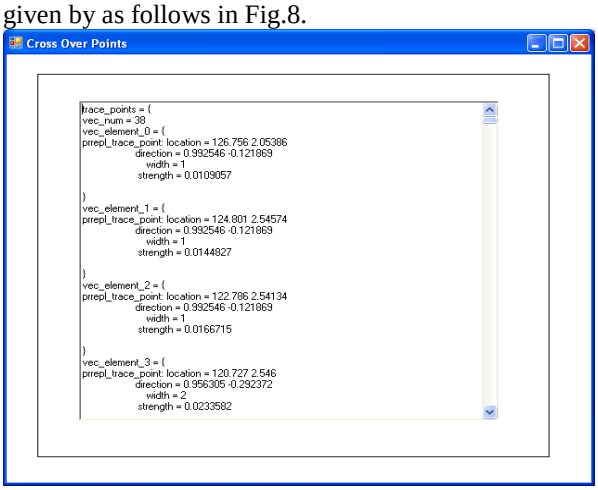

Fig. 8.a) Crossover co-ordinates – parallel method

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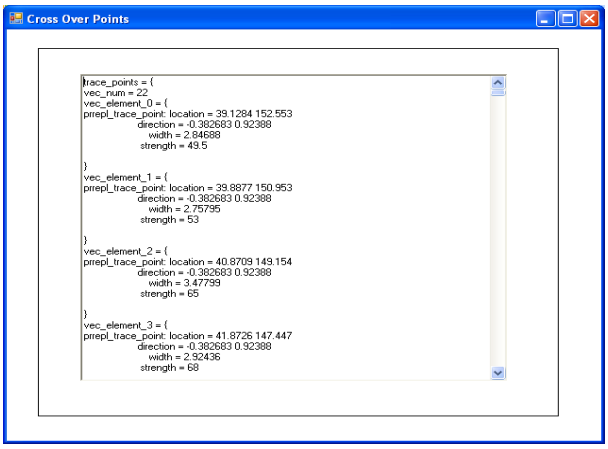

Fig. 8.a) Crossover co-ordinates – matched pixels method

Conclusion

Thus comparing the previous methods for vessel identification, the vessel identification using the cross over points gives better identification of the diseases. Graph tracer tracks the retinal vessels accurate and identifies all the crossover points. And it also implemented the post processing step to vessel segmentation and finds the optimal forest where each tree represents an individual vessel. Hence wrong diagnosis of crossovers can be overcome by using simultaneous identification of blood vessels from retina. The goal of the proposed method is to make easier the early detection of diseases related to the blood vessels of retina and it will be useful in early detection of the visual impairment.

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