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Analysis of Aiming Performance for Games Using Mapping Method of Corneal Reflections Based on Two Different Light Sources

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***Abstract*—**Fundamental motivation of this paper is how gaze estimation can be utilized effectively regarding an application to games. In games, precise estimation is not always important in aiming targets but an ability to move a cursor to an aiming target accurately is also significant. Incidentally, from a game producing point of view, a separate expression of a head movement and gaze movement sometimes becomes advantageous to expressing sense of presence. A case that panning a background image associated with a head movement and moving a cursor according to gaze movement can be a representative example. On the other hand, widely used technique of POG estimation is based on a relative position between a center of corneal reflection of infrared light sources and a center of pupil. However, a calculation of a center of pupil requires relatively complicated image processing, and therefore, a calculation delay is a concern, since to minimize a delay of inputting data is one of the most significant requirements in games. In this paper, a method to estimate a head movement by only using corneal reflections of two infrared light sources in different locations is proposed. Furthermore, a method to control a cursor using gaze movement as well as a head movement is proposed. By using game-like-applications, proposed methods are evaluated and, as a result, a similar performance to conventional methods is confirmed and an aiming control with lower computation power and stressless intuitive operation is obtained.

***Keywords*—**Point-of-gaze, gaze estimation, head movement, corneal reflections, two infrared light sources, game.

I. INTRODUCTION

ESTIMATION technique of point-of-gaze (POG) has long been researched and applied for many fields of human computer interactions [1]-[7], i.e., inputting information to computers [2][4] or observing attention of subjects on Web browser [17]. In almost all situations, one of the most significant interests has been highly precise estimation of POG. To achieve this purpose, precise measurement of a center of corneal curvature and a center of pupil considering light refractions is established [9]. It produces excellently accurate results, whereas it requires relatively high computation power which incurs undesirable latency. To minimize a delay of inputting data is one of the most significant requirements in games, and therefore, such complicated image processing should be avoided as much as possible.

On the other hand, considering an effective use of gaze estimation in games, first thing coming to mind is an application to games kind of first-person shooter (FPS). It might be applicable straightforwardly assuming entirely precise gaze estimation. However, it would easily take place that it gets out of actual POG due to many factors in reality. In such situation, an important thing in aiming targets is not always precise estimation of POG but easiness of aiming control with comfortable operation often surpass it. In other words, a matter of great importance is to be capable of having fine control of a cursor to a target with holding gaze upon a target. Incidentally, from a game producing point of view, a separate representation of a head movement and gaze movement sometimes becomes advantageous to expressing sense of presence. A case that panning a background image associated with a head movement and moving a cursor according to gaze movement can be raised as a representative example.

To satisfy these requirements, a method to estimate a head movement and gaze movement by only using corneal reflections of two infrared light sources in different locations is proposed. Proposed method can be separated into two parts. One is the simple technique for mapping a head movement to a cursor location. The other one is the simple technique for mapping POG under a head movement. The noteworthy point is that a detection of pupil center is not required in all procedures.

Following sections in this paper is organized as follows. As a preparation for a presentation of the proposed method and performance comparison, two conventional techniques are introduced in Section II. In Section III, a detailed analysis of proposed simple mapping method is presented and its effectiveness is pointed out using numerical simulation. In Section IV, the experimental system is introduced and performance comparison under several representative use cases in games is presented. Discussions about obtained results are also stated in Section IV. And results are summarized and concluded in Section V.

II. CONVENTIONAL TECHNIQUES

As conventionally studied, it is a popular method to estimate POG using reflection of light sources on corneal surface.

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TABLE I
SIMULATION PARAMETERS

Symbol	Quantity	Value
r_{head}	Head radius	10.0 cm
r_{eye}	Eye radius	2.4 cm
r_{cor}	Corneal curvature radius	1.8 cm
d_{cor}	Distance between eye center and corneal curvature center	0.8 cm
d_{eyes}	Distance between center of two eyes	7.0 cm
d_{cam}	Distance between camera and eye center	5.0 cm
d_{scr}	Distance between head center and screen center	50.0 cm
w_{scr}	Screen width	32.0 cm
h_{scr}	Screen height	16.0 cm
w_{grd}	Horizontal marker interval (grid width)	16.0 cm
h_{grd}	Vertical marker interval (grid height)	8.0 cm

