A SIMPLE DEVICE TO MEASURE GAZE ANGLES IN VISUAL TASK ANALYSES

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Keywords: Optometry, Visual strategy, Head Movements, Eye tracking, Progressive Addition Lenses.

Abstract: This paper presents a simple device to measure visual maps and head motion to analyze the visual strategy in optometric applications. Instead of using the common approach of conventional eye trackers based on continuous pupil–corneal reflection detection, a simple method based on photogrammetry is proposed. This method only measures the head movements, the gaze direction and the visual map can be calculated on the hypothesis that subjects' gaze follows a known visual stimulus accurately.

In order to validate this hypothesis, an experiment has been carried out to calculate the subject's accuracy when tracking the stimulus. The gaze direction was measured both with conventional eye tracking and with the proposed technique and the measured gaze angles were compared. The results show that the subjects effectively follow the stimulus during the task and thus the main hypothesis of the proposed system is confirmed. Therefore, the analysis of head movement can supply an indirect estimation of the visual angles that is as accurate as the measures obtained with more complex devices.

1 INTRODUCTION

Visual strategy can be defined as the coordination of eyes and head movements in order to perform a visual task. The study of visual strategy has received some interest from fields as diverse as neuroscience and psychophysics, customer behaviour analysis and advertising, ergonomics, sports or lenses design and optometry.

Techniques of eye-tracking have been used for a long time in the fields of psychophysics and neuroscience. Richardson and Spivey have published a complete survey about the main research areas in these fields (Richardson and Spivey, 2004[a]; Richardson and Spivey, 2004[b]). The analysis of visual strategies can also provide information about the consumer behaviour and thus help to identify factors that determine the attention allocated to different advertisements (Treistman and Gregg, 1979; Lohse, 1997).

In the ergonomics scope, research on visual strategy is mainly focused on the study of the visual demands of different tasks in order to improve the workplace design and task performance (Engström et al. 2005). Other applications are related to the design of technical aids for disabled people, such as control systems based on eye-gaze tracking (Sesin et al. 2003). The visual strategy is particularly important in the study of some complex tasks in sports such as ball sports or boxing, in which a player needs to determine the future trajectory of the ball (or hand). Thus, several studies have been carried out to analyze the influence of visual strategy on the subject skills (Ripoll et al. 1995; Land and McLeod, 2000).

The use of eye movement analysis in the field of optometry is more recent and its applications seem promising. Monitoring visual performance can help to quantify the state of the ocular motor system and provide valuable diagnosis and management support (Abadi, 2006). Besides, visual strategies analyses are the basis of some aspects of corrective lenses design, especially to assess the comfort of progressive addition lenses (PALs) wearers. Some studies in this field have been performed to understand the differences of users' behaviour when using different

Page A., Mateo B., Garrido-Jaén J., Marzo R., C. Dürsteler J., Prieto C. and Giménez A. (2008).
A SIMPLE DEVICE TO MEASURE GAZE ANGLES IN VISUAL TASK ANALYSES.
In *Proceedings of the First International Conference on Biomedical Electronics and Devices*, pages 119-125
DOI: 10.5220/0001046501190125

PAL designs or single vision lenses (Selenow et al. 2002; Han et al. 2003; Hutchings et al. 2007).

Several techniques have been used for measuring eye movement as well as for characterizing visual strategies. Morimoto and Mimica (Morimoto and Mimica, 2005) present a good survey of techniques for eyes gaze tracking. The most widely used are based on the automatic detection of the pupil-corneal reflection. The eye is illuminated by a distant, low-power, infra-red light source, and this creates an image that is seen as a highlight spot on the surface of the cornea. The image is analysed by a computer, which calculates the centre of the corneal reflection as well as the centre of the pupil. The distance from the pupil centre to the corneal reflection is proportional to eye rotation, and thereby provides an estimation of the gaze direction. Since the eye position varies as the head moves, the head should remain still during the measurement; otherwise the movement of the head must be measured in order to transform the relative direction of gaze into absolute directions to the visual targets.

