Proceedings of the 26th Annual International Conference of the IEEE EMBS
San Francisco, CA, USA • September 1-5, 2004

Three Dimensional Reconstruction of Conventional Stereo Optic Disc Image

H. J. Kong[1,2], S. K. Kim[1], J.M. Seo[2,3,4], K. H. Park[3], H. Chung[3], K. S. Park[2,4], H. C. Kim[2,4]
[1]Interdisciplinary Program, Biomedical Engineering Major, Graduate School, Seoul National University
[2]Advanced Biometric Research Center, Seoul National University
[3]Department of Ophthalmology, College of Medicine, Seoul National University
Seoul Artificial Eye Center, Seoul National University Hospital Clinical Research Institute
[4] Department of Biomedical Engineering, College of Medicine and
Institute of Medical & Biological Engineering, Medical Research Center,
Seoul National University, Seoul, Korea

Abstract—**Stereo disc photograph was analyzed and reconstructed as 3 dimensional contour image to evaluate the status of the optic nerve head for the early detection of glaucoma and the evaluation of the efficacy of treatment. Stepwise preprocessing was introduced to detect the edge of the optic nerve head and retinal vessels and reduce noises. Paired images were registered by power cepstrum method and zero-mean normalized cross-correlation. After Gaussian blurring, median filter application and disparity pair searching, depth information in the 3 dimensionally reconstructed image was calculated by the simple triangulation formula. Calculated depth maps were smoothed through cubic B-spline interpolation and retinal vessels were visualized more clearly by adding reference image. Resulted 3 dimensional contour image showed optic cups, retinal vessels and the notching of the neural rim of the optic disc clearly and intuitively, helping physicians in understanding and interpreting the stereo disc photograph.**

Keywords—**Glaucoma, Image Analysis, Optic Disc**

I. INTRODUCTION

Glaucoma is a group of diseases that can damage the optic nerve, resulting in vision loss and blindness. Because the loss of vision in glaucoma is irrevocable, early diagnosis and treatment are important. Even though the visual field test and tonometry are traditional and valuable methods in detecting and managing glaucoma, more accurate and objective measurement of the optic nerve damage is needed for the earlier detection and the evaluation of the efficacy of the treatment. Although retinal nerve fiber layer (RNFL) photograph and stereo disc photograph (SDP) are widely used to find and record the objective status of the RNFL and optic nerve head (ONH), objective measurement and quantification of the photographs are not easy. Optical coherent tomography (OCT) and Heidelberg retina tomography (HRT) can analyze the objective status of the RNFL and ONH, but they are expensive.

In this paper, traditional SDP was analyzed and reconstructed as 3 dimensional contour image to evaluate the status of the ONH objectively and for the convenience of the examiner's investigation.

II. METHODOLOGY

Color, paired SDP was acquired by SDP camera (TRC-SS2, Topcon Inc., Tokyo, Japan) and the 3 dimensional contour map of the ONH was simulated on the basis of SDP. (Fig. 1)

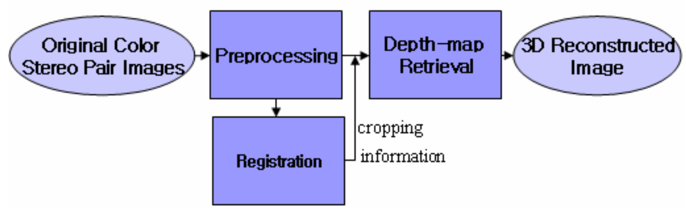

Fig. 1. Block Diagram of Overall Process

A. Preprocessing

1) *Conversion to grayscale image*: The entropy of the each color channel of color SDP in RGB JPEG format was calculated. Because the green channel showed the highest entropy among red, green and blue channels, green channel was selected as the candidate for further analysis and was converted to 8bit grayscale image.

2) *Edge enhancement*: To utilize the edge information in the registration step, edge enhancement was done through unsharp masking as follows. Gaussian blurred image of the grayscale image based on the information of green channel was subtracted from the pre-blurred grayscale image, and this procedure resulted in the edge-enhanced image because the high frequency components remained mainly after the subtraction, such as the retinal vessels and ONH margins.

