3D RECONSTRUCTION FROM STEREO DISC PHOTOGRAPH BASED ON BLOCK MATCHING METHOD WITH VARIABLE SEARCH RANGE

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Abstract: For the better prognosis of retinal disease and disorder, early detection and treatment is important and achieved by quantitative analysis of optic nerve head (ONH). Three-dimensional reconstruction of ONH based on the conventional stereo retinal camera was proposed. In this paper, registration and depth-map retrieval based on block matching method with variable search range is proposed to enhance error robustness and shorten computation time.

Introduction

Early detection and quatitative anlysis of optic nerve head change is important in the diagnosis of retinal and optic nerve diseases, such as glaucoma, optic neuritis, compressive optic neuropathy and so on. Because retinal and optic nerve diseases can severely damage vision but rarely leads to complete blindness, early detection and treatement are significant in prognosis [1]. Stereo Disc Photographs (SDP) are used for a long time for the evaluation of the optic nerve, however, the interpretation of the image is subjective. Scanning laser system such as Heidelberg Retinal Tomography (HRT) and Optical Coherent Tomography (OCT) can provide objective and quantitative data, but they are expensive.

E. Corona et al. Proposed three dimensional reconstruction of DSP by computer vision techniques. [2]. This consist of block matching method, cepstrum, zero mean cross correlation method, and triangulation. K. Deguchi et al. assumed shape of fundus as a semi-sphere, and calculated optimized parameters based on this model[3]. But this method has disadvantage that abnormal shape of fundus is hard to be analyzed. In recent days, combined registration with correlation method and feature based method, and subpixel matching was proposed[4].

In computer vision technology, several methods was introduced. In stereo matching approaches, there are two large categories, local and global mathcing. In local matching, there are block matching, gradient-based optimization and feature matching. And dynamic programming, intrinsic curves, graph cuts, nonlinear diffusion, belief propagation and correspondenceless methods in global methods. For block matching methods, normalized cross correlation (NCC), sum of squared differences (SSD), normalized SSD, sum of absolute differences (SAD), rank, census was introduced. These methods was reviewed in the reference [5].

In this papers, registration and variable disparity search with deepest point of optic nerve head are proposed to achieve more robust and fast algorithm. There is no sharp disparity change and shape of optic nerve head is similar to hemisphere. This enables to minimize search range in depth-map retrieval process and can be applied to any block matching method easily.

Materials and Methods

The primary problems to be solved in stereo vision include calibration, correspondence, and reconstruction. Calibration problem is solved by installing hardware manually. Among several correspondence methods, the block matching method with sum of absolute differences (SAD), which is commonly used in stereo vision, is adopted. And Microsoft Visual C++ 7.0 was used for image acquisition and calculation of depth-map, and MATLAB 7 to visualize three-dimensional surfaces. The 400 x 400 pixel stereo images for reconstruction were used.

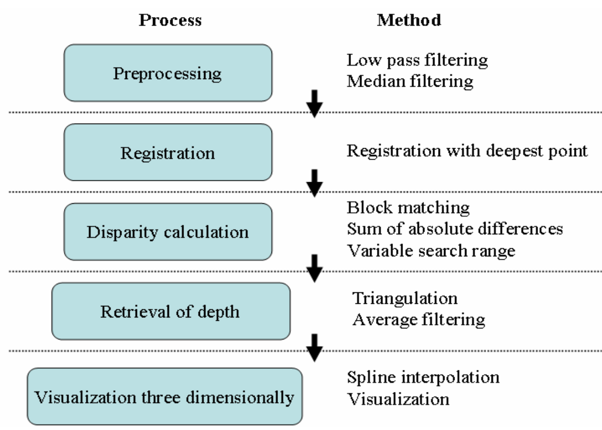

Figure 1: overall of 3-D reconstruction

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1. Image acquisition

SDP were acquired by stereo fundus camera system (Topcon TRC-SS2, Topcon Inc., Tokyo, Japan) and the image was stored in 1600x1216 pixel DICOM format and transferred. 400 x 400 pixel stereo image pair were generated including the optic disc for further analysis.

2. Preprocessing

Green channel was selected from RGB images and converted to grayscale image. Low-pass Gaussian filtering and median filtering with 5 x 5 kernel size were applied on DSP image pair.

3. Registration with deepest point

SDP was taken by horizontal beam split using prism system, thus shows disparity along the x coordinate only without global shift. In this paper, the deepest point of optic nerve head was used in registration. This point is found manually by ophthalmologist and stereo images are cropped so as to locate deepest points of left and right image to the center of each image.

