Blood Vessel Tracking Technique for Optic Nerve Localisation for Field 1-3 Color Fundus Images

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Abstract

This paper considers the problem of locating the optic nerve center, a place where the blood vessel and nerve emanate. Our algorithm first identifies the main blood vessel, which is characterized by large width and dark red color, by using amplitude modified second-order Gaussian filter. The optic nerve center is then found by tracking along this main blood vessel to a convergence point. 80 ocular fundus images of various spatial resolutions with and without disease conditions were tested and a success rate of 86% for finding the optic nerve is achieved. It should be stressed that the by-product of this algorithm, i.e. the main blood vessel found, can be used to segment the entire blood vessel network by exploiting their interconnectivity.

Index Terms – Fundus image, optic nerve, retinal vessel, matched filter.

1. Introduction

Ophthalmologists have long used fundus photography to access the health condition of a person. There are seven standard fields in fundus imaging that are considered the gold standard. Field 1 is centered on the optic disk. Field 2 is centered on the macula. Field 3 is temporal to the macula, including the fovea at 3:00 or 9:00 o’clock position. These fields are of particular interest to clinicians, and consequently to our work here. Definitions of the other fields can be obtained in [9]-[10].

The optic disk and the macula are important parts of the retina. The optic disk is the only place where the central retinal artery and central retinal vein emanate [1], supplying the retina with oxygen and nutrients. The nerve cells, which transmit information to and from the brain, will also have to pass through the optic disk.

The retina is extremely susceptible to systemic and eye-related diseases, e.g. diabetes, glaucoma and age related diseases. If the pathology is near or on the optic disk, vision impairment is at a higher risk. Thus, locating the optic disk is of high importance, especially for diseased retinal images.
2. Related work

The optic disk has traditionally been identified as the largest area of pixels having the highest gray level in the image [3]. This bottom-up method works well in normal fundus images but will give a wrong location when large areas of exudates are present. This is simply due to the fact that the color and intensity of exudates are similar to that of the optic disk.

A top-down approach combined with bottom-up approach is used in [4] to locate the optic disk. A simple clustering method is first applied on the intensity image to locate the possible regions where the optic disk may appear. The optic disk is then identified based on the distance measured between the candidate areas and the model sub-image based on the principal component analysis (PCA) technique. This model-based method has been shown to be quite robust even with the presence of large areas of bright lesions. However, this method alone may not work best in all variations of fundus images.

A voting type method is used in [5] to find the location of the center of the optic disk. In this method, the entire vascular network is segmented first. Then, blood vessel segments are modeled as line segments. Each line segment is again modeled as a fuzzy segment, whose area contributes votes to its constituent pixels. The votes are summed at each pixel to produce an image map. The map is then blurred and thresholded to determine the strongest point of convergence, which is taken to be the center of the optic nerve. Based on twenty ocular fundus images, a success rate of 65% is reported.

In [6], the detection of optic nerve is based upon tracking the vessel network to a common starting point. Similarly, the entire vascular network has to be segmented first. The tracking process then uses the angles between vessels at branching points to identify the trunk. The result is shown for two images only and no quantitative results are provided.

Our work is different from previous methods in that we do not make use of any intensity characteristics of the optic disk nor do we need to segment out the vascular network before we find the center of the optic nerve. Instead, we identify the main blood vessel and then use it to locate the center of the optic nerve. This method is useful when the priority is to locate the optic disk and macula. The macula can be easily located once the optic disk is found [2].

3. Method

Our method to identify the center of the optic nerve consists of two parts. First, we identify the main blood vessel by using the amplitude modified second-order Gaussian filter [14]. Then we track along the main blood vessel to a convergence point. Section 3.1 describes the method used to identify the main blood vessel and section 3.2 describes the tracking algorithm.

3.1 Locating the Main Blood Vessel

3.1.1 Choosing Seed Points inside the Main Blood Vessel

In field 1, 2 and 3 fundus images, the optic disk is frequently found in the region 0.4 to 0.6 of the height of the image. Thus we can segment the image into 3 regions - the upper region from the top of the image to 0.6 of the height of the image, the middle region that is 0.4 to 0.6 of the height of the image and lower region which is from 0.4 of the height of the image to the bottom of the image. Analysis of main blood vessel will be carried out in the upper and lower region only. Also, the green plane is used since it has the highest contrast [13].

