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Sector mapping method for 3D detached retina visualization

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ABSTRACT

A new sphere-mapping algorithm called sector mapping is introduced to map sector images to the sphere of an eyeball. The proposed sector-mapping algorithm is evaluated and compared with the plane-mapping algorithm adopted in previous work. A simulation that maps an image of concentric circles to the sphere of the eyeball and an analysis of the difference in distance between neighboring points in a plane and sector were used to compare the two mapping algorithms. A three-dimensional model of a whole retina with clear retinal detachment was generated using the Visualization Toolkit software. A comparison of the mapping results shows that the central part of the retina near the optic disc is stretched and its edges are compressed when the plane-mapping algorithm is used. A better mapping result is obtained by the sector-mapping algorithm than by the plane-mapping algorithm in both the simulation results and real clinical retinal detachment three-dimensional reconstruction.

1. Introduction

The main surgical repair options for retinal detachment include pneumatic retinopexy, scleral buckling, pars plana vitrectomy, and combined pars plana vitrectomy and scleral buckle [1–3]. The suitability of a repair option and the effectiveness of an operation highly depend on the accurate location of the retinal detachment. However, it is hard to clearly observe the whole retina because it is attached to the inside of the eyeball, and doctors commonly observe a part of the retina through the pupil using an ophthalmoscope or other medical instrument.

Computerized tomography, magnetic resonance imaging (MRI), optical coherence tomography (OCT), and ultrasonic methods have recently been introduced in ophthalmological practice to help doctors to diagnose retinal detachment [4–8]. However, in some cases, retinal detachment cannot be clearly visualized in images obtained by these methods because the retina is very thin and soft. Retina images taken by a retina camera are clearer than images obtained by the above means and are now widely used in retinal detachment diagnosis. However, each image obtained by a retina camera is just a part of the whole retina, which hinders doctors from accurately estimating the condition of the retina and devising a suitable treatment plan.

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A realistic three-dimensional (3D) model of the retina has been achieved by cutting, joining, and resizing 12 retinal images obtained by a retina camera [9]. A sphere 23.5 mm in diameter is used to simulate the eyeball of normal adults, as the eyeball diameter in different directions of a single person varies by no more than 1 mm. Color information of the retina on resized plane images are projected onto the sphere by the plane mapping algorithm. The whole retina with the retinal detachment is displayed in 3D by the Visualization Toolkit (VTK).

Here, a new sector-mapping algorithm is proposed. Series of simulations and comparisons are done to demonstrate the difference between the plane mapping and new sector-mapping algorithms. Details of the two methods along with their results are presented in Section 2, and the conclusion and discussion are presented in Section 3.

2. Methods and results

2.1. *Obtaining the plane image of the whole retina*

Twelve images are taken by a retina camera, where each snapshot is an image of one part of the whole retina. The objective of each image is a different part of the retina from the optic disc to the edge of iris along each angular direction of the 12 hours of a clock. An example image (in the 11 o'clock position) taken by the retina camera is shown in Fig. 1(a). The white rectangle indicates the area containing the real and clear retina image with the optic disc in the other regions. We crop the redundant areas of each slice before joining the 12 image slices together. For each of the images, the center of the optic disc is selected as the common center point, which is also the original point of the cut sectors. The two edges of each sector are selected using the angles of $\pm\pi/12$ from each hour position. After all of the 12 cut sectors have been obtained, the final retinal image is created by joining them together one-by-one clockwise, where the center point is the common point of the final image. Next, all 11 sectors are resized one-by-one according to each of its neighboring sectors. The joined and resized plane image of the whole retina is shown in Fig. 1(b), in which the gray detached part of the retina extending from 4 o'clock to 8 o'clock can be seen.

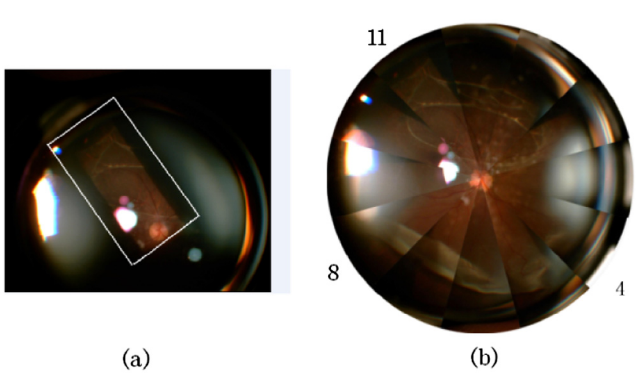

Fig. 1 – (a) Example image of the retina (in the 11 o'clock position) and (b) final plane image of the whole retina.

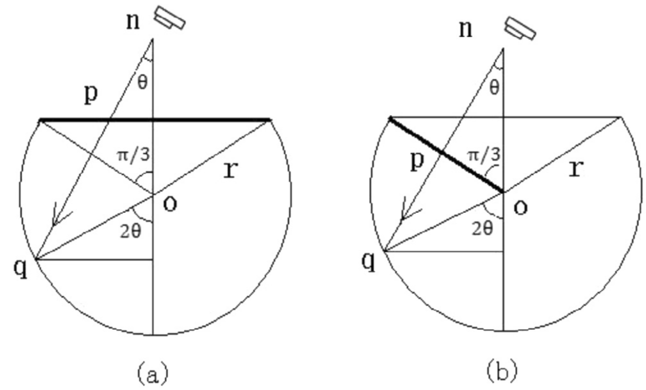

Fig. 2 – (a) Mapping plane of the plane-mapping algorithm and (b) mapping plane of the sector-mapping algorithm.

2.2. *Sphere-mapping algorithms*

After the whole resized plane image of the retina has been obtained, a texture-mapping algorithm is adopted to finish mapping the resized texture plane to the corresponding regions on a sphere [10]. The previous texture-mapping algorithm is referred to here as the plane-mapping algorithm [9].

2.2.1. *Plane-mapping algorithm*

As shown in Fig. 2(a), the pupil is assumed to be at point n on top of the sphere. Point n is selected as the origin of the sphere for easy calculation, and coordinate z starts at point n and increases to point o. A camera lens is placed on the pupil. The sphere radius is r and the iris covers the upper part of the sphere from central angle $-\pi/3$ to $\pi/3$. The lower part of the sphere is the retina, from upper angle $\theta = -\pi/3$ to $\pi/3$. The generated texture plane is placed above the retina, in the position indicated by the thick black line. Assume a ray from the camera starts at point n on the sphere, passes through point p on the plane and reaches point q on the retina on the sphere. We uniformly separate top angles θ and calculate the x and y coordinates of point p on the texture plane. We then calculate 3D coordinates x, y, and z of point q on the sphere. We finally obtain lengths Lp and Lqof points p and point q to central axis n–o:

$$\mathrm{Lp} = \frac{r}{2}\tan(\theta) \quad \left(\theta = -\frac{\pi}{3} - \frac{\pi}{3}\right)$$

$$\mathrm{Lq} = (r + r\cos(2\theta))\tan(\theta) \quad \left(\theta = -\frac{\pi}{3} - \frac{\pi}{3}\right)$$

The coordinates of point p on the texture plane are:

$$\mathrm{Xp} = \mathrm{Lp}\sin(\varphi) \quad (\varphi = 0 - 2\pi)$$

$$\mathrm{Yp} = \mathrm{Lp}\cos(\varphi) \quad (\varphi = 0 - 2\pi)$$

In addition, the coordinates of the corresponding mapping point q on the retina are:

$$\mathrm{Xq} = \mathrm{Lq}\sin(\varphi) \quad (\varphi = 0 - 2\pi)$$