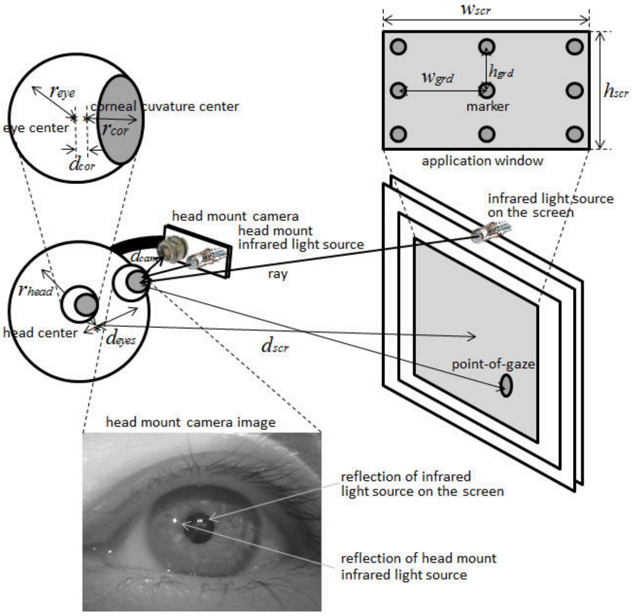

Fig. 1. Eye tracking system diagram

Fig. 1 shows a system diagram of the eye tracking system using corneal reflections. In this diagram, two infrared light sources are indicated, one is located on a screen and the other one is mounted on a head. In many studies, either of them is used for POG estimation, however, the technique presented here requires both of them. As being observed in a picture image in Fig. 1, light sources on a screen is having comparatively strong power (it consists of two arrays of three light sources), and one very low power light source is settled very close to the top of the nose. The reason for the former choice is to distinguish reflections of two kinds of light sources effectively, and the reason for the latter choice is caring about the negative influence for eyes. Furthermore, a camera is mounted on a head for the purpose of obtaining higher resolution image of an eye. A standard USB2.0 camera is used in which an infrared ray insulating sheet is removed to achieve an efficient detection performance of infrared light reflections.

By using this system, mapping transformation from the coordinates of corneal reflection point $\boldsymbol{p_{cor}}$ to POG $\boldsymbol{p_{gaze}}$ can be expressed as

$$\boldsymbol{p_{gaze}} = \boldsymbol{M}\boldsymbol{p_{cor}}, \tag{1}$$

where $\boldsymbol{M}$ is the mapping conversion matrix. In standard cases, $\boldsymbol{M}$ is calculated in a calibration process where a subject gazes several fixate specific points on a screen, normally four corners and a center, and associated coordinates of corneal reflection points are measured, respectively. Based on this relation expressed as (1), impact of a head movement for gaze estimation will be simulated using two simple gaze estimation techniques in following subsections. This simulation assumes conditions such that a subject gazes nine markers which are arranged in the grid pattern spreading fully on the screen as shown in Fig. 1, and, additionally, a subject rotates the head to leftward, rightward, upward and downward for ten degrees each. Parameters used in this simulation are described in Table I.

A. Simple mapping method to estimate POG using corneal reflection of single light source (Method A)

One of the simplest methods for gaze estimation is mapping from $\boldsymbol{p_{cor}}$ to $\boldsymbol{p_{gaze}}$, however, it is well-known that a head movement affects fairly sensitively to estimation. Method A-1 and A-2 in Fig. 2 indicate the coordinates of $\boldsymbol{p_{cor}}$ associated with each $\boldsymbol{p_{gaze}}$ on a screen. Here, Method A-1 shows the case using $\boldsymbol{p_{cor}}$ of the light source on a screen, expressing $\boldsymbol{p_{cor\,scr}}$. Then, mapping transformation can be expressed as

$$\tilde{\boldsymbol{p}}_{\boldsymbol{gaze}} = \tilde{\boldsymbol{M}}_{\boldsymbol{scr}}\boldsymbol{p_{cor\,scr}}, \tag{2}$$

where $\tilde{\boldsymbol{M}}_{\boldsymbol{scr}}$ is the calibrated mapping conversion matrix and $\tilde{\boldsymbol{p}}_{\boldsymbol{gaze}}$ is estimated POG. Method A-2 shows the case using $\boldsymbol{p_{cor}}$ of the head mount light source, expressing $\boldsymbol{p_{cor\,hm}}$. Then, mapping transformation can be expressed as

$$\tilde{\boldsymbol{p}}_{\boldsymbol{gaze}} = \tilde{\boldsymbol{M}}_{\boldsymbol{hm}}\boldsymbol{p_{cor\,hm}}, \tag{3}$$

where $\tilde{\boldsymbol{M}}_{\boldsymbol{hm}}$ is the calibrated mapping conversion matrix. These results indicate that it varies largely according to a head movement, and therefore, it will compel a subject to keep the head strictly still and only to move the eyes for precise POG estimation. Furthermore, Method A-2 is less influence of a head movement than Method A-1, however, distortion of points arrangement is worse, especially when a subject moves the head to rightward. This is caused by the relationship between a camera location and a head mount light source location and the location adjustment can