4. Disparity calculation

The block matching method with variable search range based on hemisphere model was used as a disparity calculation method and sum of absolute differences was adopted as a correspondence equation. One of stereo images is chosen for a reference image. Block matching method seeks a disparity at a point in reference image by comparing a small window about that point with a series of small windows extracted from the other image. As shown in figure 2, among searching windows, a window has maximum correspondence with reference window is defined as disparity window and correspondence equation is shown in (1). CORR(I_1,I_2) denotes correspondence between image I_1 and I_2 ,and I(i,j) denotes the intensity of a pixel (i,j) in a window.

$$CORR(I_1, I_2) = \frac{1}{\sum_i \sum_j \left| I_1(\mathrm{i_L}, \mathrm{j_L}) - I_2(\mathrm{i_R}, \mathrm{j_R}) \right|} \qquad (1)$$

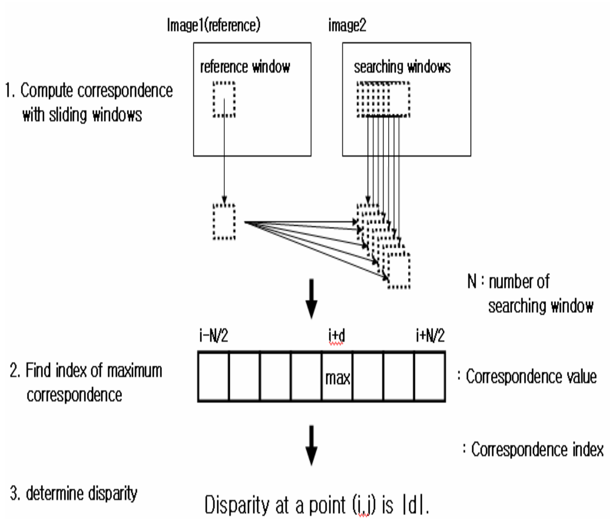

Figure 2: disparity mapping

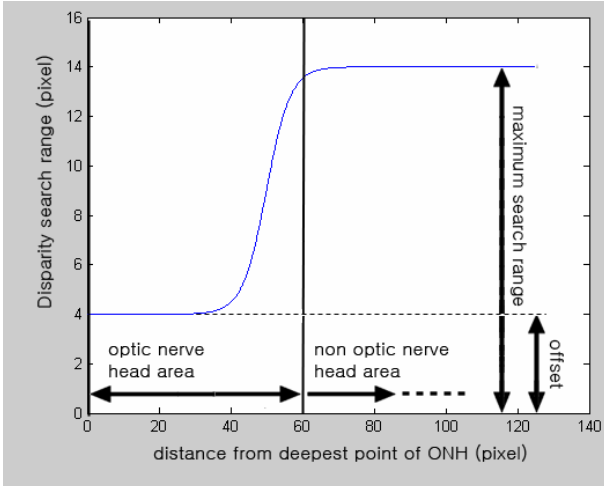

Figure 3: sigmoidal function

Disparity of a point (i_L,j_L) is difference of x coordinate between reference window (i_L, j_L) and found disparity window (i_R, j_R) and is shown in (2). DSP(I1,I2) denotes disparity at a point (i,j), $i_{reference}$ denotes x coordinate of reference window and $I_{disparity}$ denotes one of disparity window.

$$DSP(i,j) = \left| \mathrm{i_{Reference}} - \mathrm{i_{disparity}} \right| \qquad (2)$$

Number of comparing windows is determined by sigmoidal function (3) and non-linearly proportional to distance from the deepest point of ONH in the reference image. maxR denotes the maximum search range, and c is average radius of ONH (distance from deepest point to outer of ONH), (i, j) denotes coordinates of the point that we want to know the disparity, (x, y) denotes coordinates of the deepest point of ONH in the reference image and N denotes searching window number.

$$N = (\max R - offset)\frac{1}{1+\exp^{-a(r-c)}} + offset \qquad (3)$$

$$r = \sqrt{(i-x)^2 + (j-y)^2} \qquad (4)$$

5. Retrieval of depth

The disparities gained in the previous step was converted into the depth by triangulation. Triangulation was done on the fact that disparity of a point is inverse proportional to depth of that point. Because the focal length of cameras, baseline length and disparity between the two images on the film is already known by the system specification, the depth can be calculated from the disparity by the following equation as

$$Z(i,j) = f\,\frac{T}{d(i,j)}, \qquad (5)$$

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where Z denotes depth of a point (i, j) and f denotes focal length of cameras, T is baseline length between two cameras, at last, d(i, j) is disparity of a point (i, j).