3) *Binarization*: Thresholding by the moment preserving method was done on the edge-enhanced image to acquire more clarified image. This method is less heuristic compared to other methods in determining binarization threshold and image distortion is also minute.

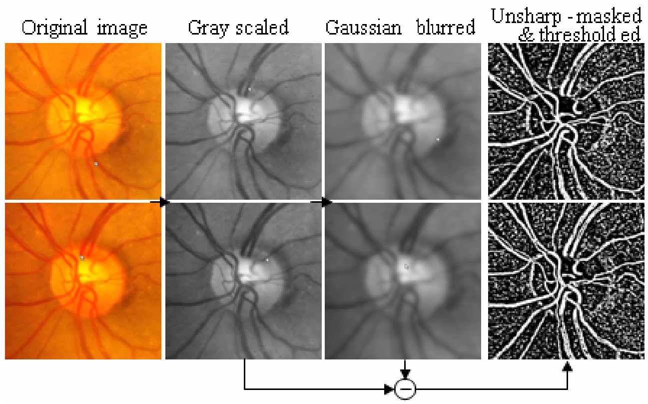

Fig 2. Preprocessing: Gray-scaling, Edge Enhancement & Binarization

B. *Registration*

To calculate the 3 dimensional depth coordinate in pre-processed SDP, image registration between the paired images of SDP is necessary. Power cepstrum is used in this study.

Before cepstrum analysis, to reduce the isolated speckle noises that were visualized during pre-processing steps, median filter was applied. This resulted in clearer image with well-preserved edges of the ONH and retinal vessels.

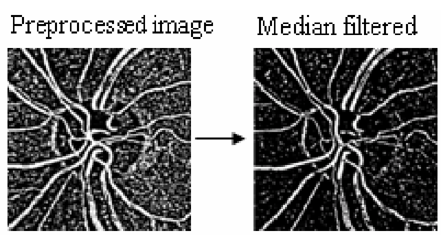

Fig. 3. Noise reduction for preprocessed images

For the paired SDP image processed by above median filter, one image is considered as reference one, $w\ (x,\ y\ )$, and the other image is considered as shifted one, $w\ (x + x_0,\ y + y_0)$, and the amount of the shift in this assumption is x_0 and y_0. If these two images were added and the result were considered as $i\ (x,\ y\ )$, then the power cepstrum P[$i\ (x,\ y\ )$] of the fused image is as follows. (In the formula, F means the Fourier transform)[1].

$$\begin{aligned} P[i(x,y)] &= \left| F\left(\ln\left(\left| F[i(x,y)] \right|^2 \right) \right) \right|^2 \\ &= P[w(x,y)] + A\delta(x,y) + B\delta(x \pm x_0, y \pm y_0) \\ &\quad + C\delta(x \pm 2x_0, y \pm 2y_0) + \cdots. \end{aligned} \tag{1}$$

By subtracting P[$w\ (x,\ y\ )$] from P[$i\ (x,\ y\ )$], x_0, y_0 and the multiple integer of the x_0 and y_0 can be acquired as peaks(Kronecker deltas).

