Segmentation of Retinal Images Guided by the Wavelet Transform

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Abstract

Glaucoma is one of the major causes of preventable blindness in the world. It induces nerve damage to the optic nerve head (that region of the retina where nerve fibres and blood vessels pass through the eye) via increased pressure in the ocular fluid. It is presently detected either by regular inspection of the retina, measurement of the intraocular pressure (IOP) or by a loss of vision. It has been observed that nerve damage precedes the latter two events and that direct observation of the nerve head could therefore be the best method of detecting glaucoma, if the observations could be made reliably. This paper describes our work in isolating the optic nerve head in images of the retina: we describe previous attempts that have made using simple image processing techniques and the current multiresolution approaches we are taking, we present a sample of our initial results. Once the nerve head has been located, its shape will be quantified using measurements that have already been shown to be effective.

Introduction.

The neuroretinal rim forms the outer boundary of the optic nerve head: that region of the retina where blood vessels and nerve fibres pass out of the eye. It is normally a circular structure, but is known to change shape due to nerve damage in glaucoma. It has been suggested that the nerve damage occurs before the intraocular pressure (IOP) increases. Since measuring the IOP is the primary screening test for glaucoma, damage to the eye will have occurred by the time the disease is diagnosed. The progress of glaucoma and its treatment is assessed by further measurement of IOP and by changes in the shape of the neuroretinal rim. At present, the shape of the rim is assessed manually, either subjectively by direct inspection or by tracing it from photographs of the optic disk. Both of these methods have been shown to be unreliable [1].

In this project we are concerned with automatically locating the neuroretinal rim using a multiresolution algorithm based on the wavelet transform. In doing this we shall eventually provide ophthalmologists with an additional tool for diagnosing and assessing the treatment of glaucoma.

A second strand in this work is the investigation of multiresolution segmentation techniques. What may be termed classical image segmentation algorithms take a single resolution viewpoint: the data is captured and segmented at the same, highest possible, resolution. Whilst this is the resolution at which results are required, the approach results in non focused processing since effort is expended in examining regions that are clearly either object or background (and could be identified as such by other techniques) rather than concentrating on the more problematical boundary regions. Pyramid and hierarchical algorithms achieve focussed processing by firstly examining a low resolution version of the data and coarsely segmenting the image. The segmentation is progressively refined by increasing the resolution at which the data is examined until the original resolution is regained. We view the wavelet transform in this light, a wavelet transformed image will contain representations of the image at varying resolutions. This information may be used to initiate a segmentation and progressively refine the boundaries between object and background (cf. [2]). The algorithm is more efficient than the traditional technique as regions that may be clearly labelled are
identified early and excluded from further processing which concentrates on the boundary regions.

**Background.**

Automatically identifying the neuroretinal rim is not an easy task. The images are taken under low light conditions and are therefore noisy. (The data used in the present investigation was collected by attaching a video camera to the eyepiece of a Zeiss fundus camera. The retina was illuminated with a photographic flash and the video image grabbed. Cox and Wood [3] describe the instrumentation in more detail.) The structure itself is indistinct and partially obscured by blood vessels. In fact, if a simple edge detector is applied to these images it is the blood vessel boundaries that give the strongest response, the required features respond very weakly if at all. Figure 1 shows a normal retina, portions of the required boundaries are clearly visible.

A significant amount of work has been reported on attempts at automatically detecting the neuroretinal rim, though none has met with significant success. The earliest was by an ophthalmologic equipment manufacturer who simply thresholded an image of the optic disk. The thresholded region was approximated by an ellipse and thus characterised by the ellipse’s properties. Cox and Wood [3] presented a semi-automated method: an observer indicated extremal points on the boundary which were automatically connected by tracing along the boundary. They showed how important it was for the same observer to perform all of the measurements since the inter observer variability was similar to the difference between normal and abnormal classes [1]. Morris and Wood [4] initially presented a completely automatic method which traced between points on the boundary identified automatically by their grey level gradient properties. They have latterly returned to semi automated methods which are proving to be more reliable [5]. Lee and Brady [6], and Donnison and Morris [7] have both investigated using active contour (snake) methods to locate the boundary. Both sets of authors have highlighted the importance of pre-processing the images to emphasise the difference between retinal and optic disk regions of the image before searching for the boundary. Donnison and Morris appear to have had more success in their implementation, probably due to their formulation of the active contour.

Multiresolution methods have long been seen as an attractive method of segmenting images. From a theoretical viewpoint, they mimic the human visual system, pragmatically they allow us to make early decisions as to the approximate locations of image features and focus attention on just those areas for further processing. A number of approaches have been followed. Image pyramids [e.g. 8] are generated by progressively reducing the size of an image from the base (the original full resolution image) to the top (a single pixel whose value is the average grey value of the image). They seem to have been used most often in edge detection applications. Scale spaces [e.g. 9] may be generated by applying a feature detector at varying resolutions to the original image; a volume is generated: two axes coincide with the spatial axes of the original image, the third represents scale. As the scale is varied the size of the detected feature changes. In a typical application, Marr’s edge detector could be used [10], the scale parameter would equate to the $\sigma$ of this operator. The common theme in all of these approaches to segmentation is that information extracted at a lower resolution is used to guide the extraction of information at the next level of the hierarchy. In this project we are using the wavelet transform as a means of generating the hierarchical representation of the image data and thus to guide its segmentation.

**Materials and Methods.**

The wavelet transform generates an image which can be divided into four quadrants. Three represent horizontally and vertically oriented and corner features at some scale.
The fourth quadrant repeats this basic structure at a smaller scale. It is our intention to use this structure to guide the interpretation of the original image.

Suppressing the coefficients corresponding to small scale image features effectively enhances the gross image features we are seeking. But it does not allow their boundaries to be accurately delimited. Figure 2 shows a retinal image which has been filtered using the Daubechies wavelet, the fourth stage coefficients have been set to zero and the data inverse transformed. It is apparent that gross features of the image remain and small scale features (the blood vessels) have been removed. We have thus enhanced (portions of) the boundary between the optic nerve head and the retina and may therefore suggest the approximate location of this boundary. More importantly, we may suggest regions of the image that are definitely nerve head and regions that are definitely retina. The suggested boundary may be refined by considering the information that is regained by reinstating coefficients from lower stages of the transform. Ultimately we would use the information contained in the image at its original resolution.

![Figure 1. Original Fundus Camera Image.](image1.png)  ![Figure 2. Wavelet Filtered Image.](image2.png)

Having derived an algorithm for locating the neuroretinal rim, its shape will be characterised using measures known to be clinically relevant. Essentially these are measures of the vertical eccentricity of the structure, since it is known that nerve damage occurs most readily in these areas, which coincide with the blood vessels. We shall perform a retrospective study on data collected in previous work. This data consists of approximately 500 images collected from normal and abnormal classes. These will be analysed blind by one of the authors and the results validated by the other. If the results are satisfactory, we shall then perform a prospective study in conjunction with a local eye hospital. If these trials are successful we shall have developed a tool which could be used in the diagnosis of glaucoma, certainly in assessing its treatment.

**Conclusions.**

In this paper we have discussed the importance of quantifying the shape of the optic nerve head and described previous attempts at doing this. We have outlined the use of the wavelet transform in guiding the analysis of images of the retina, specifically to segment the optic disk from the retinal background. We have also described how we intend to validate the algorithm using clinical data. Finally, we have shown how we have progressed towards our goal of deriving a useful tool in the diagnosis and treatment of glaucoma.
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