Results

400 x 400 stereo image pair was used and shown in figure 4. The deepest point was checked manually and disparity mapping with block matching, which has variable search range, was performed. Block matching window size was 41 x 41, maximum search range was 10, the radius of ONH was 50 and the offset was 4.

Figure 5 (left) shows reconstructed depth-map, and 11 x 11 average filtering was applied to depth-map three times. (right). At last, surface of ONH was shown three dimensionally by MATLAB 7 (Figure 6).

Figure 7 shows depth-map from traditional 3D reconstruction, which use 41 x 41 block matching windows and has 20 pixel disparity search range. There is no difference between a method proposed in this paper and traditional one in the ONH region.

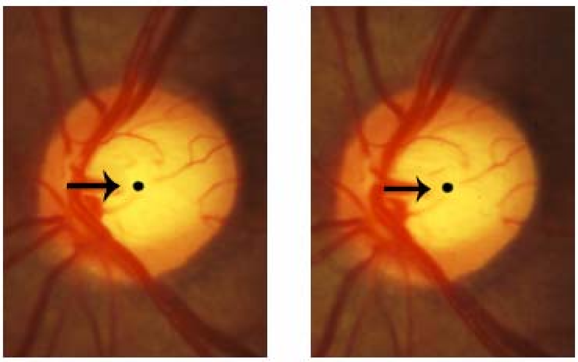

Figure 4: left and right stereo images. Arrows indicate deepest points.

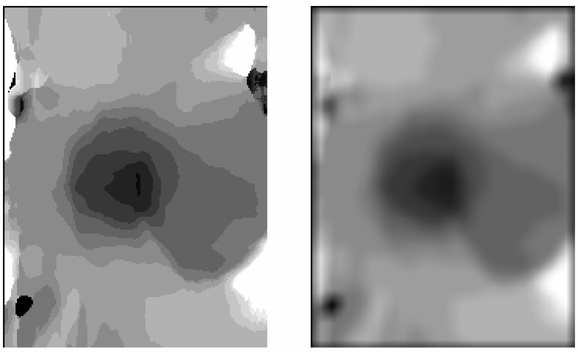

Figure 5: raw depth-map (left) and average filtered depth-map (right)

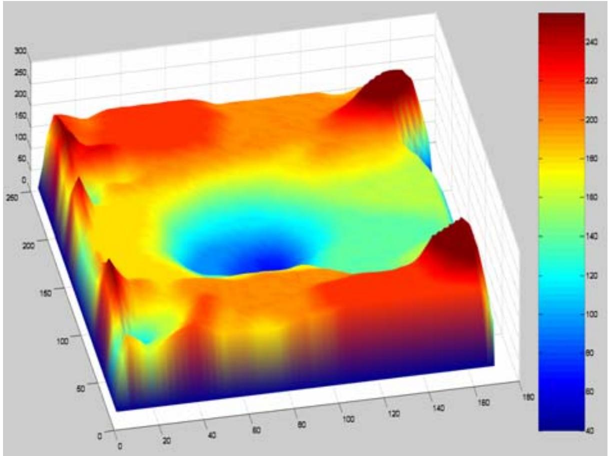

Figure 6: 3-D visuallization

Figure 7: depth map not using variable search range.

If we approximate sigmoidal function as a step function, computation profit of $N^2 \times \pi C^2 \times (MaxR - Offset)$ multiplication can be achieved compared to the traditional method, where N is sliding window side length, C is radius of ONH, MaxR is maximum disparity.

Discussion

Depth-map retrieval based on block matching methods takes considerable computation time and has weakness in the appearance of same patterns. These weak points can be overcome by shortening search range. In order to this, stereo images were registered by the deepest points, and variable search range dependent on the distance from the deepest point was used. This approach results in not only delicate result but also fast computation time. Although this method is based on hemisphere model, it doesn't find parameter of hemisphere but only shortens disparity search range. So depth-map can be similar or better than traditional one. For further work, automation of finding the deepest point and radius of ONH should be investigated.

Conclusions

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Deformation of optic nerve head is significant indicator of retinal and optic nerve diseases. Traditional diagnostic methods of ONH are subjective or expensive. As a method that can satisfy both objectification and low price, three-dimensional reconstruction of optic nerve head from SDP, which is used by ophthalmologist for a long time, was proposed. For this purpose, variable search range based on deepest point was used. We achieved $N^2 \times \pi C^2 \times (MaxR - Offset)$ computation time reduction and robust result due to shortening of search range. And this method can be adopted to other applications easily.

Acknowledgement

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