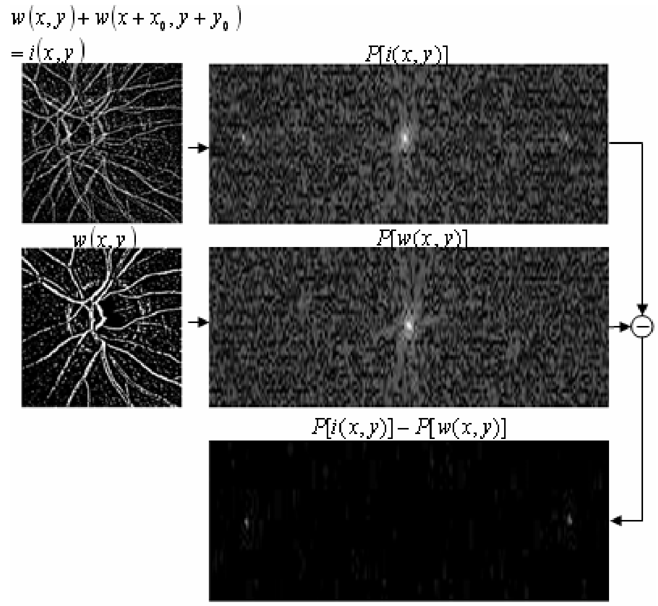

Fig. 4. Cepstrum analysis to extract shift information of stereo pair

Among all the peaks acquired by the subtraction, only one point is $(x_0,\ y_0)$, and there are several image matching metric methods to detect this real shift on the basis of the nonparametric and area approach. In this paper, zero-mean normalized cross-correlation (ZNCC) was adopted. On each coordinate of the peaks, ZNCC values of the paired two images were calculated respectively, and the largest value near 1 was considered as $(x_0,\ y_0)$, the amount of the shift between the paired images. Image cropping of the pre-processed SDP was done on the basis of the shift information.

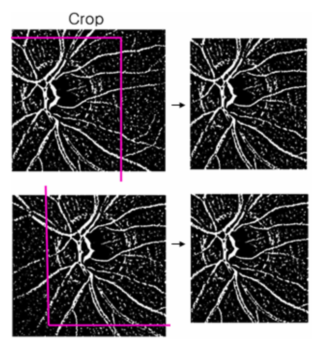

Fig. 5. Image registration for preprocessed stereo images

C. *Depth-map Retrieval*

The optics of the SDP camera used in this study is as Fig. 6, and the depth information D in the 3 dimensionally reconstructed image is in inverse proportion with the disparity $(x_1 - x_2)$ of the same point on the retina in the paired image by triangulation.

$$D = B \cdot f / (x_1 - x_2). \quad (2)$$

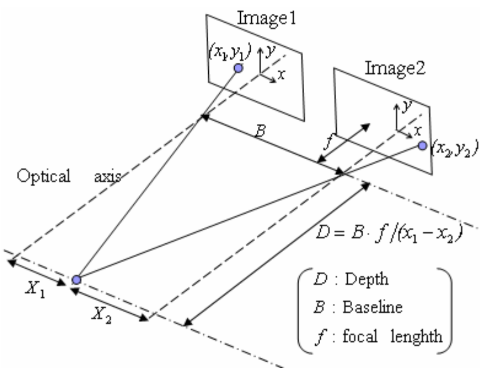

Fig. 6. Optic system of the stereo disc photography

1) *Noise Reductions*: Gaussian blurring and median filter were applied on the cropped pre-processed image to eliminate the noises without deteriorating the detailed edges in the image such as the capillaries.

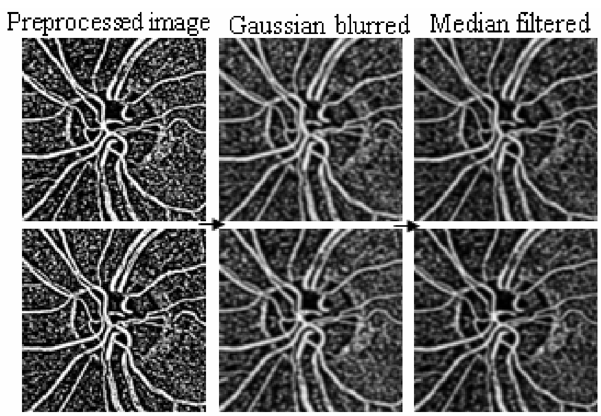

Fig. 7. Noise reduction for preprocessed images

2) *Disparity pair search & Interpolation*: disparity pair search was performed by comparing N x N area (green window on Fig. 8) of reference image and N x 3N area (red window) of the other image, using N x N sliding window. Disparity was measured by the ZNCC.

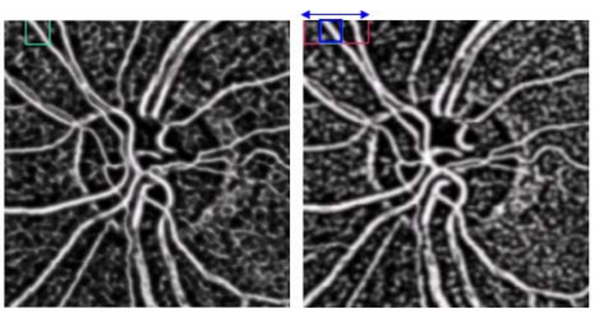

Fig. 8. disparity pair searching using sliding window

Depth information D in the 3 dimensionally reconstructed image can be calculated by the formula (2) after disparity pair searching, and the depth map was calculated by changing N value from 10 to 20. All the calculated maps were added and the final depth map was postulated by smoothing through cubic B-spline interpolation.

