R&D ACTIVITIES IN RETINAL IMAGE ANALYSIS AT CRIM

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Abstract

We present an overview of some R&D activities in retinal image processing at CRIM. The reviewed topics are: image quality evaluation, detection of anatomical structures and lesions associated to diabetic retinopathy, image registration and fusion between optical and angiographic images or between angiographic images taken at different stages, and integration within prototype software with user-friendly graphical user interface.

INTRODUCTION

Ophthalmologists are manipulating more and more retinal images with computers. This is in part due to (1) the development of new technologies for retinal image acquisition (e.g. digital non-mydriatic cameras), (2) the archiving and network access of digital images and (3) the increase in the number of retinal exams for specific diseases like diabetic retinopathy. Combination between technological advancements and socio-medical needs opens the way to a more systematic use of software tools for diagnosis assistance.

The R&D department of the Centre de Recherche Informatique de Montréal (CRIM) has been involved, over the last four years, in the development of image processing algorithms to assist ophthalmologists for retinal image analysis. These include: (1) visual image quality evaluation, (2) automatic detection of anatomical structures (optic disk, macula and retinal blood vessels), (3) detection of lesions (microaneurysms and exudates) associated to diabetic retinopathy, (4) image registration and fusion between optical and angiographic images or between angiographic images taken at different stages and (5) 3D reconstruction of fluorescein distribution from uncalibrated angiogram sequences. Here, we will concentrate on the first four items and report on the results of those activities, paying a particular attention to the integration of the various algorithms within user-friendly software.

The paper is divided into two main sections. First section briefly presents the principal research outcomes regarding the above activities, along with visual examples and performance measures. The second section describes the two prototypes software that have been developed as a result of those activities. These software have been designed according to usability specifications from image analysts and/or medical specialists. They provide the required user-friendly environment for diagnosis assistance tools.

R&D ACTIVITIES

Image quality evaluation

We have developed a method to automatically assess the visual quality of retinal images, motivated by the idea that images of good quality possess common features that can define a "quality" model. The features used are (1) the histogram of the edge magnitude distribution in the image (which is essentially related to the focus quality) and (2) the local histograms of pixel gray scale values (which essentially capture the presence of abnormal bright or dark regions). Histogram matching functions that allow acceptable discriminating between images of good, fair and bad visual quality, have been proposed [1].

Two series of tests have been performed. The first test was on a set of 40 images of 640X480 pixels acquired from a digital non-mydriatic camera CANON CR6-45NM. The results showed 80% of agreement in image quality assessment with respect to an independent expert evaluation. The second test was much more extensive and was performed on a set of 197 images of 800X600 pixels acquired from a TOPCON camera [2]. The results were 47% of agreement with the expert, 2% of total disagreement (e.g. good versus bad) and 51% of partial agreement (e.g. either the expert or the system says the image is of fair quality). For partial agreement, the algorithm was almost always more severe than the expert, which is preferable than the opposite.

Detection of anatomical structures

The detection of the principal anatomical structures is a key preprocessing element prior to lesions detection. We have developed algorithms for the detection of the Optic Disk (OD), the macula (fovea) and the retinal blood vessels [3,4]. Here we review the first two.

The OD algorithm assumes that (1) one knows *a priori* whether the eye is the left or the right as well as whether the acquired image is centered on the macula or OD and (2) the OD is the brightest region in the green band. It uses a combination of (1) pyramidal decomposition to detect region of interest, (2) contour search through template matching with Hausdorff distance and (3) Dempster-Shafer fusion to reinforce detection confidence. The procedure has been tested on 40 images of 640X480 pixels which correspond to a resolution of about 20 microns/pixels. The results were 95% of correct detection for the papilla and 85% of correct detection for the macula. Examples of detection on two retinal images are given on Figure 1. Even for very affected eyes, the algorithm is robust enough to provide a fair detection.

