Progress towards automated detection and characterization of the optic disc in glaucoma and diabetic retinopathy

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Abstract
The shape and appearance of the optic nerve head region are sensitive to changes associated with glaucoma and diabetes that may be otherwise asymptomatic. The changes can be diagnostic of the diseases, and tracking of the changes in sequential images can be used to assess treatment and the progress of the illness. At present, change detection and tracking are performed manually, which can be a cause of poor repeatability. We are concerned with developing automated techniques of generating quantitative descriptions of the retinal images that might be used in diagnosis and assessment. In this paper, we investigate the use of images that have been collected and stored remotely, as this will replicate capture and automated processing by outreach clinics. Normal and abnormal images were collected from a range of sources, to simulate the mass screening process. The images were processed using simple signal-processing methods and divided into two groups. Using a chi-squared test, the separation of normal and abnormal images using this test was found to be highly significant ($p < 0.05, n = 60$).

Keywords: Image processing, eye disease, screening

1. Introduction

The optic-nerve head is that area of the retina where nerve fibres and blood vessels pass through the sclera. It appears to consist of two areas: the cup and disc. The cup, as its name suggests, is a depression in the surface of the retina where the vessels and fibres pass through the sclera. Surrounding the cup is the disc. The two regions are coloured slightly differently to the surrounding retina and each other. In the normal eye, the cup’s diameter is in the region of one-third of the disc’s. Figure 1a shows an image of a normal nerve head; the nerve head has been elongated in the vertical direction by the imaging process. Blood vessels supplying the internal surface of the retina can be seen overlying the nerve head and partially obscuring its borders; this is a significant problem that must be overcome if automated methods of quantifying the structure are to be derived, it is particularly acute for the cup/disc border as the density of vessels is greater, and the contrast across the boundary is weaker. The disc/retina border is quite easily defined, although, as Cox et al. observed [1], experts fail to agree
on the border’s exact location. The cup/disc border is particularly indistinct and has not yet been successfully traced automatically.

The nerve head is sensitive to changes in intraocular pressure (IOP) that are associated with glaucoma and that may occur with no other symptoms. The changes can be diagnostic and must be tracked to monitor the progress of treatment. Likewise, there are changes in the appearance of the retinal surface that are associated with diabetic retinopathy that are also diagnostic and should also be tracked to allow the progress of the disease and treatment to be assessed. Currently, a clinician (or clinicians) performs the diagnosis, and uniform standards of assessment cannot be guaranteed [1]. Likewise, a clinician (or clinicians) performs the repeat examinations, and the repeatability of the assessments cannot be guaranteed. We are seeking methods of quantifying the optic disc objectively: first to identify groups of patients who have abnormal ocular appearances and should be further investigated; and second to track changes in the appearance of the retina. In this paper, we report on an investigation into methods of solving the former problem. We shall provide a brief overview of previous attempts at quantifying the optic nerve head, describe the data capture process that simulates a mass screening process, and then describe the algorithms used to analyse the images and present sample results. We conclude the paper by evaluating the algorithm and suggesting directions of further work.

2. Review

One of the symptoms of glaucoma is an increase in pressure within the eye as a result of blockage of the flow of aqueous humour, a watery fluid produced by the ciliary body. The increase in pressure damages the optic nerve that carries information from the retina to the brain. It is thought that raised IOP can compress blood vessels on the retinal surface, reducing blood flow and causing necrosis, or the raised pressure can physically force the nerve head through the sclera. In either case, the outcome is the same: tissue in the optic nerve head is necrotized, the cup is eroded, and there is loss of vision.

