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# Detection and Registration of Vessels of Fundus and OCT Images Using Curevelet Analysis

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***Abstract*—In recent years, advanced analysis of retinal images, has built automatic systems for diagnosis of various diseases. These devices help us save both time and money. The new techniques of 3D-Optical Coherence Tomography (OCT) imaging is very useful for detecting retinal pathologic changes in various diseases and determining retinal thickness abnormalities. Fundus color images have been used for several years for detecting retinal abnormalities too. If the two image modalities were combined, the resulted image would be more informative because some abnormalities such as drusen, geographic atrophy, and macular hemorrhages are detected in color fundus images but the exact morphology and localization of these abnormalities are released in OCT images. The first step to combine the different modalities is to register color fundus images with OCT projection. Ten eyes were imaged in this study with Topcon 3D OCT-1000 instrument. This instrument is used to observe the retina, take fundus and tomograms and record them. An en face representation of OCT reflectivity can be registered with color fundus photography. In this study curvelet transform is used to extract vessels for both modalities. Then the extracted vessels from two modalities are registered together. In this way more blood vessels can be obtained and the results would be more informative.**

***Index Terms*—Optical Coherence Tomography (OCT), color fundus image, curvelet transform, vessel detection, registration**

## I.INTRODUCTION

The new techniques of 3D-Optical Coherence Tomography (OCT) imaging [1-8] is very useful for pathological purposes. OCT uses low coherence interferometry in which the light source is split between that entering the eye and a reference path. Due to the coherent detection (multiplication of the reference and sample arm), OCT allows measurements of weakly reflecting retinal layers. Because OCT images have a high resolution, examination of the living eye has become possible without removing the tissue and examining it under the microscope.

OCT imaging is a reliable tool to quantitatively know a variety of eye diseases. OCT is employed for localization of macular hemorrhage [1], retinal structural changes associated with retinal arterial macroaneurysm [2], subretinal fluid from anterior ischemic optic neuropathy [3], three-dimensional visualization of the detached membrane in valsalva retinopathy [4], retinal thickness measurement and evaluation of natural history of the diabetic macular edema [5], qualitative and quantitative analysis of the optical nerve head and retinal nerve fiber layer and analyzing progression of glaucoma [6-7].

Registration of retinal images is a new application of image fusion [8]. There is great potential to work on registration of different modalities and also temporal images of retina.

The first work has been done by Pinz et all on mapping the human retina which was published in 1998. They present a feature-based fusion method where the coarse contours of anatomical and pathological features (vessels, fovea, optic disc, scotoma, subretinal leakage) are extracted from scanning laser ophtalmoscope images and superposed on the same image [9]. In 1999 Zana et all presented an algorithm for temporal and/or multimodal registration of retinal images based on point correspondence [10]. Registration of stereo and temporal images of the retina was done by Ritter et all with the use of mutual information as the similarity measure and simulated annealing as search technique [11]. More recently different modalities (color, fluorescein angiogram), different resolutions have been registered based on global point mapping with blood vessel bifurcations as control points [12].

Registration of 3D spectral OCT volumes using 3D SIFT feature point matching is a new work by Niemeijer et all in 2009 [13]. However to our knowledge there is not a thorough study which presents registration of OCT with fundus retinal photographs and there is not an automated system which combines fundus images with OCT images. Furthermore an en face representation of OCT reflectivity can be registered with color fundus photography. The purpose of this study is to register blood vessels extracted from fundus and OCT en face images. In section 2 we explain about our curvelet-based registration method. In this method curvelet transform is used for extraction of blood vessels from color fundus image. A grayscale fundus image is also obtained from projection of 3-D OCT data and vessels of this image are extracted using a similar curvelet-based method. Finally the extracted vessels are combined together to produce the final vessels. The results of this method is presented in section 3 that shows more blood vessels can be obtained and the results would be more informative. Finally this paper is concluded in section 4.

## II. METHOD

An example of colour fundus images is shown in Fig. 1. As it is shown in the figure, the central part of the retina (the area inside the green square which is 688×688 pixels) is imaged with optical coherence tomography technique. OCT images contain images of 650 different layers with a size of 650×512×128 voxels and a voxel resolution of 3.125mm×3.125mm×7mm (Fig. 2).

