A Fast Eye-Movement Tracking Using Cross-Division Algorithm

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***Abstract* - This study shows that a precise eye tracking and pupillometer system, neither interfering visual field nor influenced by head movement, can be implemented by analyzing first Paikinje image of visual field which has a few reference points. If two or more reference points are sited around the center of visual field, then eye camera captures the overlapped image of reference points and pupil.**

Four high intensity infra-red light-emitting diodes (IR LEDs) are used as reference points in this study not to disturb the subject's attention. These reference points appear as four highlighting points in the captured pupil image. The actual gazing point can be calculated by finding the distance between the center of these four reference points and pupil center and angle. Head movement causes some shift of location of pupil and reference points in the same direction and with the same amount hence does not change the relation of them.

This technique can afford to make a system that has fast sampling time and high resolution without extra servo-mechanism to chase subject's head movement.

***Index Terms* – Gazing Point Detection**

I. INTRODUCTION

Information acquired by tracking of eye movement can be applied to develop useful techniques for design of rehabilitation equipment for disabled people, diagnosis and therapy devices in ophthalmology, measuring equipment for recognition function of human being, human-like robot and several other fields and these techniques will improve ordinary life for disabled people.

A few methods of eye movement tracking were already developed. The first one is VOG technique and it finds a gazing point by processing of eye image captured by a CCD camera. The second one uses cornea reflecting technique and it finds rotated direction and displacement of eye by measuring the reflected angle of illuminated infrared rays or ultrasonic. The EOG technique is the third one and it measures signal intensity obtained from periphery muscle for eye movement. The magnetic induction technique uses the amount of electric current induced by relative movement between coil attached on a contact lens and fixed magnetic field enclosing the subject.

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The method proposed in this study uses the VOG technique but a new approach which does not require constraint of subject. The purpose of this study is realizing an algorithm for determining a gazing point by finding the center of pupil through processing of eyeball image captured by CCD camera. The image data used in this study has a spatial resolution of 640 pixels by 480 pixels and each pixel has 8-bits information in depth. The pupil area of the actual images obtained in the experiment is partially covered by an eyelid. Fig.1 shows diagram of digital image acquisition.

Fig. 1. Diagram of Digital image acquisition

II. MATERIALS AND METHODS

Four infra-red light emitting diodes (IR LEDs) are located at the center points four side of computer monitor which shows a visual stimulus pattern and these four LED make four small bright points on eye image. Fig.2 shows these four points (p_1, p_2, p_3 and p_4) superimposed on pupil area. These four points are used as reference points and this method allows a subject to move his/her head in a certain range of angle.

Assume that pupil area is a perfect circle. Let the center point of the pupil area be c and its coordinate be (0, 0), the radius of the pupil area be r, the virtual center point of four reference points be g and its coordinate be (x, y), the distance between c and g be δ, the angle between the horizontal line crossing the c and virtual line connection c and g be θ.

Then, we can get

$$\delta = \sqrt{x^2 + y^2} \tag{1}$$

and

$$\theta = \tan^{-1}\frac{y}{x} \tag{2}$$

If the diagonal distance between two reference LEDs on the computer monitor is D and that on eye image is d, and the ratio r is

$$r = \frac{D}{d} \tag{3}$$

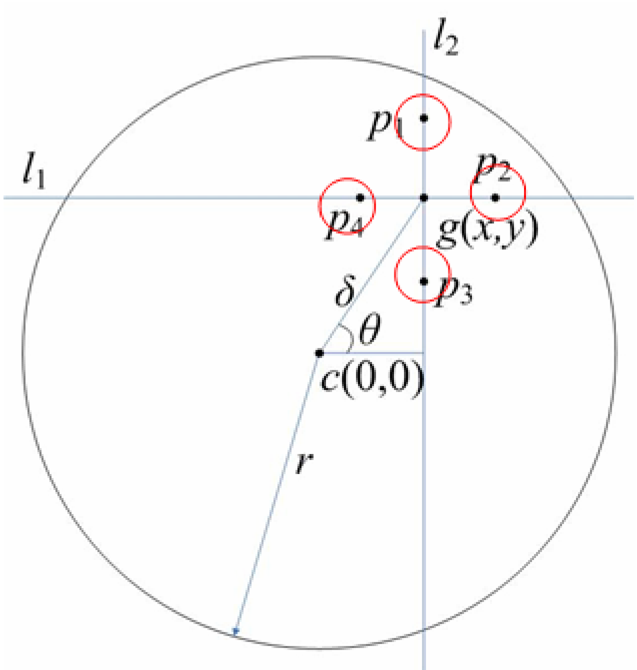

Fig. 2. Basic concept of the cross-division technique.

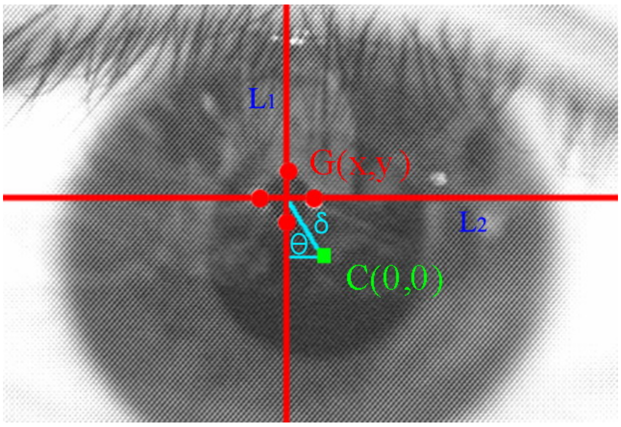

Fig. 3. Actual image to which the basic concept of cross-division algorithm was applied.

then, the actual gazing point on the computer monitor is the point which is apart $r\delta$ from the center of the monitor with the angle of θ.