In most cases, the damage occurs asymptptomatically, i.e. before the patient notices any changes to their vision. Due to the nature of the damage, it is impossible to predict which region of the visual field will be affected. Furthermore, the damage is irreversible; treatment can only reduce or at best halt the advance of the disease. Visually, the damage is observed as a change in the relative areas of the optic disc and the cup within the disc. Figure 1a shows the

Figure 1. (a) Example of a normal optic disc. (b) Optic disc in a severe case of glaucoma.
normal optic-nerve head, and Figure 1b shows an image of a seriously affected optic-nerve head. The disc/retina boundary remains fixed, but the cup is enlarged in depth (which is not distinguishable in this image but can be observed stereoscopically or with real-time imaging) and area, and encroaches into the disc region. The ratio of the cup to disc areas is greatly increased. Blood vessels are displaced and damaged. In extreme cases, the blood vessels may even become detached from the retina. Estimating the cup-to-disc ratio is one of the major screening tests performed at regular eye examinations. It is estimated by visual inspection. We can hardly expect an accurate measurement; nor can we expect the measurement to be made consistently by one clinician over time or among a group of clinicians.

Diabetes mellitus is a disorder of carbohydrate metabolism characterized by dysfunctional production of insulin, and thereby elevated blood sugar levels. This leads to problems with different organs such as the eyes, kidneys, heart and cardiovascular system, and nerves. Untreated, diabetes mellitus can cause diabetic retinopathy (DR). Figure 2 illustrates some of the problems associated with diabetic retinopathy. Figure 2a illustrates the normal retina: in a colour image, the background tissue would appear orange and blood vessels a darker orange or red, and the optic nerve head is visible as a bright region at the centre of the image.

DR is divided into two types: non-proliferative (NPDR) and proliferative (PDR). NPDR occurs earlier and can cause the retinal vessels to enlarge, to become irregular in shape, and to develop small weak spots which in turn will leak blood and fluid into the retinal tissue (exudates). NPDR can develop into PDR which is characterized by neovascularization and possible rupture of the new vessels. Figures 2b and 2c illustrate the various stages of the disease. It is possible to classify the severity of the disease according to the lesions that are visible in the image. Retinopathy is one of the main causes of blindness in the working-age population [2].

To characterize the optic disc (and retina) and hence identify an affected retina, the optic disc and retinal vasculature could be identified: any remaining structures will therefore be due to lesions. Most authors do not attempt to characterize the lesion, as there is too much variability to ensure that this is done reliably; rather, an affected retina is flagged for manual inspection, and so one attempts to separate patients into low- and high-risk groups.

In previous work, the optic disc has been identified using the maximum variance as an indicator for its location [3], template matching followed by principal-component analysis (PCA) [4], measuring the strength of vessels and the attributes of the bright areas of the image [5], or identifying the origin of the vessel tree [6]. Colour morphology and dynamic contours (snake) in different colour spaces [7,8] and wavelet segmentation [9] have been used. Edge detection followed by curve fitting has also been used [10,11]. These techniques have report varying levels of success, but none has matched experts’ accuracies. Manual screening is

Figure 2. (a) Example of a normal retina. (b) Example of a retina affected by diabetes mellitus and showing many exudates. (c) Example of a retina affected by diabetes mellitus and showing neovascularization.
reported to detect diabetic retinopathy and glaucoma with sensitivities and specificities of 76% and 95% [12] and 71% and 94% [13].

3. Materials

The tools to be developed will be used in multiple clinics that are unlikely to have the same image-capture devices. To simulate this, our data were gathered from a range of sources. Diabetic retinopathy images were obtained at the Department of Optometry at UMIST, using a Topcon NW6S Non-Mydriatic Retinal Camera. These images were saved as 24-bit true-colour JPEG files. Images were taken with a field view of 45°. Glaucoma images were collected from Manchester Royal Eye Hospital; these images were also in JPEG format. Normal images and a second set of diabetic retinopathy images were downloaded from the STARE (STructured Analysis of the Retina) website [14].

All images were converted to a similar size, as close as possible to 512 × 512 pixels, given the constraints of scaling by an integral factor and retaining the images’ aspect ratios. Pixels were represented as 24-bit values. The scaled images were stored in JPEG format using the best quality settings, i.e. near lossless.

Although approximately 90 images were gathered, only 16 normal, 31 glaucoma, and 13 diabetic retinopathy images were suitable for processing. Of the other 30, some were blurred, and others did not contain the whole optic disc. Full-colour images were captured.

4. Methods

The green band of the images was processed as it was found that these images had the greatest contrast between the optic disc and the retinal tissue. To classify the stages properly, we would have to identify all the normal anatomy and be able to identify the lesions correctly. As mentioned above, this is not something we are yet attempting to do. Rather, we are reporting a simple method that separates normal vs. abnormal images.