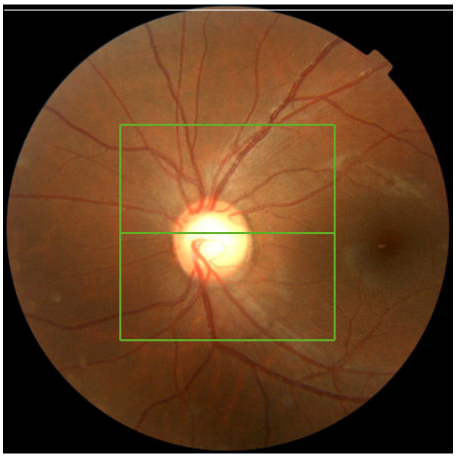

Fig. 1. An example of a color fundus image and selected area for OCT imaging

Fig. 2. An OCT image of retina layer at a fixed azimuthal interval (650× 512) (corresponding to the central green line in the previous image).

Fig. 3. An OCT image of retinal layer at a fixed axial interval (128×512)

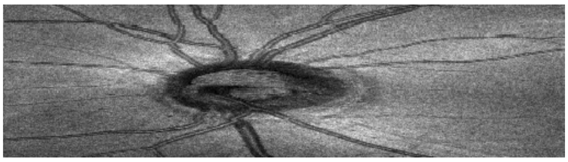

Fig. 4. OCT projection image obtained from variance of 650 OCT layers

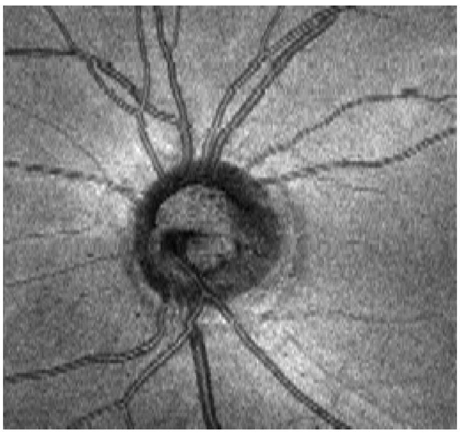

Fig. 5. Resized OCT projection image

It is possible to collapse three-dimensional OCT volumes along the depth axis to build a two-dimensional plane using mean or variance of layers at different axial intervals which are shown in Fig. 3. In this study variance of all 650 layers is calculated and considered as the OCT projection (Fig. 4. and Fig. 5.).

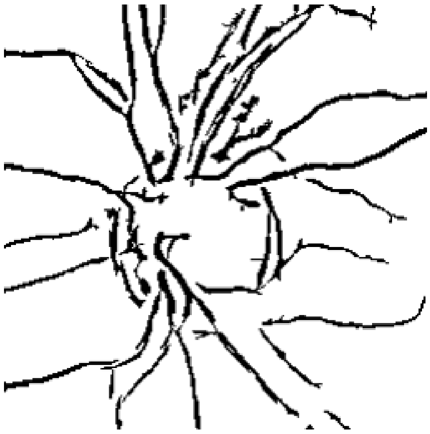

Fig. 6. Extracted vessels from fundus image

Vessels of the colour fundus image are extracted using the algorithm proposed by Esmaeili et al [14]. The algorithm is composed of four steps: curvelet-based contrast enhancement, match filtering, curvelet-based edge extraction, and length filtering. In this base, after reconstruction of enhanced image from the modified curvelet coefficients, match filtering is used to intensify the blood vessels. Then curvelet transform is employed to segment vessels from its background and finally the length filtering is used to remove the misclassified pixels [14]. Fig. 6. shows extracted vessels from color fundus image.

A similar approach is applied on the OCT projection image in order to extract the vessels from OCT:

1) Apply curvelet-based contrast enhancement method on the OCT projection image.
2) Take curvelet transform of the match filtered response of enhanced image in previous step.
3) Remove the low frequency component, and amplify all other curvelet coefficients.
4) Apply inverse curvelet transform.
5) Thresholding using the mean of the pixel values of the image.
6) Apply length filtering and remove misclassified pixels.

Figures 7 to 10 show results of different steps of the vessel extraction algorithm for OCT projection data. Fig. 8. illustrates extracted vessels from the corresponding OCT projection image. Then a search algorithm is completed to register vessel images. The algorithm works by expanding and contracting the images in x and y direction and calculating the similarity measure between them while the center of two images is kept at the same point.

Similarity measure is calculated as:

$$(A \cap B)/(A \cup B) \qquad (1)$$

where A is the image of vessels extracted from fundus and B is the image of vessels extracted from OCT projection.

The best x and y correspond to the maximum similarity measure.

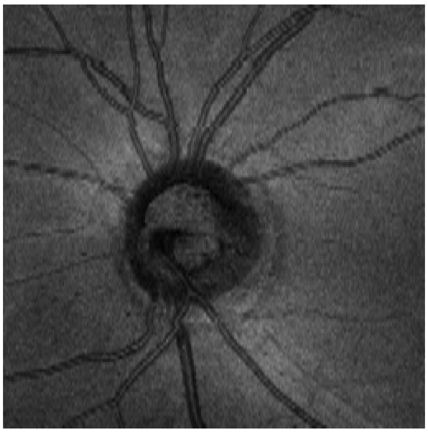

Fig. 7. OCT projection image after step 1.

