CHAPTER 7

CONCLUSION AND FUTURE WORK

Images of the ocular fundus can convey the retinal, ophthalmic, and even systemic diseases such as diabetes, hypertension, and arteriosclerosis. The use of colour retinal images captured with digital fundus cameras provides a non-invasive way of search and screening for ophthalmic and systemic pathologies. A completely automated segmentation of colour retinal images can greatly help in the management of certain diseases like diabetic retinopathy which require the screening of large populations. But the development of an automated system for this purpose needs a robust system capable of fast segmentation of the normal anatomical features of the retina which is not yet available.

With digital retinal imaging playing an increasingly prominent role in today's diagnosis and treatment of eye diseases, the problem of extracting clinically useful information has become important. For example, retinal vasculature, optic disc boundary, macula and location of exudates help to define the character and extent of diseases like diabetic retinopathy and glaucoma, aiding diagnosis and treatment. Therefore, segmentation of these features becomes a key challenge for proper analysis, visualization and quantitative comparison.

The aims of the research presented in this thesis have been to investigate and develop techniques for a structured analysis of the retina, that singly analyze retinal features and segment the major anatomical features which in turn aid to detect ophthalmic and other pathologies from fundus images. This is achieved amongst the high variability of the retinal structures, light artifacts, noise, diabetic and none diabetic lesions. Few novel algorithms have been specifically designed to accurately locate, segment and classify retinal structures from the aforementioned image distracters. It is this development that has formed the basis of the work presented in this thesis.

Equalization of uneven illumination was found to be the key issue for the success of the research in segmenting the features automatically. Thus, existing illumination equalization methods were compared and the best method suited for fundus imagery was selected.

Since the quality of fundus images vary due to difficult imaging conditions, methods for detecting regions of poor image quality were discussed. Two types of image quality problems were noticed: noise and distorted fundus color. Both these types appear in regions where illumination has been inadequate. It was not clear why the colors in some images were distorted. It is understood that all the delivered fundus images were unprocessed. Since the images were taken earlier to be examined by an ophthalmologist, there is a possibility that some of the images were processed to be more suitable for a human observer. This was supported by the fact that the illumination was somehow uniform in the green channel in those fundus images where the color was found distorted.

A typical image presented in MESSIDOR database is of the dimension 1440 X 960 pixels and is having a higher size of around 3.66 MB while the typical images presented in DRIVE database is having a size of only 565 X 584 and occupies a size of only 716 KB. Hence the processing of a MESSIDOR image takes much more time when compared to an image belonging to DRIVE database. All the computational time mentioned in this thesis corresponds to images from DRIVE database.

Some of the main clinical objectives reported in literature for retinal vessel segmentation are the implementation of screening programs for diabetic retinopathy, evaluation of the retinopathy of prematurity, macular avascular region detection, arteriolar narrowing, vessel tortuosity to characterize hypertensive retinopathy, vessel diameter measurement to diagnose hypertension, and cardiovascular diseases, and computer-assisted laser surgery. Other indirect applications include automatic generation of retinal maps for the treatment of age-related macular degeneration, extraction of characteristic points of the retinal vasculature for temporal or multimodal image registration, retinal image mosaic synthesis, identification of the optic disc position and localization of the fovea. Furthermore, the network of retinal vessels is distinctive enough to each individual and can be used for biometric identification, although it has not yet been extensively explored.

As smaller blood vessels called capillaries change angle within the retina, their retinal appearance becomes non-continuous and this is the primary cause of false classifications by the algorithm. Further investigation into segmentation algorithm is therefore required to segment small non-continuous capillaries. The presence of new retinal vessels (Neovascularization) that are commonly narrow, tortuous, weak and prone to vascular leakage is an indicator of the retinopathy severity. Identifying these new vessels is a challenging task due to their restricted diameter and interweaving appearance. The current vascular segmentation algorithm is incapable of reliably detecting such vessels and would consequently require additional work.

Further study is required to investigate a range of fundus resolutions, reapplying the presented algorithms at each resolution and comparing the performance to an ophthalmic gold standard evaluation. The first aspect, left with in this regard, is the testing on bigger datasets. This would allow confirming or contradicting the good performance obtained so far. Also, it will make possible to evaluate the optimal size of training samples required. In the method developed, segmentation algorithms were developed and tested for OD macula and retinal vasculature. Although the results of the segmentation were comparable to existing gold standards and best known methods, it is felt that there is room for improvements in the execution time and accuracy. Fortunately, many new algorithms are continuously being developed and segmentation of ROI is a common preprocessing step for many work related to medical imaging.

Although the results presented here have demonstrated the effectiveness of the proposed methods, there is still a lot of scope for improvement in the automatic retinal image analysis system. The segmentation of retinal vessels can further be used for number of purposes. The retinal vascular toruosity is shown to become a predictive factor for cardiovascular diseases and diabetes. The changes in retinal vascular toruosity might be a sign of severity or improvement of the disease. A new technique to analyze and quantify toruosity by considering vessel segment's width has to be found. For the registration of images of a patient taken over a time or acquired using different modalities, the retinal vessel branching points can be used as control points that are to be mapped in two images. The changes in the shape and size of optic disc can be used to detect and diagnose sight threatening diseases like glaucoma. The method has to be further improved to detect optic cup part of the disc, so that changes in the disc to cup ratio can be used as a measure of glaucoma.

There are several proposals for improvements if more resources are available for researching machine vision-based retinal analysis. It should be studied whether it is enough to use a green filter and take gray-scale images containing only the wavelengths of green color or whether a wider range of wavelengths should be used. In this study the segmentation algorithms searched only in the green channel of RGB color fundus images, but also other color channels may give additional information about the region of interest. Another proposal is to use the ground truth of several ophthalmologists instead of a single one. In this study, it was not investigated how much difference is there between diagnosis and segmentation made by different human observers, but the ground truth of only one ophthalmologist was used. Since ophthalmologists may make classification mistakes, it would be worthwhile to use only region information that is accepted by several ophthalmologists. When the results of the developed machine vision methods are published, it may be reasonable to mention how much variance is there among different human experts in addition to variance between the computer-based system and a human expert.

Overall, this work has presented several advancements in retina image processing geared towards improving the state-of-the-art in automated screening and segmentation of retinal features. A larger clinical evaluation of the segmentation process is the essential first step for the acceptance of the medical community. This will allow to better identify the system deficiencies and to propose solutions, possibly by combining existing approaches.