CHAPTER-9

CONCLUSIONS AND FUTURE WORK

In this thesis, a reliable Fundus Image Analysis system is developed to give an ophthalmologist the most comprehensive view of the retina state to diagnose diabetic retinopathy. To build this Fundus Image Analysis system, normal and abnormal features of fundus images are extracted by applying various newly developed image processing and pattern recognition methods. This system extracts the fundal features such as retinal blood vessels, optic disk, fovea, exudates, cottonwool spots, hemorrhages and microaneurysms even for a low quality colour fundus image. The Fundus Image Analysis system detects and grades the severity of diabetic retinopathy, macular edema consistently irrespective of variations in colour, illumination levels and amount of noise. Hence, this system can also function as an automatic tool for the mass screening of diabetic retinopathy.

To evaluate the performance of the proposed Fundus Image Analysis system a dataset of 1540 images is used. When compared to other diabetic retinopathy screening systems [113-115], the Fundus Image Analysis system detected diabetic retinopathy with a high sensitivity and specificity of 100% and 96.98% respectively. The other features of the Fundus Image Analysis system are: it grades diabetic retinopathy, macular edema and gives the location and area of lesions
which are not present in the existing diabetic retinopathy screening systems [113-115].

The Fundus Image Analysis system is built in a modular way with each component solving a well defined task. The efficiency of all the six integral components of the Fundus Image Analysis system is presented here.

A novel approach for automated segmentation of the blood vessels in digital fundus images is proposed in Chapter-3. The proposed HMLRE blood vessel segmentation approach comprises histogram matching, matched filtering, local relative entropy thresholding and label filtering. The HMLRE method is compared with two supervised methods [48] [49] and three unsupervised methods [18] [20] [51]. The proposed HMLRE method is computationally simple, and at the same time, attains accurate detection results in normal retinal images and images with obscure blood vessel appearance. The methods presented in [18] [20][51][48][49] mis-detected and mis-enhanced bright pathologies as blood vessels. But the HMLRE method segmented blood vessels in pathological regions efficiently and also extracted thinner vessels even in low contrast regions. This method achieves an area under ROC of 0.9518 for DRIVE database and 0.9602 for STARE database. The results indicate that the performance of the proposed unsupervised HMLRE method is significantly better than other unsupervised methods and is on par with the supervised methods.

PCA based method and a method based on finding the vessel branch with most vessels are investigated for localizing the optic disk
in Chapter-4. The PCA based method failed to locate the optic disk in retinal images that contains large areas of lesions around the optic disk as such case is absent in the training set. It has a success rate of 97.25%. Despite the presence of large areas of bright lesions and noise in retinal images, the proposed method of finding the vessel branch with most vessels is faster and accurate in locating the optic disk. The success rate of this method is 99.25%.

To estimate the contour of the optic disk, a Geometric active contour method is proposed in Chapter-4. This method involves colour morphology in *Lab* space and geometric active contour model with new variational formulation. The performance of the proposed optic disk contour detection method is compared with the performances of existing Hough transform method [54] and GVF snake method [57]. The existing methods [54] [57] failed to detect contour when the optic disk is having ill-defined boundary or fuzzy boundary. But the proposed Geometric active contour method detected the contours with high accuracy. This method is advantageous in detecting the optic disc contour in retinal images that contain discontinuous or blurred optic disks and has an accuracy of 96.95%.

In Chapter-5 an approach to detect vascular arcade, fovea and macula is developed. This approach attained an accuracy of 94.86%. The method is fairly robust in identifying fovea even though the pathologies and bad illuminated regions that have similar appearance to fovea are present.
An efficient method based on SWFCM clustering is proposed (Chapter-6) to detect bright lesions in fundus images. The SWFCM clustering method is fast compared to other FCM based methods in detecting bright lesions as the gray level histogram of the image is employed in the clustering process instead of the whole data of image. Due to the consideration of the neighbourhood information, the method becomes noise resistant. KNN and SVM classifiers are used to separate true bright lesions from bright non-lesions. To evaluate the SMFCM clustering method lesion based evaluation and image based evaluation are used. When determining whether an image contains bright lesions, the proposed approach achieves an accuracy of 96.61%, sensitivity of 100% combined with 88.23% specificity. For lesion based evaluation, it obtained an accuracy of 96.36%, sensitivity of 96.95% and a specificity of 97.03%.

A novel hybrid detection method is developed (Chapter-7) to detect dark lesions in digital fundus images. This method combines morphological based dark lesion detection with candidate dark lesion detection scheme based on matched filtering and local relative entropy. KNN and SVM classifiers are used to isolate true dark lesions from dark non-lesions. For image based evaluation, the proposed method got an accuracy of 98.3%, sensitivity of 100% combined with 87.5% specificity. For lesion based evaluation, the proposed method attained an accuracy of 95.65%, sensitivity of 97.16% and a specificity of 94.79%.
This Fundus Image Analysis system identifies all important anatomical landmarks necessary to find the approximate location and area of an abnormality on the retina. Given the location with respect to the normal anatomy, the medical urgency associated with a particular lesion type can be determined. The lesions outside the vascular arcade have a lower urgency than lesions inside the vascular arcade. The lesions within the inner circle of fundal coordinate system will cause more harm to vision compared to other lesions. Clinically, these cases have medical urgency and ophthalmologists will treat these cases with Laser.

The research presented in this thesis has shown encouraging results and indicates that the proposed Fundus Image Analysis system is very successful in extracting both normal and abnormal features. As the Fundus Image Analysis system detects abnormalities with very high sensitivity and reasonable specificity, it can be employed to assist ophthalmologists in diagnosis for providing second opinion and also can function as a tool for the mass screening of diabetic retinopathy.

9.1. FUTURE WORK

The Fundus Image Analysis system developed in this thesis can be implemented on an embedded processor mounted on the fundus camera itself. This will directly indicate the severity of the disease in real time so the patients with advanced diabetic retinopathy can be urgently directed to the nearby Health center. This fundus camera
with inbuilt processor removes the need for trained technician near the screening site. Embedded processors have limited computational power. So computationally simple detection algorithms based on KNN and SVM classifiers can be loaded into them. This requires coding in the assembly language.

Even though the target of the Fundus Image Analysis system presented in this thesis is to detect the retinopathy caused by the metabolic syndrome, this system can also be extended to detect other diseases that affect the retina. The SWFCM clustering based bright lesion detection method presented in Chapter-6 can be used to detect Age-related Macular Degeneration which is the leading cause of central vision loss in people above the age of fifty years. In hypertensive retinopathy the major signs that appear on the retina are hemorrhages and cottonwool spots. The methods described in Chapters 6 and 7 may be used to detect these.

Diabetic retinopathy is a progressive disease; abnormalities can appear and disappear on the retina. Since patients are supposed to have a regular dilated retinal exam, the images of previous visits will usually be available. By analyzing the progressive changes in the retina over time, subtle abnormalities could be detected. In practice this would mean registering the older data with the images most recently acquired and analyzing the differences between the images. Temporal change detection is a technique which could be interesting for automatic screening in the long term. Retinal registration is a prerequisite for the development of a change detection algorithm. The
Fundus Image Analysis system can be extended by developing algorithms for retinal image registration and retinal change detection which in turn assists the ophthalmologist to study the post medication improvements.