In the upper and lower region, horizontal lines were drawn across the image and the pixels along the lines are analysed. They are first convolved with kernels described in [14] and the matched filter response (MFR) for the line is noted. A 0° and 45° kernel with σ=2.5 is shown in Figure 3a and Figure3b respectively. This procedure is similar to that used by Collorec and Coatrieux [15] but it addresses the problem of finding local intensity minima using 1-D sliding window length Ns. A small Ns can detect thin vessels but will locate no quantitative results are provided.

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3.2 Tracking the Vessel Network to Convergence

In field 1, 2 and 3 fundus images, the optic disk is frequently found in the region 0.4 to 0.6 of the height of the image. Thus we can segment the image into 3 regions - the upper region from the top of the image to 0.6 of the height of the image, the middle region that is 0.4 to 0.6 of the height of the image and lower region which is from 0.4 of the height of the image to the bottom of the image. Analysis of main blood vessel will be carried out in the upper and lower region only. Also, the green plane is used since it has the highest contrast [13].
Figure 3: (a) A 0° kernel with $\sigma=2.5$. (b) A 45° kernel with $\sigma=2.5$. (c) Segments with MFR value more than 350 are marked with thick lines for better viewing.

Apart from blood vessels, edges of bright objects e.g. optic disk boundary and exudates boundaries, also gives high MFR values. To eliminate these false points, the left and right contrasts in these segments are detected. The contrast is defined as the difference between the maximum and minimum intensity values. Both contrasts must be above a threshold to be considered as points inside a blood vessel. A value of 15 is chosen in our case.

From the remaining candidate seed points, the one with the highest MFR value is the seed point for the line.

3.1.2 Tracking from Seed Points

From each seed point, the vessel is tracked in both forward and backward directions, along with obtaining the width of the vessel. The next point $(i^{k+1}, j^{k+1})$ is found from the current point $(i^k, j^k)$ using

\[
\begin{bmatrix}
  i^{k+1} \\
  j^{k+1}
\end{bmatrix} = \begin{bmatrix}
  8.\sin(\phi^k) \\
  8.\cos(\phi^k)
\end{bmatrix} \begin{bmatrix}
  i^k \\
  j^k
\end{bmatrix} + \begin{bmatrix}
  8.\sin(\phi^k) \\
  8.\cos(\phi^k)
\end{bmatrix} \begin{bmatrix}
  i^k \\
  j^k
\end{bmatrix} \text{ forward 1a)}
\]

and

\[
\begin{bmatrix}
  i^{k+1} \\
  j^{k+1}
\end{bmatrix} = \begin{bmatrix}
  8.\sin(\phi^k) \\
  8.\cos(\phi^k)
\end{bmatrix} \begin{bmatrix}
  i^k \\
  j^k
\end{bmatrix} - \begin{bmatrix}
  8.\sin(\phi^k) \\
  8.\cos(\phi^k)
\end{bmatrix} \begin{bmatrix}
  i^k \\
  j^k
\end{bmatrix} \text{ backward 1b)}
\]

and

\[
\phi^k = \begin{cases} 
  \phi(i^k, j^k), & \text{if } |\phi(i^k, j^k) - \phi^{k-1}| \leq \pi / 2 \\
  \phi(i^k, j^k) - \pi, & \text{if } |\phi(i^k, j^k) - \phi^{k-1}| > \pi / 2 
\end{cases} \text{ 2a)}
\]

where $\phi(i^k, j^k)$ is the vessel direction which can be found from the kernel with highest response.

A step size of 8 is chosen because the main blood vessel is generally not very tortuous and a large step size means faster tracking speed.

Due to digitizing error, the point $(i^{k+1}, j^{k+1})$ may not be in the center of the blood vessel. A search in a 5x5 neighborhood is performed and the highest MFR value is chosen to be $(i^{k+1}, j^{k+1})$. To determine if $(i^{k+1}, j^{k+1})$ is inside a vessel, the pixels in a 3x3 window are convolved with the kernels and the direction of the highest scoring kernel is noted. All the directions of the highest scoring kernels in this window must be similar as points inside a vessel should have similar directions. Furthermore, to ensure that tracking proceed along the same vessel, $\phi^k$ and $\phi^{k-1}$ must have similar direction. If any condition is violated, tracking stops.