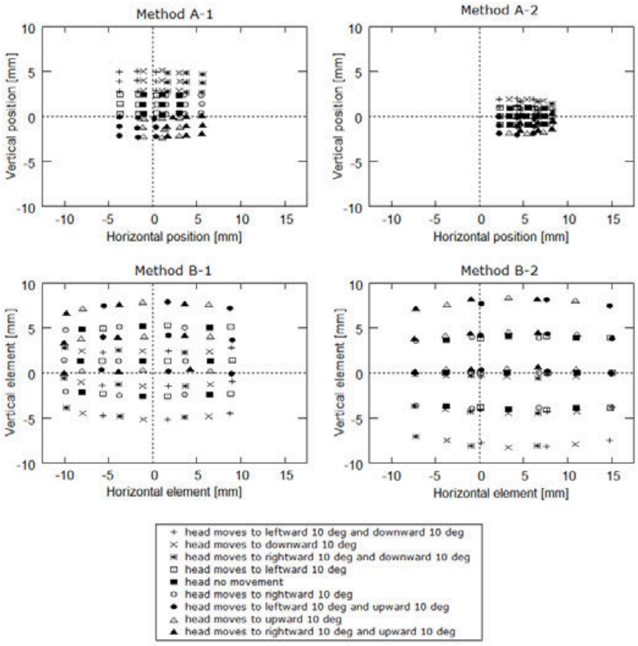

Fig. 2. The coordinates of p_{cor} associated with p_{gaze} under an influence of a head movement in Method A and B

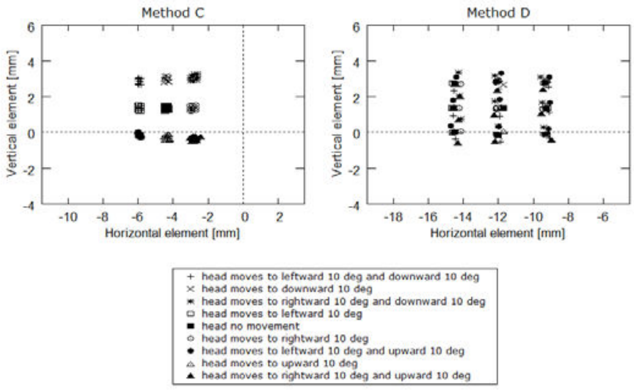

Fig. 3. The coordinates of p_{cor} associated with p_{gaze} under an influence of a head movement in Method C and D

mitigate the situation, however, the tendency will not change significantly.

B. Mapping method to estimate POG using relative position between corneal reflection and pupil center (Method B)

It is also well-known that detecting relative position between p_{cor} and pupil center and mapping to p_{gaze} is comparatively insensitive to a head movement. Method B-1 and B-2 in Fig. 2 indicates the coordinates of the relative position between p_{cor} and pupil center associating with each p_{gaze} on a screen. Here, Method B-1 shows the case using p_{cor} of the light source on a screen. Then, mapping transformation can be expressed as

$$\tilde{p}_{gaze} = \tilde{M}_{scr-pup}({p_{cor}}_{scr} - c_{pup}), \tag{4}$$

where $\tilde{M}_{scr-pup}$ is the calibrated mapping conversion matrix and c_{pup} is the coordinates of a center of pupil. Method B-2 shows the case using p_{cor} of the head mount light source. Then, mapping transformation can be expressed as

$$\tilde{p}_{gaze} = \tilde{M}_{hm-pup}({p_{cor}}_{hm} - c_{pup}), \tag{5}$$

where $\tilde{M}_{hm-pup}$ is the calibrated conversion mapping matrix. These results indicate that the influence of a head movement is comparatively less than Method A-1 and A-2, and therefore, the estimated POG does not vary much even when a subject moves the head. Moreover, it is observed that the dynamic range of detected ${p_{cor}}_{hm} - c_{pup}$ are larger than Method A-1 and A-2. This means that higher resolution of $\tilde{p}_{gaze}$ can be obtained using Method B-1 and B-2. On the other hand, although it cannot be directly observed from these results, calculation is much more complicated to detect c_{pup} and its accuracy is not always much guaranteed due to an unreliable pupil recognition and influence of light refractions, especially when pupil is not settled around a center of an eye. In addition, it is well-known that influence of a head movement can be improved much less when a camera is placed far from a subject. According to our another simulation which is not described here, influence of a head movement becomes negligible small when a camera is located at the top of the screen. However, in the analysis described here, the higher resolution of a camera image is prior to these advantageous performance, since a use of far field camera requires advanced detection and recognition techniques and incurs undesirable decline of estimation performance.