Then, a complete description of visual strategy needs both gaze direction and head position analysis. Head motion can be accurately measured in real-time by means of a magnetic location system (Hutchings et al. 2007), although these systems are intrusive because a device must be placed on the subject head. There have been some recent attempts to avoid such kind of devices by measuring head movements by means of a 3D face tracking analysis, as proposed in (Beymer and Flickner, 2003).

The systems based on pupil-corneal reflection need some type of calibration to transform the input data (reflections' locations) into absolute gaze directions. A typical calibration procedure presents the user a set of visual targets that the user has to look at while the corresponding measurement is taken. From these measurements a map of correspondences or calibration function can be obtained. Although several models to calibrate the eye tracker systems have been developed, the calibration process is one of the worst problems in current commercial systems. On the one hand, the calibration functions are very sensitive to head motion, which is the cause of the main source of inaccuracy. On the other hand, calibration is a troublesome process that demands controlled environmental conditions. For these reasons some tracking systems are difficult to use and inadequate for applications outside a research laboratory (Schnipke and Todd, 2000).

A strategy to improve the accuracy and simplicity of the systems is to adapt them to specific functions, so that only the precise information is measured in the simplest way. For example, some clinical and optometric applications are focused on the ocular motor performance when the subject performs a specific task with well-known stimuli (Abadi, 2006). This way, the measurement of the absolute gaze direction is unnecessary and the measurement of head movements and relative eyes motion is enough.

The objective of this paper is to describe and validate a new device to measure the relative motion of eyes with the aim of obtaining visual maps. This information could be useful to analyze differences of visual strategies in the design of progressive addition lenses. The device uses video-photogrammetry techniques and it is based on the assumption that only head motion measurement is necessary to estimate eye gaze direction when the target position is known.

In order to validate this proposed technique, an experimental study has been performed in which the subject accuracy when tracking a visual stimulus is calculated. The measures obtained with our device were compared with those a conventional eye tracker. The results show that the measurement of head movement can supply an indirect estimation of the visual angles when the tracked target locations are known and the results are as accurate as the measures obtained with more complex devices.

2 MATERIALS AND METHODS

2.1 General Description of the Equipment

The principle of operation of the proposed technique assumes that a subject can effectively gaze at a mobile target, so that eye gaze direction in relation to the head is determined by knowing both target and head positions, as well as the relative location of eyes with respect to head.

The measurement system consists of a 650 x 500 mm dark screen, which shows a 1 cm illuminated spot that moves along a continuous trajectory. At both sides of the screen, two synchronised video cameras record the subject's head motion. Cameras have a 640 X 480-pixel resolution with a 25 fps recording speed. The cameras are equipped with infrared filtersCameras have been previously calibrated using the DLT algorithm (Abdel-Aziz and Karara, 1971) and lenses distortion corrected by means of the procedure described in (Ahmed and

Farag, 2005). Therefore, it is possible to accurately measure head position and motion. This analysis can be made from the coordinates of some face distinctive points, using well-known image analysis protocols as the Harris corner detector (Hartley, 2004). However, in order to simplify the computations and to allow a real-time analysis, no computational expensive image processing has been used. Thus, the position and motion of head are measured by means of a set of active makers. The markers cluster consists of four infrared leds placed on a diadem that adjusts at the head.

Besides, the system has an infrared light source placed in the middle of the screen to create a corneal reflection that allows detecting eyes' position during the calibration step.

2.2 Measurement Process

The measurement process is performed in two steps: first the measurement of an initial reference position, and then the measurement phase, where visual angle is recorded during the performance of a tracking visual task. In the first step, the subject sits 50 cm in front of the screen. He is asked to adopt a neutral head posture with the gaze direction approximately horizontal. This position is considered as the reference posture. Then measurement system detects the markers' positions and places the target in the middle of the screen at approximately the eyes height. Eyes positions are detected by the corneal reflection produced by infrared light source. The corneal reflection 3D position is automatically measured. Thus, eyes centre position is calculated assuming a spherical shape of the cornea with known radius.