## III. RESULTS

Vessel extraction is done successfully with curvelet transform for both modalities. After registration of the images we notice that we can have more vessel information. The results prove that when vessel images of two modalities are registered, they show more information compared to one modality. Fig. 11 shows two images registered when similarity measure is maximum. We can see the final extracted vessels in Fig. 12. Another example using this procedure for a macular OCT is shown in Fig. 13.

10 3D OCT data obtained from Topcon 3D OCT-1000 with a size of 650×512×128 voxels and a voxel resolution of 3.125mm×3.125mm×7mm used in this study. For each OCT data the corresponding colour fundus image is also available and after extraction of OCT projection, the vessels of both colour fundus and grayscale fundus (extracted from OCT data) registered together using the proposed curvelet-based method in previous section. The mean and std value of maximum similarity measure, obtained across 10 subjects is obtained $0.92 \pm 0.1$.

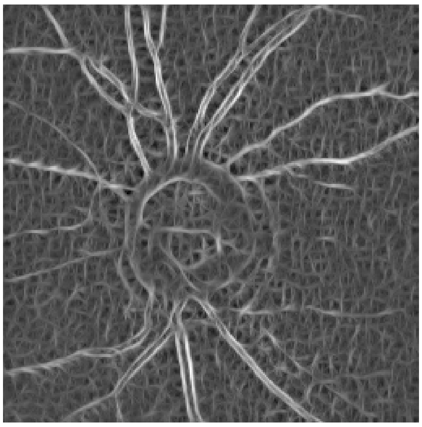

Fig. 8. OCT projection image after step 4.

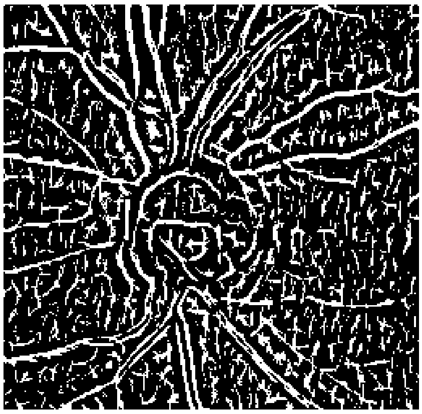

Fig. 9. OCT projection image after step 5.

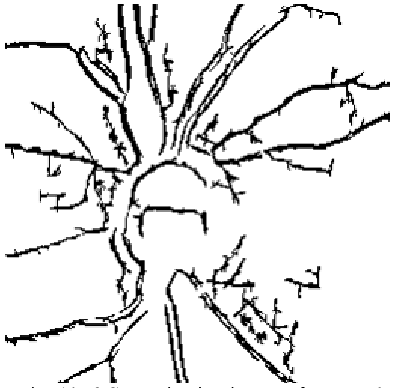

Fig. 10. OCT projection image after step 6.

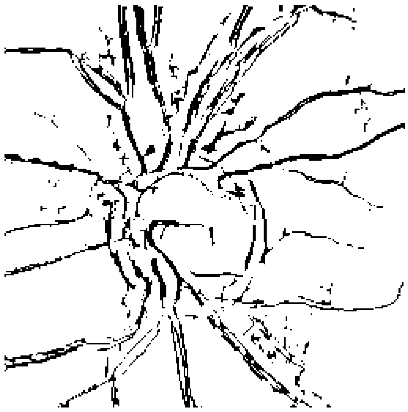

Fig. 11. Registration of vessel images

Fig. 12. Registration of vessels on fundus image.

Fig. 13. Registration of extracted vessels from macular OCT (and colour fundus image) on colour fundus image.

## IV. CONCLUSION

In conclusion, the current study has further established the importance of registration of OCT images and fundus images. For this reason, after preparation of a projection image from 3D OCT data, the vessels of both colour fundus and gray-scale fundus (extracted from OCT) are registered together using curvelet analysis.

In our registration we did not consider rotation, but results show that there is rotation between two images. Therefore, the best result of registration can be obtained when scaling and rotation would be considered together.

For future work, affine transformation can be employed to address this problem and improve the registration results.

In addition to vessels, other objects in fundus images such as macula in macular OCT imaging, or cup and rim in optic disc (OD)-based OCT imaging, or various pathologies can be registered together.

## V. ACKNOWLEDGMENT

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