III. PROPOSED TECHNIQUE

The proposed technique is based on the characteristic that relative position between ${p_{cor}}_{scr}$ and ${p_{cor}}_{hm}$ reflects a head movement. In addition, in combination with Method A, new technique for gaze estimation under a head movement is presented. Significant point is that detection of pupil center is not required in all procedures, and therefore, relatively light computation power is required.

A. Mapping method to estimate a head movement using position relationship between corneal reflections of two light sources (Method C)

Method C in Fig. 3 shows the coordinates of relative position between ${p_{cor}}_{scr}$ and ${p_{cor}}_{hm}$. Then, mapping transformation can be expressed as

$$\tilde{p}_{gaze} = \tilde{M}_{scr-hm}({p_{cor}}_{scr} - {p_{cor}}_{hm}), \tag{6}$$

where $\tilde{M}_{scr-hm}$ is the calibrated mapping conversion matrix. This result indicates that the element of ${p_{cor}}_{scr} - {p_{cor}}_{hm}$ purely reflects a head movement and an influence of gaze movement is almost canceled. According to our simulation and experimentation results, the relation between a head mount camera location and a head mount light source location slightly affects to the result, and therefore, rough adjustment for their placement should be considered.

B. Mapping method to estimate POG using position relationship between corneal reflections of two light sources (Method D)

Method A is the simplest technique to estimate POG, however, an influence of a head movement is significantly huge. On the other hand, Method C purely reflects a head movement and an influence of gaze movement is almost canceled. The proposal presented here is originated with the idea to cancel an influence of head movement in Method A by using Method C. Using Method A-2, Method D can be expressed as

$$\tilde{\boldsymbol{p}}_{gaze} = \tilde{\boldsymbol{M}}_{hm}\boldsymbol{p}_{cor\,hm} + \tilde{\boldsymbol{M}}_{scr-hm}(\boldsymbol{p}_{cor\,scr} - \boldsymbol{p}_{cor\,hm}). \quad (7)$$

It is observed that when $\tilde{\boldsymbol{M}}_{hm}\boldsymbol{p}_{cor\,hm} = \boldsymbol{0}$, (7) is equivalent to (6), and this means that (7) can be achieved if $\tilde{\boldsymbol{M}}_{hm}\boldsymbol{p}_{cor\,hm} = \boldsymbol{0}$ can be ensured in calibrating $\tilde{\boldsymbol{M}}_{scr-hm}$. Actually, it is not difficult to realize by performing the calibration process as follows:

1. Estimate $\tilde{\boldsymbol{M}}_{hm}$by measuring $\boldsymbol{p}_{cor\,hm}$ and calculating the conversion matrix from $\boldsymbol{p}_{cor\,hm}$ to $\boldsymbol{p}_{gaze}$. A subject should keep the head still and track *"markers-for-calibration"*,
2. by using the result of this first calibration, indicate *"marker-1"* which represents $\tilde{\boldsymbol{p}}_{gaze}$ $(= \tilde{\boldsymbol{M}}_{hm}\boldsymbol{p}_{cor\,hm})$ on the screen,
3. indicate *"marker-2"* at the center $(= \boldsymbol{0})$ of the screen, and
4. estimate $\tilde{\boldsymbol{M}}_{scr-hm}$ by measuring $\boldsymbol{p}_{cor\,scr} - \boldsymbol{p}_{cor\,hm}$ and calculating the conversion matrix from $\boldsymbol{p}_{cor\,scr} - \boldsymbol{p}_{cor\,hm}$ to $\boldsymbol{p}_{gaze}$. A subject should pay attention to make *"marker- 1"* to overlap with *"marker-2"* in tracking *"markers-for-calibration"*.

Another possible way is to measure $\boldsymbol{p}_{cor\,hm}$ and $\boldsymbol{p}_{cor\,scr} - \boldsymbol{p}_{cor\,hm}$ in gazing a center of a screen and moving a head. By calculating the relation between these two elements, $\tilde{\boldsymbol{M}}_{hm}{}^{-1}\tilde{\boldsymbol{M}}_{scr-hm}$ can be obtained. Actually, Method D in Fig. 3 can be obtained by simulating $\boldsymbol{p}_{cor\,hm} + \tilde{\boldsymbol{M}}_{hm}{}^{-1}\tilde{\boldsymbol{M}}_{scr-hm}(\boldsymbol{p}_{cor\,scr} - \boldsymbol{p}_{cor\,hm})$, where the mapping conversion assumes simple linear transformation. This result means that an influence of a head movement in Method A-2 can be canceled by using the result of Method C and $\tilde{\boldsymbol{p}}_{gaze}$ can be estimated correctly.