Simultaneously, markers' positions are determined and a local reference system linked to the subject's face is defined. The X axis is traced from left to right eyes. The local coordinate's origin O is placed in the middle point between the eyes. The Z axis is the most vertical axis belonging to the plane perpendicular to X axis which pass throughout O. Finally, the Y axis is defined to make the reference system right-handed.

Therefore, right eye coordinates in the local system are [d/2, 0, 0], where *d* is the subject's interpupilar distance.

Detection of corneal reflection is necessary only at the first step. Once eyes relative positions with respect to the diadem are identified, their position in space can be determined from the head motion, and no more check up is necessary. This fact avoids having to perform high computational cost image processing tasks and allows free head movements.

Figure 1 shows the equipment operating scheme during a tracking test of a moving target. At each instant, the target is located on the screen at a known position, **P**. The subject has moved his head from the reference position to a different one. This movement is defined by translation **t** of the local reference system and by the rotation matrix **R** in relation to the initial reference position. Using **t** and **R**, the eyes' current positions are determined. Specifically, right eye will be placed at point **D**.

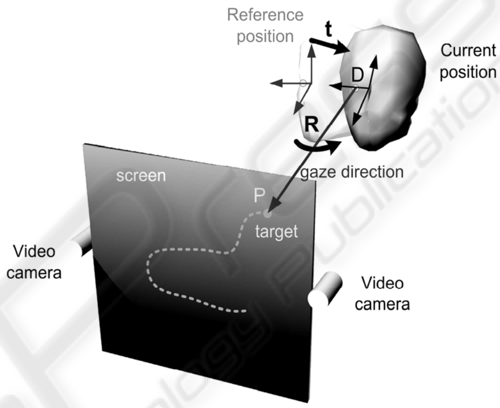

Figure 1: Equipment operating scheme.The subject looks at a mobile target P on the screen. Head position and motion are measured by means of two synchronized videocameras. Gaze direction is estimated from head position, location of P and the relative position of eyes in the head.

Calculation of head position and movement is performed in real time from the diadem's markers' coordinates by using the algorithm described in (Woltring et al., 1994). This algorithm allows obtaining rotation matrix **R** and translation vector **t**Assuming that a person tracks the target, actual gaze direction is given by vector **DP** (Figure 1) which can be calculated in the absolute reference system. If this vector is expressed in the local reference system, then the horizontal angle is calculated as the angle that forms the **DP** projection on the Z=0 plane with the local axis Y, whereas the vertical angle is the one formed by **DP** line with the Z=0 plane.

2.3 Equipment Accuracy Random Instrumental Errors

The measurement of vision angles has two main sources of error. First, the instrumental errors associated to 3D reconstruction process and head movement measurement. Second, the error due to the subject's gaze deviation when tracking the target. The latter error is studied in the experiment described below, so this section focuses on instrumental accuracy only.

Measurement errors of the markers' coordinates depend on camera resolution, accuracy of the marker centroid determination, and separation between the cameras (Hartley, 2004). In our system, focal distance is close to 1000 pixels, measurement centroids accuracy is estimated to be 0.3 pixel and photogrammetric system baseline is b = 650 mm. This configuration provides instrumental coordinates' error of around 0.1 mm in X and Z coordinates and close to 0.2 mm in Y direction.

Angular and position errors associated to this coordinates' error estimation can be calculated by means of the procedure described in (Page et al., 2006). For the diadem geometry (four markers in a 15 x 15 cm squared), these errors are about 0.1º. Linear displacement error is less than 0.1 mm. The worst accuracy appears in the location of the eyes centres, where a well-known corneal radius is assumed. Then, an error of around 1 mm can be expected. Nevertheless, this error has little effect on the gaze angle estimation, because of the great distance between subject and screen. So, if this distance is 500 mm, the systematic angle error is less than 0.1º for a gaze angle of 20º. Note that a correct estimation of corneal radius is critical in conventional tracking systems, because angle direction computation depends upon this measure.

In summary, random instrumental errors associated to photogrammetic techniques are really small and they are negligible in relation with subject performance errors due to the subject's gaze deviation when tracking the target. This source of error is studied at the following section.