First, the blood vessels in the image were suppressed by morphological methods (the closing operator). Then, we defined 24 radial vectors using the approximate centre of the optic disc as the origin. The image was resampled along these vectors to form a representation that was subsequently processed.

4.1. Optic-disc location and image resampling

An approximate location of the centre of the optic disc is required. The image was first enhanced using the Sobel operator and then thresholded using the local mean and variance to compute the threshold value. The remaining points were inputted to a circular Hough Transform, and the largest circle was found consistently to correspond to the optic disc. Figure 3a shows an image processed to suppress the vasculature, and Figure 3b shows the edge detected and thresholded image: linear artefacts due to the JPEG coding and the morphological operator are present, as is a cluster of points on the optic disc boundary. Figure 3c shows a portion of the Hough transform results, that is the votes cast for a circle of radius 76 pixels. The co-ordinates of the maximum entry indicates the origin of the circle with the most votes. Finally, Figure 3d shows the circle that was detected superimposed on the original image. The origin of the circle was used for the resampling vectors. We would not expect the circle identified by this transform to correspond exactly to the optic disc, not least because the disc is not perfectly circular. Nevertheless, it serves our purpose of identifying an origin for the resampling vectors that is near the optic disc centre.
Twenty-four uniformly distributed vectors were defined, starting at the optic-disc centre. The image was resampled at regular intervals along these using nearest-neighbour interpolation.

4.2. Processing resampled images

The resampled images were processed using the Lee filter [15] which suppresses small-scale variations while retaining significant features. An $11 \times 11$ pixel kernel was used. The Lee filter is defined by Equation 1, where $r(x, y)$ and $i(x, y)$ are the result and input images, $\mu(x, y)$ and $\sigma(x, y)$ are the local mean and variances, and $n(x, y)$ is the local noise value

$$ r(x, y) = \mu(x, y) + \frac{\sigma(x, y)}{\sigma(x, y) + n(x, y)} (i(x, y) - \mu(x, y)) $$

(1)

It was found that in many images of normal retinas (set A), the cup region was transformed into a region of maximum intensity spanning the width of the image, but not extending

Figure 3. Locating the optic disc using the Circular Hough Transform. (a) Colour image after deleting vessels. (b) Edge points detected by the Sobel filter. (c) Circular Hough Transform space. (d) OD by applying CHT on edge points.
the image’s height. This image was also thresholded, at a value of mean + 0.5 × standard deviation. It was found that a set of normal images (set B) also had a region of maximum intensity spanning the width of the image but not extending the image’s height. The union of the two sets includes virtually all of the normal images.

5. Results

Sixty images, including 16 normal and 44 abnormals, were processed as described above. If the resultant images were members of set A or set B, they were classified as normals. The results are summarized in the contingency table (Table I).

A chi-squared test gave a significant result (p < 0.05), indicating that the test is able to separate normal from abnormal (glaucoma or diabetic retinopathy) images. A success rate of 65% was obtained, with sensitivity and specificity rates of 60% and 84%, respectively.

6. Conclusions

In this study, we set out to develop methods of separating normal from abnormal images of the retina (abnormal being cases of glaucoma or diabetic retinopathy). The methods would be used in a screening clinic to identify at-risk patients who would then be examined more closely by an expert.

Images were collected from various sources to mimic the data collected at a range of sites. Methods were developed to separate the normal from the abnormal images; this was done with some success: significant differences were found between the two populations, but the differences are probably too inconsistent to be useful in a diagnostic application. The limited success could be attributed to the simplicity or insensitivity of our algorithm; it can also be attributed to the nature of the diagnosis: we are labelling images as being abnormal or not, without recognizing that there is a spectrum of appearances.

The tests indicate that the optic disc’s appearance is more uniform in the normal case and becomes progressively less so as the diseases progress.

Future work is directed in two directions: accumulating further data to confirm these results and developing more robust and accurate methods of processing these highly variable data. This will be directed towards matching structures in the image to the anatomy of the retina.

References