IV. EXPERIMENTS

A. Experimental system

To compare the performance of each method described in former sections, the experimental system shown in Fig. 4 is used. This is the very first prototype, and therefore, the appearance is just handmade, however, sufficient functionality is applied. In this picture, two cameras are found in front of each eye and only one of them is used for the evaluation described here. The size of the image captured from the camera is VGA and the capturing speed is around 10 fps at this moment.

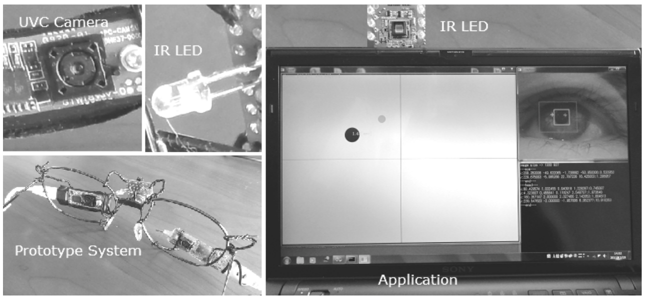

Fig. 4. Experimental system

B. Calibrations

Calibration process consists of two phases. The first one is for Method A-2 and the second one is for Method C. Fig. 5 indicates the calibration process and the calibration result for each phase. In calibration process for Method A-2, a subject stares at nine markers consecutively as shown in Process for Method A-2 in Fig. 5. In this procedure, a subject has to keep the head still and moves gaze only, is an important point. An example result of measured $\boldsymbol{p}_{cor\,hm}$ is shown in Result of Method A-2 in Fig. 5. In this figure, the unit of each axis is camera pixel on condition that the full size of captured camera image is 640×480 pixels. After this step, calibration process for Method C begins. Movements of markers are similar to the previous sequence, and moreover, the center marker and the estimated POG of Method A-2 are indicated all through the procedure. A subject gazes nine markers one after another with moving the head to make the marker of estimated POG overlap with the center marker, respectively. An example result of measured $\boldsymbol{p}_{cor\,scr} - \boldsymbol{p}_{cor\,hm}$ is shown in Result of Method C in Fig. 5. This result indicates that the head movement element can be measured relatively accurately. In addition, since $\tilde{\boldsymbol{M}}_{hm}\boldsymbol{p}_{cor\,hm} = \boldsymbol{0}$ is hold all through the calibration process of Method C, Method D can be achieved by the linear combination of Method A-2 and Method C as represented in (7).

C. Comparison of POG estimation

Since the evaluation presented here is not focusing on the accuracy of POG estimation but being particular about easiness to reach the target, the algorithm is not tuned to perform the precise gaze estimation. The mapping algorithm is simple linear transformation and not using other advanced filters other than a Gaussian filter in the initial process. In