3 VALIDATION

The device operates on the hypothesis that subjects' gaze follows the target accurately. Consequently, it is possible to calculate the relative gaze direction from the target location and the head movements. Therefore, the validation consisted on evaluating the subject's gaze deviation from the target in a tracking visual task. In order to do it, the measures obtained with the proposed devices were compared with the ones provided by a commercial eye tracker.

Two visual tasks were performed. The first had to aim to estimate the accuracy of the conventional eye tracker. The second consisted on a dynamic task, tracking a moving target, with the aim to quantify the deviation of gaze direction with respect to the actual target location.

Five subjects participated in these experiments.

3.1 Equipment

Eye and head movements were recorded during the tasks using a head mounted eye-tracker (Model 501, ASL Applied Science Laboratories) integrated with a head-tracker, **3SPACE FASTRAK** (Polhemus, Colchester, VT 05446, USA).

The eye-tracker measures the angle of gaze with respect to a calibrated scene in the horizontal and vertical directions. The accuracy reported in the equipment specifications is less than 1 degree and may increase to 2 degrees in the periphery of the visual field.

3.2 Experimental Procedure

The visual tasks were displayed on a 19 inches computer screen. Subjects sat in front of the screen. The distance between monitor and subjects was 50 cm. The monitor height varied depending on the subject to obtain a zero vertical gaze angle when looking at the centre of the screen, point 5 in the calibration scene (Figure 2).

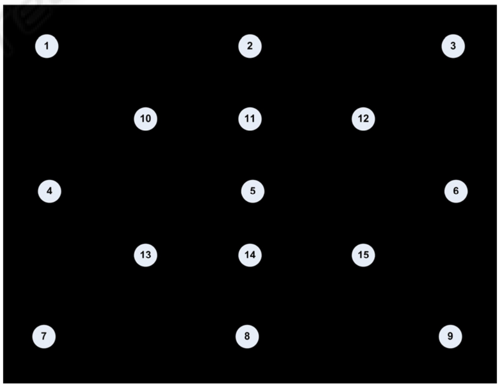

Figure 2: Calibration Scene.

Previous to performing the tasks a calibration process was completed for each user. This calibration consisted on looking at 17 target points located at known positions. During this process the eye tracker records the corneal reflection of the left eye as well as the pupil and head movements.

Once the calibration was carried out, the subjects performed two visual tasks. In the first task (static task) the subjects looked consecutively at each one to 17 target points of the calibration scene during three seconds while the eye and head position were registered.In the second task (tracking task) subjects were asked to follow with their eyes a moving target onto the 19’’ black screen. The target was a red spot moving with a pseudo-random trajectory on the screen during two minutes. The trajectory consisted on a set of concentric circles and radial lines from the centre of the screen with a randomized sequence (see figure 3). The velocity of the point motion was 7 cm/sec (8º/sec gaze angle, approximately). This velocity is similar to the one used to measure the visual maps.

4 RESULTS

The data registered in the static task was used to estimate the accuracy of the eye tracker system as the deviation between the gaze lines and the measured ones by means the eye-tracker.

For each subject, the accuracy of the eye tracker system was quantified as the standard deviation in degrees of the horizontal and vertical eye angle differences between actual and measures lines while performing this static task (Table 1)

Results show that the standard deviations of errors are smaller than 1º in all subjects for horizontal angles, and a bit greater in vertical angle measurements. Mean values of these errors are smaller than 1º. Thus, the calibrated eye tracker fulfils the accuracy specified by the manufacturer.

The eye angular deviation when executing the tracking task was obtained in a similar way. At each time, the theoretical eye line of gaze corresponding to the moving target was calculated and it was compared with actual gaze line measured by the eye-tracker. Vertical and horizontal angle deviations were analyzed.

Table 1: Errors in the static task. These errors quantify the accuracy of the reference conventional eye-tracker.

System Error (standard deviation)		
Subject	Horizontal (º)	Vertical (º)
s1	0.42	0.58
s2	0.51	0.53
s3	0.95	1.52
s4	0.67	0.47
s5	0.57	0.84
Mean	0.65	0.88

Table 2: Errors of the horizontal and vertical angles for the dynamic tracking task.

