Chapter 7

Conclusion

7.1 Thesis Summary

This thesis has considered the new methods for the automatic identification of anatomical features like optic disc, blood vessels, macula and pathological feature like hard exudates in digital colour retinal images. This has led to the development of computer based system for detection and severity level grading of diabetic maculopathy. The system finds its direct application during the screening of eye diseases for ever increasing diabetic population.

A general introduction of the potential and challenges of retinal image analysis was first presented in Chapter 1. With digital retinal imaging playing an increasingly prominent role in the 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. This has been the main focus of this dissertation, i.e., segmentation of normal and abnormal features in colour retinal images. The Chapter 2 provided a review of common segmentation algorithms for retinal image features. From both
number and diversity of algorithms used for retinopathy detection it was clear that there is no gold standard which solves entire problem.

Chapter 3 has been devoted to the preprocessing and description of retinal image databases used to evaluate the methods. The database obtained from KMC has a very large variability in terms of disease and image quality. Some of the images were discarded by ophthalmologists prior to the diagnosis. But such images were included in the database to check the robustness of the developed system. Images that suffered from non uniform illumination and poor contrast were subjected to preprocessing, before subjected to segmentation. Colour normalization was performed to attenuate colour variations in the image by normalizing the colour of the original retinal image against a reference image. In order to correct non uniform illumination and to improve contrast of an image, contrast-limited adaptive histogram equalization was used. These preprocessing steps were found to improve the segmentation results of optic disc and exudates. For each image in the database fundus mask was detected, that facilitated the detection of vessels and exudate pixels within the region of interest.

The segmentation of blood vessels in colour retinal images using Gabor filters has been described in Chapter 4. It was found that the appearance of vessels is highly sensitive in the gray scale image containing only the wavelength of green. Therefore, for segmentation of vessels was performed using only green channel of RGB colour image. Gabor filter, whose application can be found in problems such as, strokes in character recognition and detecting roads in satellite image analysis, were explored to detect and enhance vessel features in retinal image. When compared with the matched filter for detecting line like features, Gabor filter provided a better result as it has optimal localization in both the frequency and space domains. The Gabor filter was tuned to a suitable frequency and orientation was able to
emphasize vessels along that direction and filtering out background noise and other undesirable structures. Values of all the filter parameter were selected based on the properties of vessels. When filter was aligned along orientation of vessel it produced single peak response along that direction. Bank of 12 Gabor filters oriented along different directions in the range of 0 to 170 degrees were used to enhance the multi-oriented vessels. Increasing the number of filter banks did not result in significant improvement of result but increased the time consuming convolution operation. The resulted enhanced vessels were then subjected to thresholding for vessel pixel classification. Entropic threshold calculation based on gray level co-occurrence matrix as it contained information on the distribution of gray level frequency and edge information have been presented. Two publicly available databases were used to evaluate the performance of the method and also to compare it with the matched filter methods. It was found that for DRIVE database the method provided sensitivity of 86.47±3.6 % and 96±1.01 specificity. And for the STARE database 85% sensitivity and 96% specificity were achieved. It was found that the number of miss classified pixels was less compared to matched filter methods using the same database.

Segmentation of optic disc boundary and localization of macula has been discussed in Chapter 5. Detection of these two features of retina was necessary for the proper detection of exudates and also for knowing the severity of the diabetic maculopathy. Based on the fact that optic cup part of the disc being the brightest part in the image, optimal thresholding technique was employed to calculate initial threshold. After experimenting with individual red, green and blue channel of RGB colour image, it was found that gray scale image containing green channel provide better result when subjected to thresholding. The interfering vessels in the optic disc made the process
of finding the approximate center of disc complicated. Fragmented optic disc regions had to be merged to get the center of the disc. According to the prior information about the diameter of optic disc in a standard retinal image, connected components and iterative thresholding was used to locate optic disc. The macula was localized based on its distance and position with respect to the optic disc as it remained relatively constant. Even though macula is considered to be one of the darkest regions without vessels in a retinal image, less contrast between the macula and background makes it difficult to locate based on image variance. Therefore, a rectangular region was formed as a search area to locate the macula in an image. Among 148 images considered for evaluating the methods optic disc and macula were localized with sensitivity of 99.32% and 96.6% respectively.