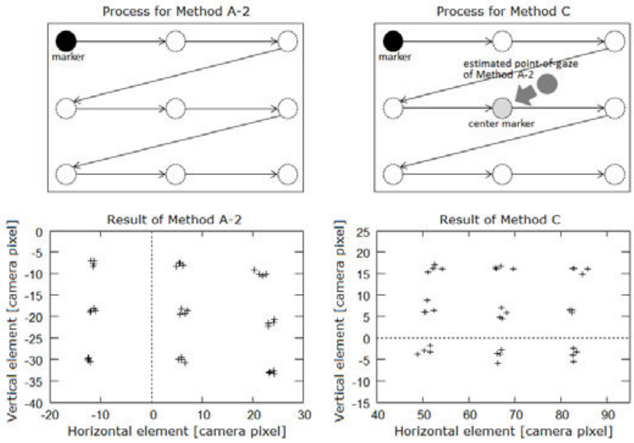

Fig. 5. Calibration process and calibration results of Method A-2 and Method C

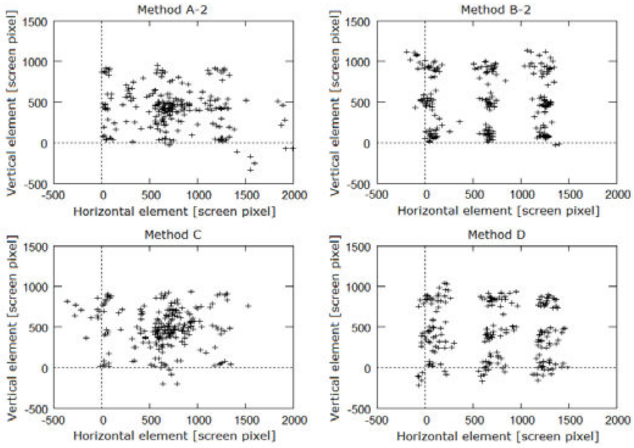

Fig. 6. The static characteristics comparison of each method

this condition, Fig. 6 indicates estimated POG when a subject tracks nine markers on a screen. In this experiment, a subject is not restricted to move a head, and therefore, an influence of a head movement can be observed directly. In this figure, the unit of each axis is screen pixel on condition that the full size of panel is 1920×1080 and the window size of the experimental application is 1300×940 which corresponds to the size of 20cm width and 14cm height. As a result, it is observed that estimated POG are converged around the points of nine markers in case of Method B-2 and Method D even when a head movement occurs.

D. Comparison as a method to move a cursor

Fine accuracy of POG estimation will contribute to prompt movement of a cursor, however, the capability to reach targets is also important. Fig. 7 shows trajectories when a subject attempts to move a cursor to overlap with ten fixed markers one after another. In case of Method A-2, fast cursor movement is executed first and, after that, settling sequence by a head movement is observed. Sometimes, overshooting occurs, however, a cursor reaches to markers certainly. Actually, since effect of a head movement is explicit in Method A-2, stress of a subject was not serious. In case of Method B-2, prompt movement of a cursor is excellently executed and settling sequence is not required in most cases. However, when a cursor is off the marker, a subject often suffers from the stress not to be able to slightly move a cursor to the marker. In case of Method C, the situation is fairly different. A cursor is controlled only by a head movement, and therefore, comparatively slow approach of a cursor is observed. However, it reaches to markers certainly. In case of Method D, perfect seeking and settling of a cursor is executed. Actually, effect of a head movement is explicit and intuitive in Method D, a subject looks comfortable to operate.

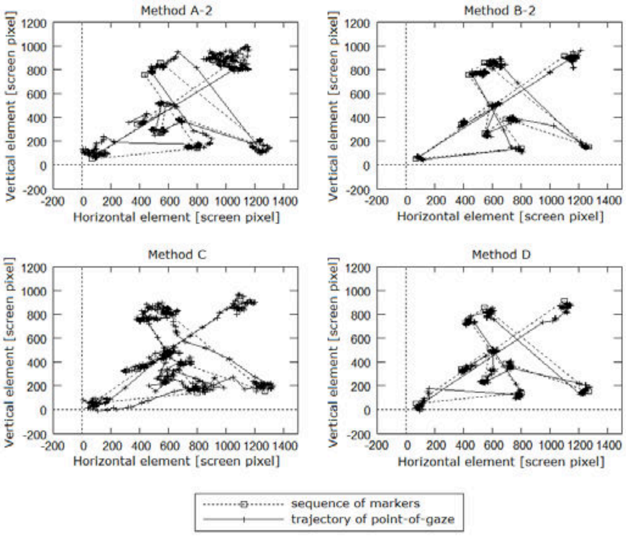

Fig. 7. An example trajectory to move a cursor

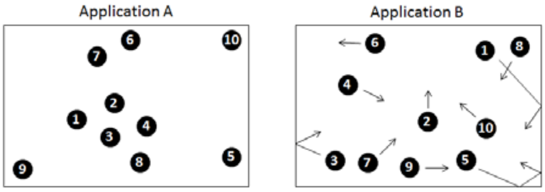

Fig. 8. Gaming applications

E. Performance comparison in gaming applications

To evaluate performance in gaming use cases of each method, game-like-applications shown in Fig. 8 are utilized. In Application A, ten markers appear consecutively and they do not move. A subject should control a cursor representing estimated POG to overlap a marker. Overlapping period is