If tracking proceeds for more than 5 iterations in the same direction, all its points are stored and measured for its width. The width is measured using the method described in [14], taking note that the length of the kernel is greater than the width. All points tracked from a seed point have the same unique label number. If tracking is less than 5 iterations, the points are not stored. This threshold is to prevent boundaries of optic disk and exudates to be labeled as vessel.

3.1.3 Choosing the Main Blood Vessel

From the measurements made during tracking, the width of the largest vessel can be found. The path with the most number of points with similar width is identified as the main blood vessel. A measure of similarity is taken to be 0.2 less than the maximum width. Figure 4 shows the main blood vessel being highlighted using this method.

Figure 4: The main blood vessel is highlighted

3.2 Tracking to Convergence

The starting points for tracking to convergence in both the upper and lower region are the points nearest to the middle region. From the starting points, the one in the upper region will track down while the one in the lower region will track up alternately. The tracking algorithm is similar to that detailed in section 3.1.2 except that for the upper region it is tracking in
backward direction while for the lower region it is tracking in forward direction, a step size of 4 is used for finer tracking, a search window of 3x3 is used for compensating digitization and there is only 1 iteration. A small step size is used here to prevent tracking from jumping to another vessel as the optic disk has a high density of blood vessels inside it.

Tracking from the upper and lower region proceeds alternately and independently until the stopping criteria described in section 3.1.2 are met. For instance, if tracking for the top region is stopped, the bottom region still continues until the stopping criteria are met or a convergence point is found. The convergence point is the midpoint between the upper and lower point if they are within a 30x30 neighborhood or if both are stopped before reaching this neighborhood, they must be within a 120x120 neighborhood. These windows are chosen after observing that the radius of optic disk is around 60 pixels for a 700x605 image.

Figure 5a shows the result of tracking to convergence point. As can be seen, there is no guarantee that the point will not track beyond the convergence point. Thus, an improved technique takes care of this problem. The new algorithm is outlined in Figure 6.

- From the two starting points, a midpoint is calculated. If the midpoint is above the midline, a line that is at a position half the height of the image, the upper point will track only and vice versa.
- If tracking for upper point is terminated, this condition will be overruled and the bottom point will track only and vice versa.
- When the distance between the two points in the x or y direction is less than 30 pixels, both points will track together.
- When the two points are inside a 30x30 neighborhood, or a 120x120 neighborhood if both are terminated early, the midpoint is the center of the optic nerve.
- The process is repeated until the optic nerve is found or deemed to be unidentifiable or a maximum number of iteration is reached.

Figure 5b shows the result of this improved tracking algorithm.

Figure 5: (a) Result of using the original tracking method. (b) Result of using the improved tracking control technique. Notice that it is nearer to the true optic nerve center.

Figure 6: Improved tracking control technique

4. Results

Our method was tested on 80 fundus images of resolution ranging from 250x184 to 700x605 and in disease and non-disease conditions. The center of the optic nerve is hand labeled by 2 observers who were briefed on how to identify the points. The optic nerve center is considered successfully identified if the convergence point is within the optic disk or is within 60 pixels from the mean point located by the observers, whichever is more appropriate for its spatial resolution.

Out of 80 images, the optic nerve was successfully located for 69 of them, giving a success rate of 86%. Table 1 shows the error mean and error standard deviation of the located optic nerve center using the algorithm when compared to the observers’ mean location. We can see that the located optic nerve center is close to the location that the observers labeled and is well within the optic disk, using the mean radius of the optic disk to be 60 pixels

<table>
<thead>
<tr>
<th>Image size</th>
<th>Error mean</th>
<th>Error standard deviation</th>
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<td>9.1</td>
</tr>
<tr>
<td>512x512</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larger than 512x512</td>
<td>22.8</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Table 1: Results of our experiment
5. Conclusion

We have presented a new way of locating the optic nerve center without using the intensity level properties. By first identifying the main blood vessel using amplitude modified second order Gaussian filter, we can then track along it to a convergence point. That convergence point is the optic nerve center.

Our method has an extra advantage in that the main blood vessel found can be further used to segment the vascular network, by using the connectivity property of blood vessels.

References