Detection of optic disc boundary becomes important for the diagnosis of glaucoma. Difficulty in finding the optic disc boundary is due to its highly variable appearance in retinal images. Geometric active contour model was explored to segment the optic disc boundary as classical segmentation algorithms failed to provide good result. Image segmentation was performed by starting with initial curve and evolving its shape by minimizing energy function represented by level set function. The iterative curve evolution was stopped at the image boundaries where the energy was minimum. Experiment was performed on both RGB image and gray scale image and found that implicit active contours provided better result with gray scale images. Total of 74 images were used to evaluate the method. Optic disc boundary drawn manually by an expert was used as ground truth. The method was able to achieve average sensitivity of 90.67% with mean of ±5.05. Based on the result obtained in optic disc boundary detection, it can be stated that geometric based implicit active contour models
provide a better segmentation for images with weak boundaries when compared to parametric models.

The detection of hard exudates in retinal images and development of automated system for the detection of diabetic maculopathy has been described in Chapter 6. Hard exudates that are responsible for exudative maculopathy was detected using two levels of segmentation for improved accuracy. The coarse segmentation of exudates, that was achieved using K-Means clustering provided a better initial coarse segmentation when compared with the variance based method proposed in the literature. Fine segmentation using morphological reconstruction technique classified the correct exudate pixels from the background. Also, automatic threshold calculation after morphological reconstruction is important, and it was achieved with entropic thresholding, thus making the method to work without manual intervention. Total of 148 images from KMC database and 88 images from Diaretdb1 database were used to evaluate the method. Average image based sensitivity of 97.9% and specificity of 96.1% was achieved for KMC database. And 93% sensitivity and 97.7% specificity was achieved for Diabetdb1 database. Based on the location of exudates in the macular region, the severity levels of diabetic maculopathy were classified into mild, moderate and severe. The existing models of retinal screening are expensive, time consuming and require trained ophthalmologists. The developed automatic system is able to detect diabetic maculopathy and its severity level in less time. The sample image data used to validate this software was comparable across manual graders with regard to the distribution of severity of the disease. An overall sensitivity of 95.6% and specificity of 96.15% was achieved by the system. Graphical user interface was also developed for assisting the clinicians during the screening process. The results proved that it is possible to use the developed algorithms for assisting
an ophthalmologist to segment fundus images into normal regions and lesions, and thus support the ophthalmologist in decision making.

### 7.2 Contributions of the Thesis

The major contributions of this dissertation can be summarized as:

- The development of new methods for the detection of the following three anatomical structures in retina.
  - (i) Automatic localization of optic disc using optimal threshold and connected component analysis. And optic disc boundary detection using geometric based active contour model.
  - (ii) Automatic localization of macula.
  - (iii) Automatic segmentation of retinal blood vessels using Gabor filters and entropic thresholding.

- Automatic detection of hard exudates in retinal image for the detection of diabetic retinopathy.

- The development of computer based system for automatic detection and severity level classification of diabetic maculopathy. Also development of GUI for assisting ophthalmologists during screening process.

### 7.3 Future Direction

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 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.

As described earlier, the changes in the shape and size of optic disc can be used to detect and diagnose sight threatening disease called 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.

Detection and classification of diabetic retinopathy has to be improved by identifying other types of lesions like, hemorrhages, microaneurysms and cotton wool spots. Hard exudate detection has to be improved further by considering other clustering techniques. The system developed so far is capable of detecting maculopathy. It has to be further developed to include detection and severity of retinopathy. Finally, a feature to embed patient diagnosis information within the image will be beneficial.