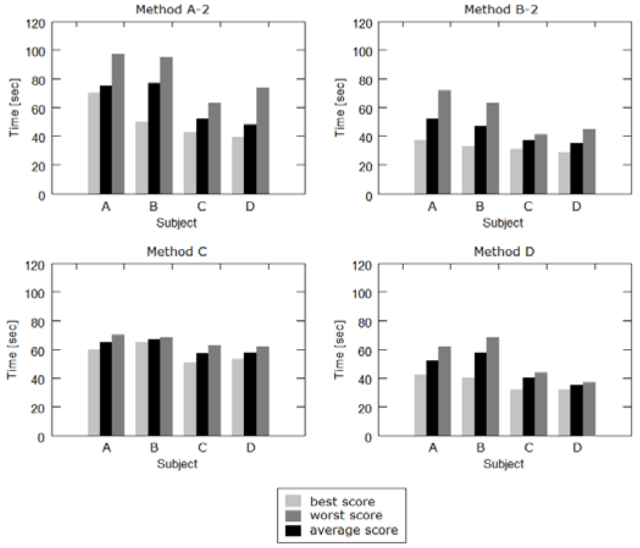

Fig. 9. Results of Application A

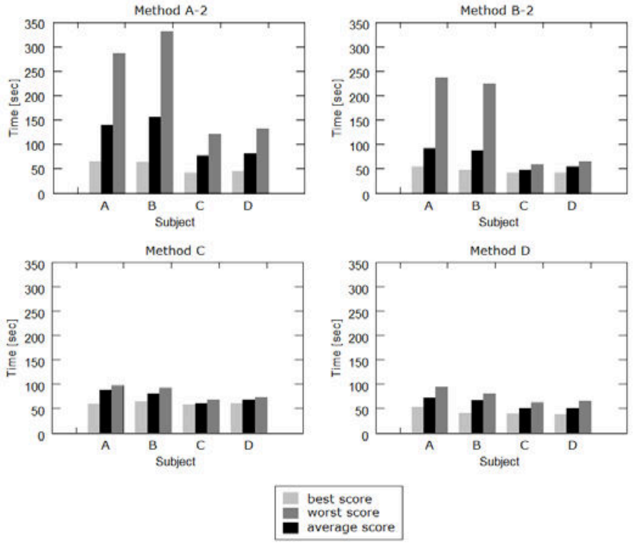

Fig. 10. Results of Application B

counted and if it exceeds 2 seconds, a maker disappears and another maker appears. Multiple markers do not exist at the same time, and therefore, a subject should concentrate on one marker and defeat it sequentially. Markers are indicated as circles of 40 pixels (6mm) radius and a cursor representing estimated POG is a circle of 20 pixels (3mm) radius. When the edge of each circle comes in contact, in other words, when the distance between their centers becomes less than sixty pixels (9mm), it regards as they overlapped. In Application B, appearance condition of markers is just the same as Application A, and moreover, markers move at a velocity of about 200 pixels per second (30mm/sec). Fig. 8 is just an example, and therefore, locations and directions of markers are determined randomly. The total time taken to disappear all ten markers is measured and evaluated.

Four subjects participated experiments, who are 24-year-old female, 35-year-old male, 43-year-old female and 45-year-old male. 43-year-old female and 45-year-old male were familiar with this system and other two subjects attempted this system for the first time. All subjects conducted each application five times after short free run. Results are shown in Fig. 9 and Fig. 10. As described, it takes at least 2 seconds to disappear a marker, and therefore, 20 seconds will be consumed at minimum for one trial run.

From the result of Application A, it can be observed that results of all methods are within 100 seconds and not having particularly bad records. The good condition of the average score is made by Method B-2 and Method D and the best score was made by Method B-2. The score dispersion is least in Method C, however, Method B-2 and Method D is not much worse. The worst score was made by Method A-2. On the other hand, from the result of Application B, some particularly bad scores are observed in Method A-2 and Method B-2. The best average score is made by Method D and Method B-2 follows by a narrow margin. The score dispersion is least in Method C and most in Method A-2.

F. Discussion

Method A-2 forces subjects to keep their heads still and move gaze only. Moreover, Method A is having characteristics that a cursor moves to the opposite direction to a head movement, and therefore, to move a cursor to right, subjects have to move their heads to left. When a cursor comes off the marker, subjects try to move their heads to the opposite direction to the marker, however, it sometimes confused subjects in tracking moving markers.

Method B-2 provides fine gaze estimation and is robust to a head movement. Conversely, Method B-2 has negative characteristics that once a cursor is off the marker, correction of that error is relatively difficult to achieve using a head movement. This is the reason for occasional particularly bad score. It is not as remarkable as Method A-2, but Method B-2 is also having characteristics that a cursor moves to the opposite direction to a head movement. However, since its effect is fairly small, some subjects could not experience its effect explicitly and sometimes felt no way to make a cursor closer. In such situation, some subjects attempted to escape by moving gaze to be slightly off the marker.

Method C is not affected by gaze movement, and therefore, subjects have to control a cursor only by a head movement. Since prompt movement of a cursor by saccadic eye movement cannot be expected, Method C has a weak point such that it consumes a time to make a cursor closer to the marker. However, all subjects were sure to reach markers with an explicit head movement, and felt sense of security. As a result, despite that it takes time for approaching a cursor, stable score was obtained.