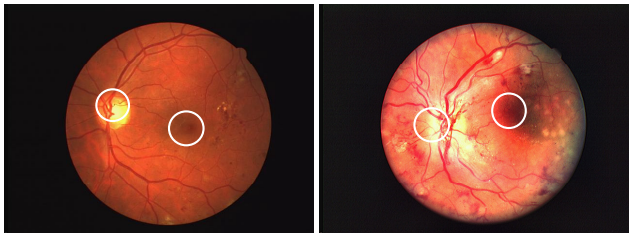

Figure 1: Examples of OD and macula detection on retina at early and late stage diabetic retinopathy

Detection of lesions associated to diabetic retinopathy

Diabetic retinopathy is the most common cause of blindness in the industrial countries. Microaneurysms (MAs) (red lesions over a red background) and exudates (yellow lesions) are the two most important lesions associated to the early stage of diabetic retinopathy. We have proposed and tested practical algorithms to detect MA and exudates. The MA detector combines top-hat transform to get rid of linear features like the retinal blood vessel, Constant False Alarm Rate (CFAR) detector to pin-point small dim object (potential MAs), region growing for segmenting potential MAs and color and geometric features for discriminating against false detection [5]. Exudates detector basically uses color information in order to discriminate between yellow lesion and red background [6]. The algorithms have been especially designed for low-resolution images, which make them particularly interesting for low-cost ophthalmic system for a mass screening program.

Again, tests have been performed on a set of 40 images of 640X480 pixels which represents a resolution of 20 microns/pixels. The results show 90% sensibility and 75% specificity for microaneurysms (see Figure 2 for an example) and 100% sensibility and 87% specificity for exudates.

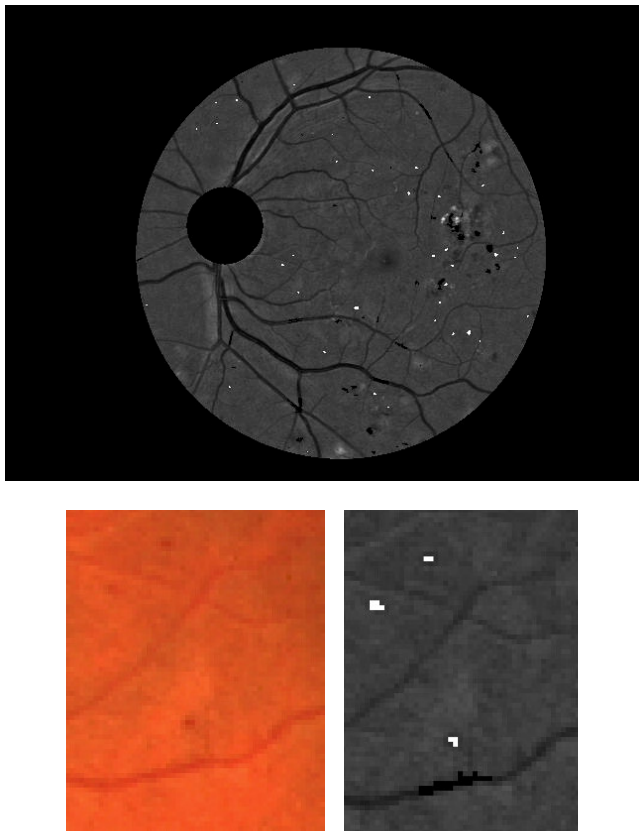

Figure 2: (top) Example of microaneurysms detection on left image of Figure 1. (bottom) Zoom on the right hand-side of the OD to show the detected MAs.

Image registration and fusion

We have developed a registration tool that allows spatial alignment between two images in order to e.g. assess the evolution of some disease over time [7]. The tool first automatically detects landmark points from both images and then proceeds to find the best transformation (similarity, affine or polynomial) that maps one set of points to the other. Typically, bifurcations of the blood vessels are chosen as landmark points. A transformed (warped) image is then produced (Figure 3). Registration is the first step before pixel-based image fusion.