III. RESULTS

In this study, the experiment was made with six subjects. In each experiment, the subject gazed at each of four pre-defined test points and a center test point. Each test point is 10 cm apart from the center of four points in four directions (up, down, right and left) and an eye image was captured for each case as shown in Fig. 4 and Fig.5. In addition, four high intensity IR LEDs were located at the center of each side of computer monitor. Four bright points shown in Fig. 4 and Fig. 5 were overlapped in the pupil area.

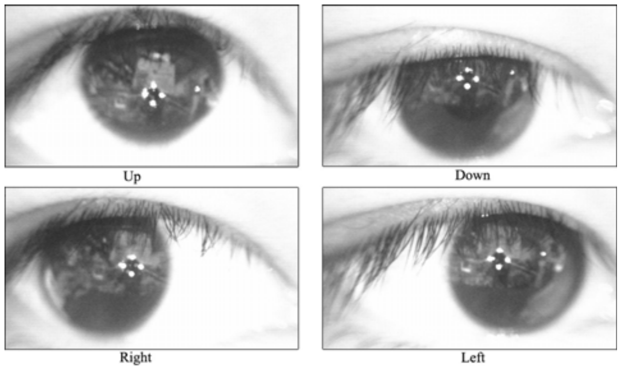

Fig. 4. Eye images when a subject gazed at the pre-defined test points.

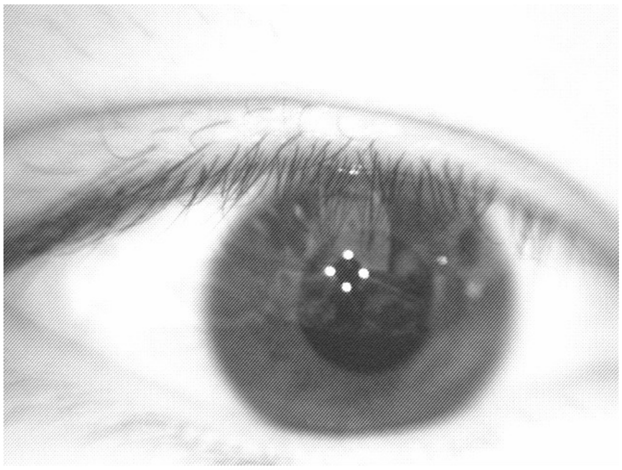

Fig. 5. Typical image showing pupil area and four reference points.

Fig. 6. An image containing four reference points only.

The center point of pupil area could be obtained by using the algorithms developed in our previous studies [8] and the image of four reference points could be obtained by subtracting an image captured when IR LEDs were turned off from an image captured when IR LEDs were turned on. The resulting image is shown in Fig. 7.

Table I and Fig. 7 show the experiment result for six subjects, S1 through S6. The value of δ is in pixel unit and θ is in degree unit.

IV. Discussion and Conclusion

As shown in Table I and Fig. 7 it is apparent to recognize the direction a subject gazes, but the average distance and maximum distance errors for gazing points are too big to be used in practical applications. This is considered that the distance error was caused by using a camera that had no zooming function. A regular camera was used in this experiment and it was installed too close to the subject, i.e. only 15cm apart from computer monitor screen to capture pupil area only. In this study has subjects of brown pupil, but next experiment, the study is demanded for subjects have the different color of pupil.

TABLE I
EXPERIMENT RESULTS

Subjects		Center	Left	Right	Up	Down
S1	δ	2.2	54.0	48.0	44.9	36.3
	θ	63.4	178.9	357.6	78.4	277.9
S2	δ	1.4	50.2	52.2	19.6	54.1
	θ	45.0	185.7	355.6	104.7	266.8
S3	δ	4.2	41.3	66.2	35.5	28.9
	θ	45.0	187.0	345.1	80.3	284.0
S4	δ	2.0	38.1	44.1	28.0	26.2
	θ	90.0	183.0	356.1	88.0	276.6
S5	δ	7.1	50.0	50.0	42.4	36.1
	θ	135.0	191.5	0.0	98.1	273.2
S6	δ	15.8	43.2	76.2	51.0	28.0
	θ	34.7	193.4	4.5	87.8	272.0
Average distance	δ	5.5	46.1	56.1	36.9	34.9
Maximum Distance error		18.4	16.3	33.2	32.8	28.6

The value of δ is in pixel and θ is in degree.

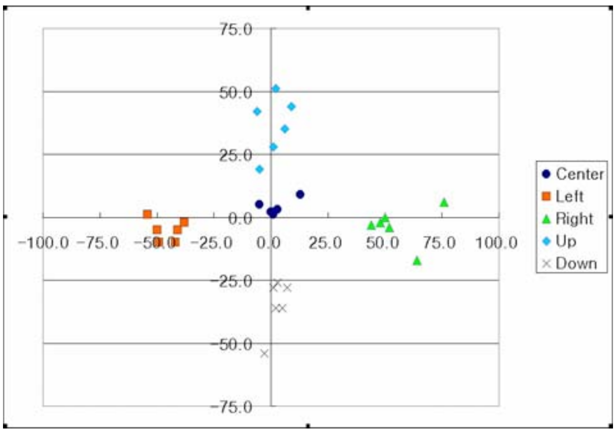

Fig. 7. Distribution of calculated gazing points.

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