Method D has both characteristics of a head movement effect in Method C and gaze movement effect in Method A-2. When subjects gaze to the fixed point and move their head, then a cursor moves gently to the same direction as a head movement. Despite that quality of gaze estimation is slightly worse than Method B-2, even when a cursor is off the marker, subjects can make a correction easily by intuitive head movement. This is why particularly bad score was not happened in Method D. It can be concluded that Method D has a proper balance between prompt movement by saccadic eye movement and intuitive operation by a head movement.

V. CONCLUSION

In this paper, application of gaze estimation to games is considered and performance comparison among two conventional methods and two proposed methods by using game-like-applications are described. And, focusing on surely moving a cursor to a target, performance of aiming control is presented. As a result, a similar performance to conventional methods is confirmed instead of calculating a center of pupil, and an aiming control with lower computation power and stressless intuitive operation is obtained.

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REFERENCES

[1] R. J. acob, "The use of eye movements in human computer interaction techniques: What you look at is what you get," *ACM Transactions on Information Systems 9*, 1991, pp. 152-169.

[2] S. Zhai, C. Morimoto, and S. Ihde, "Manual and gaze input cascaded (magic) pointing," *Proceedings of the SIGCHI conference on Human factors in computing systems*, 1999, pp. 246-253.

[3] A. T. Duchowski, "A breadth-first survey of eye-tracking applications," *Behavior Research Methods Instruments & Computers 34(4)*, 2002, pp. 455-470.

[4] C. H. Morimoto, and M. R. Mimica, "Eye gaze tracking techniques for interactive applications," *Computer Vision and Image Understanding, Special Issue on Eye Detection and Tracking 98*, 2005, pp. 4-24.

[5] C. H. Morimoto, A. Amr, and M. Flickner, "Detecting eye position and gaze from a single camera and 2 light sources," *Proceedings of the International Conference on Pattern Recognition*, 2002.

[6] Z. Zhu, and Q. Ji, "Eye gaze tracking under natural head movements," *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR05)*, 2005.

[7] F. L. Coutinho, and C. H. Morimoto, "Free head motion eye gaze tracking using a single camera and multiple light sources," *Proceedings of the XIX Brasilian Symposium on Computer Graphics and Image Processing*, 2006, pp. 171-178.

[8] J. Chen, T. Tong, W. Gray, and Q. Ji, "A robust 3D eye gaze tracking system using noise reduction," *Proceedings of the 2008 symposium on Eye tracking research & applications*, 2008, pp. 189-196.

[9] E. D. Guestrin, M. Eizenman, J. J. Kang, and E. Eizenman, "Analysis of subject-dependent point-of-gaze estimation bias in the cross-ratios method," *Proceedings of the 2008 symposium on Eye tracking research & applications*, 2008, pp. 237-244.

[10] D. Model, and M. Eizenman, "User-calibration-free remote gaze estimation system," *Proceedings of the 2008 symposium on Eye tracking research & applications*, 2010, pp. 29-36.

[11] M. Eizenman, R. Sapir-Pichhadze, C. A. Westall, A. M. Wong, H. Lee, and Y. Morad, "Eye-movement responses to disparity vergence stimuli with artificial monocular scotomas," *Current Eye Research 31(6)*, 2006, pp. 471-480.

[12] E. D. Guestrin, and M. Eizenman, "Remote point-of-gaze estimation with free head movements requiring a single-point calibration," *Proceedings of Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2007, pp. 4556-4560.

[13] D. W. Hansen, J. S. Agustin, and A. Villanueva, "Homography normalization for robust gaze estimation in uncalibrated setups," *Proceedings of the 2008 symposium on Eye tracking research & applications*, 2010, pp. 13-20.

[14] S. Munn, and J. B. Pelz, "3D point-of-regard, position and head orientation from a portable monocular video-based eye tracker," *Proceedings of the 2008 symposium on Eye tracking research & applications*, 2008, pp. 181-188.

[15] F. Li, S. Munn, and J. Pelz, "A model-based approach to video-based eye tracking," *Journal of Modern Optics, Special Issue onPhysiological Optics*, 2008.

[16] S. M. Kolakowski, and J. B. Pelz, "Compensating for eye tracker camera movement," *Proceedings of the 2006 symposium on Eye tracking research & applications*, 2006, pp. 79-85.

[17] J. H. Goldberg and J. I. Helfman, "Visual Scanpath Representation," *Proceedings of the 2008 symposium on Eye tracking research & applications*, 2010, pp. 203-210.

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