Image fusion can be of interest to ophthalmologists since it provides a compact representation of complementary information from different image modalities or from different stages of an angiographic examination. Figure 4 shows the result of fusing two source images using a pyramidal gradient method [7], which is one of the fourteen fusion method we have

explored during the project. The true color image retains the good contrast of the angiogram as well as the color information, which is useful for diagnosis according to our medical partner.

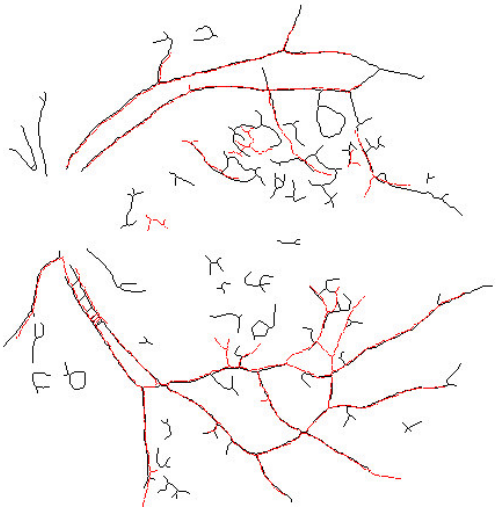

Figure 3: Example of result showing registration between retinal networks from an optical image and an angiogram using an affine transform.

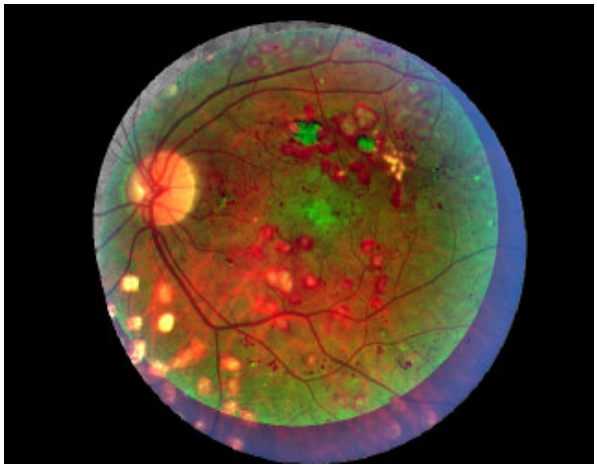

Figure 4: Example of image fusion between optical and angiographic images using a pixel-based pyramidal gradient method.

SOFTWARE INTEGRATION

Retsoft

Retsoft was the first diagnosis-aided software to be developed at CRIM for ophthalmic applications [8]. It has been especially designed to provide an assistance tool for mass screening of diabetic retinopahy. All the functionalities are specific to this sector: automatic image quality assessment, OD and macula detection, microaneurysms and exudate detection.

It is adapted to medical specialists, not software developers. Its interface has been designed according to medical usage as expressed by our ophthalmologist partner. Typically, the software constrains the user in browsing images on a standard per-patient file basis, that is, requiring to open a patient file in order to have access to images for diagnosis assistance. Figure 5 gives a snapshot of the main Retsoft window. The left part shows thumbnails of images present in the patient file. The rest of the window is divided into four regions: left regions are reserved to display raw images while the right regions present the processing results.