Tracking error (standard deviation)		
Subject	Horizontal (º)	Vertical (º)
s1	0.53	0.48
s2	0.49	0.61
s3	0.49	0.59
s4	0.56	0.77
s5	0.61	0.70
Mean	0.54	0.64

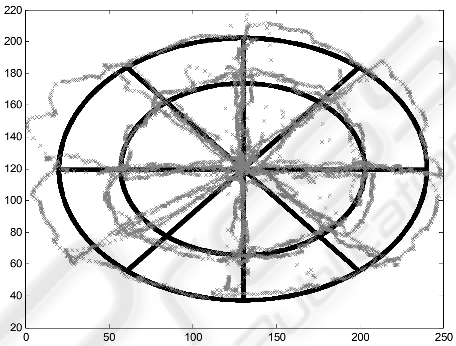

Figure 3: Deviations in tracking task. Black solid line is the trajectory of the target on the screen. Grey markers represent the actual gaze direction.

Figure 3 shows an example of the results in an individual dynamic task. The black solid line represents the actual trajectory of the moving target on the screen. The grey markers represent the intersection of measured gaze line with the screen. This way, the distances between the actual target location and the one obtained from the measured gaze line quantifies the gaze error when executing the task. These distances were normalized as angles (by means of the distance to the screen). The “accuracy” of the tracking task was quantified by the standard deviation of the measured angular deviations for both vertical and horizontal angles.

Table 2 shows the errors for each user as well as the mean of the sample. The errors are smaller than 1º in all cases, both for vertical and horizontal angles. In fact the order of magnitude is the same as the accuracy of the conventional eye-tracker in static calibrated tasks.

Note that the errors measured in the dynamic task have two sources of variance. First, we can expect some instrumental error associated to the accuracy of the eye-tracker device. This error can be estimated by the results obtained in the static task and is quantified in Table 1. Second, the dynamic errors depend on the subjects’ ability to effectively follow the moving target. The errors described in table 2 are the associated to both sources.

By comparing the magnitude of static errors (Table 1) and total errors (Table 2), we can see that these errors are similar. Thus, the mean errors in the static tasks are around 0.65º for horizontal angles and around 0.88º for the vertical ones. The errors estimated in the tracking tasks were similar (0.54º and 0.64º, respectively). We can conclude that the subjects effectively follow the moving target during the experiments, in any case within the margin of accuracy of a conventional eye-tracker.

Therefore, the main hypothesis of operation of the proposed system is confirmed: it is possible to measure the relative gaze angles from the movements of the head if the location and motion of the target is known.

5 CONCLUSIONS AND DISCUSSION

Despite the extensive development of the eye tracking techniques, the available commercial devices present some problems, mainly related with a robust recognition of eye characteristics, their sensitivity to head movements and the necessity of previous calibrations. All these factors have influence on the devices' accuracy as well as on the reliability and feasibility of their use in poorly controlled environments.

However, some specific applications in the filed of optometry use only specific information about gaze lines that do not need complex equipment. This is the case of the visual maps measurement, an application of eye-tracking techniques to analyze the user response to progressive addition lenses. In these applications, the use of specifics technologies could avoid the drawbacks of conventional equipments.

In this paper we propose an effective and simple technique for the accurate measurement of the relative gaze angles while executing visual tasks. The system operates on a simple principle: the use of a visual target with controlled location and the measurement of head movements. Determining once the location of the subject's eyes in a reference posture, the estimation of gaze direction is feasible just with head movement measurement.

The use photogrammetric techniques allows a very accurate measurement of these movements, with an instrumental error lower than 0.5º. However, the system reliability depends on the subjects' effectiveness on tracking the target.

The experimental validation with subjects demonstrated accurate target tracking, with an error below the accuracy of the conventional eye-tracker used in the experimentation.

Therefore, the proposed technique permits a simple and robust measurement of the visual maps, with the same accuracy as the measure performed with a complex and expensive equipment.

ACKNOWLEDGEMENTS

This research has been partially supported by the Spanish Ministry of Science and Education Grant DPI2006-14722-C02-01 (A. Page).

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