To visualize retinal vessels more clearly, the reference image shown in Fig. 8 was added onto the smoothed depth map with offset (Fig. 9), and the final result was reconstructed as 3 dimensional image.

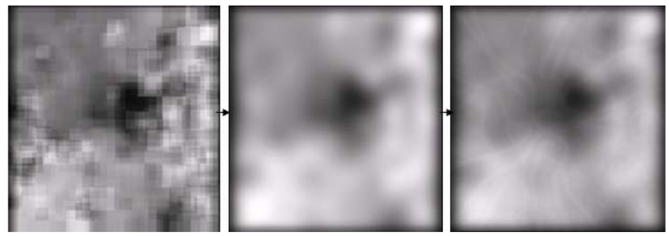

Fig. 9. Interpolation & vessel adding

III. Results

Resulted 3 dimensional contour image showed optic cups, retinal vessels and the notching of the neural rim of the optic disc clearly and intuitively, helping physicians in understanding and interpreting the SDP. (Fig.10)

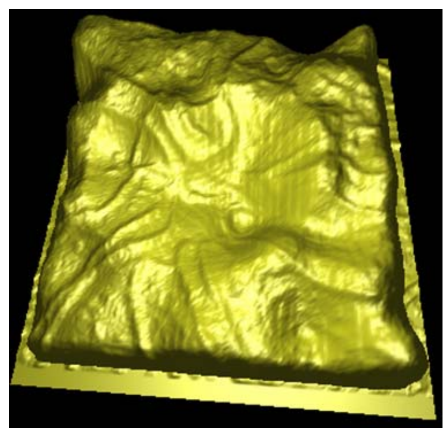

Fig. 10. 3D reconstruction of ONH

IV. Discussion

To get the real 3 dimensional coordinates of ONH is difficult because the optic system of the eye is different in each people. All the factors that determine the refractive power of the eye can affect the measurement result of the ONH by noninvasive methods, i.e. refractive power of the cornea and the lens, depth of the anterior chamber and axial length of the eye.

Although OCT is known to be the most accurate method that can correct such kind of personal optic variation, it is expensive and takes more than 5 minutes for the exact measurement under good cooperation of the patient. SDP is simple, inexpensive and takes less than one minute to get the result. If we can approximate the reconstructed image of SDP to the result of OCT, it will be much more useful, providing various features helping diagnosis and treatment of glaucoma.

ZNCC was adopted in this paper in the image matching metric procedure. It will be also beneficial to comparing our result to the results by other methods such as the pattern intensity and mutual information.

V. Conclusion

3 dimensional contour image can be successfully reconstructed from the conventional SDP by the proposed method. It will help physicians in understanding and interpreting SDP.

Acknowledgment

This work was supported by the Advanced Biometric Research Center of Seoul National University, which is an ERC supported by the Korean Science and Engineering Foundation (KOSEF) and BK21 Human Life Science program.

References

[1] E. Corona, S. Mitra, *et al.*, "Digital stereo Image Analyzer for Generating Automated 3-D Measures of Optic Disc Deformation in Glaucoma ", *IEEE Trans. Medical Imaging*, vol. 21, no. 10, Oct. 2002

[2] J. M. Ramirez, S. Mitra, J. Morales, "Visualization of the Tree-dimensional Topography of the Optic Nerve Head through a Passive Stereo Vision Mode", *Journal of Electronic Imaging*, pp.92-97, Jan. 1999

[3] C. M. Parfitt, F. S. Mikelberg, N. V. Swindale, "The Detection of Glaucoma Using an Artificial Neural Network, *1995 IEEE-EMBC and CMBEC Theme 4: Signal Processing*, pp. 847-848, 1997

[4] M. Seul, L. O'Gorman, M. J. Sammon, "Practical Algorithms for Image Analysis", Cambridge, United Kingdom: Cambridge University Press, 2000