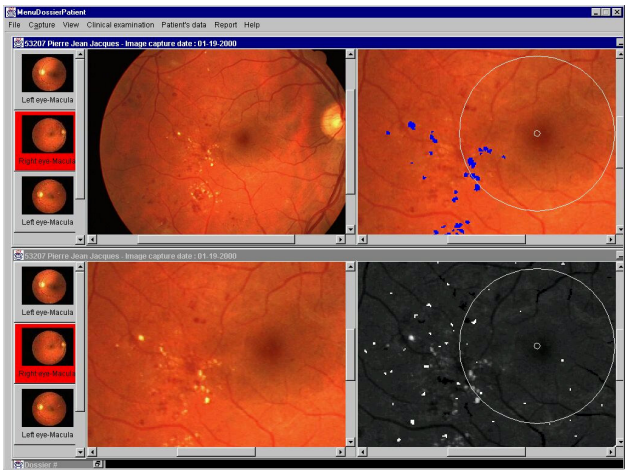

Figure 5: Snapshot of Retsoft

Retsoft+

Retsoft+ is an extended and improved version of Retsoft [9]. It exhibits a more open environment and additional functionalities like: (1) access to a wizard to guide non-expert users through the diagnosis processes, (2) simpler architecture to allow addition of new image processing algorithms and (3) more versatile and powerful image viewer (*xv* for Unix). It is more adapted to developers as it rather uses a weak notion of patient file to allow the user to visualize and possibly re-use any intermediate result images or data (Figure 6).

Usability is a key feature to Retsoft+. A wizard guides the non-expert user through the various steps of the analysis he wishes to carry out. Figure 7 shows an example of such a wizard. Here, the wizard helps the user process an image for automatic extraction of landmark points in the image prior to image registration: the left part of the panel shows the series of steps to be performed (the current step is shown in

bold), and the right part informs the user about what to do (pick an image from the image tree, set parameters, etc.). The navigation bar allows the user to go back and modify a previous choice, which is convenient when experimenting with a method that requires some parameter tuning.

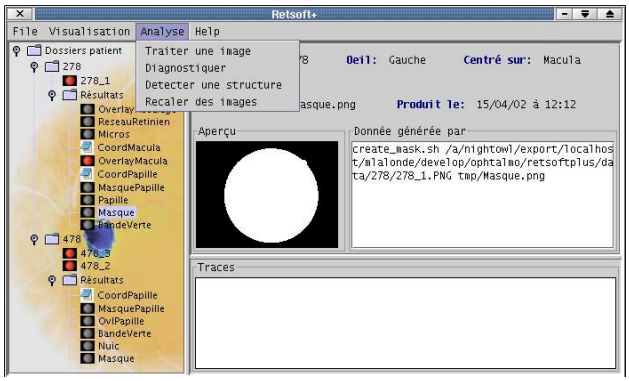

Figure 6: Main window of Retsoft+

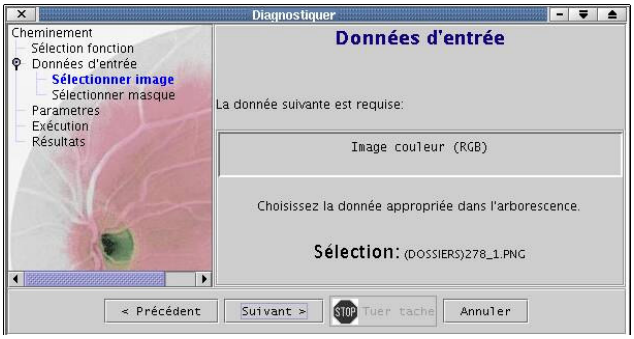

Figure 7: Snapshot of the wizard interface in Retsoft+

CONCLUSION

We presented an overview of recent activities in ophthalmic image processing at CRIM covering automatic detection of anatomical structures and lesions and image fusion. Many of the above research outcomes have been integrated in two software prototypes satisfying usability specifications for image analysts or medical specialists. In particular, Retsoft+ is a retinal image analysis application that has been carefully designed to (1) provide users with powerful image analysis functionalities (detection of anatomical structures, assistance in diagnosing lesions, image registration and fusion, etc., with mechanisms for easy integration of new algorithms) and (2) assist the users in a friendly way using wizards that guide them as they use these functionalities.

All the above developed technologies are available for transfer to the industry for further development. Thanks to the modular approach adopted for the development of our algorithms, it is even possible to develop sub-products of the software which can meet specific needs for diagnosis assistance.

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