New technique to measure eye movements for ophthalmological applications

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https://doi.org/10.13140/RG.2.2.13392.67843

15/09/2013

Abstract:

This study presents a new technique to measure eye movements for ophthalmological applications without using the corneal reflex.

The detection of the subject's head is obtained by using a reflective dot while the eye positions are given by the two eye pupils. The eye gaze orientation is obtained from the position of the two eye pupils relative to the reflective dot. The working distance can be from 30 up to 50cm from the camera. This method does not require immobilizing the head.

The comparison between the proposed method and the method using the corneal reflex and the pupils was established, showing that the new method is more robust and the limits of detection are larger in all gaze direction. Moreover, difficulties related to the detection of the corneal reflex, such as artifacts on tears or eye glasses, and dry eye, are absent.

The system is fast and easy to administer. Preliminary tests show that the reflective dot is well accepted by children. It is currently under evaluation in ophthalmology for the recording of eye movements in children.

Keywords: image processing; eye movement measurement; ophthalmology

1 Introduction

This study presents a head and eye tracker that has been developed and evaluated to record eye movements for ophthalmological applications, especially for children.

Eye movements have an important contribution in ophthalmology. The observation of oculomotor behavior is used for the diagnostic and the follow-up of eye movement disorders (nystagmus, abnormal pursuits, saccades, etc.) [a7], and also to measure visual functions [b2].

Several methods have been applied to clinical applications. Electrooculography (EOG) [c 6], for example, uses electrodes placed on the eye canthus to record the eye movements. Patient's preparation and the placement of electrodes need non negligible time. Furthermore, electrodes are not always tolerated by children and only horizontal eye movements are properly documented. Head movements cannot be recorded, so the head must remain steady.

Others techniques use image processing [d, e1, 8]. In these techniques, the response is recorded using eye marks such as the corneal reflex and the pupils (CR&P). Eye movements are measured using the relative position of the pupils and the corneal reflex (Hirschberg principle). However, these techniques have some limitations: the corneal reflex is not correctly detected at large eccentricities (over +-30° in the horizontal direction and +-25° in the vertical direction) [f 5]; artifacts appear due to tears or eyeglasses; there are difficulties to obtain a detectable corneal reflex in patients with dry eye or wearing contact lenses.

We present in this article a new technique to record eye movements that does not use the corneal reflex, and compare it with a technique that uses the CR&P.

2 Methods

The equipment used to record the eye movements includes a near infra-red (NIR) light source, a video camera, and a filter that blocks visible light (Figure 1-a). The video capture device is installed below a video display monitor (VDM) that is used to generate visual stimulations. The NIR light and filter source allows to obtain images independent of the ambient light. The axis of the camera and the NIR light source make an angle of 30 degrees with the eye gaze axis, while the subject is looking straight ahead, to the center of the VDM. The dimensions of the VDM cover a field of +-30 degrees in the horizontal direction and +-25 degrees in the vertical direction when the subject is placed on the head rest at a distance of 310 mm from the VDM.

The detection of the subject's head is obtained by using a reflective dot while the eye positions are given by the two eye pupils. The reflective dot is placed on the forehead, as showed in figure 1-b, and it is made of a material that reflects NIR light. Consequently, it appears bright in the image, and is easily detected.

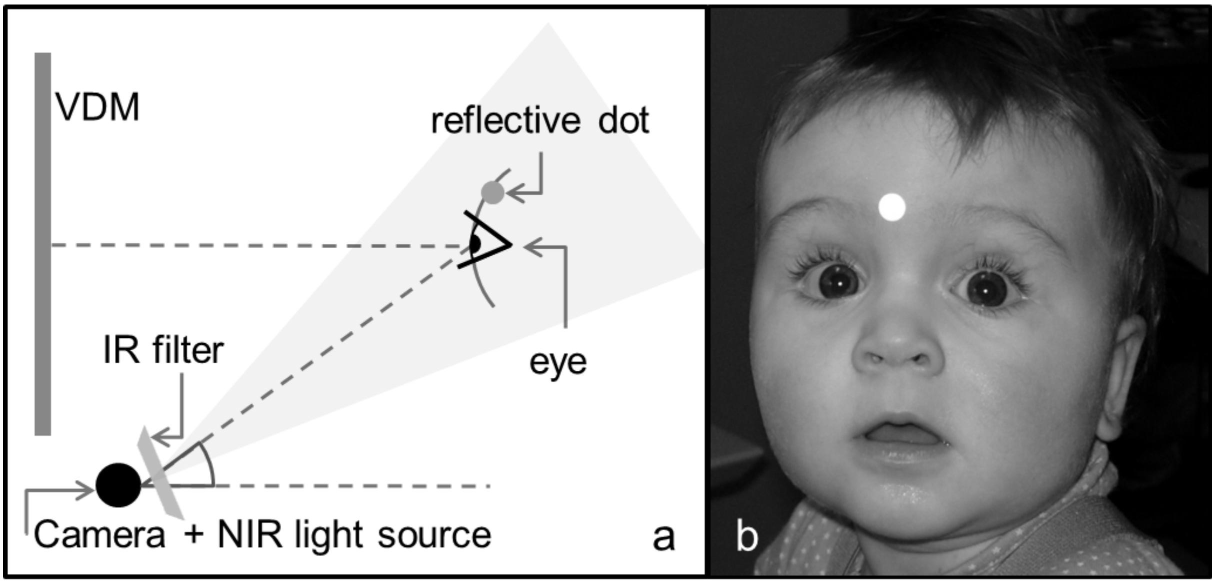

Figure 1 (a) schema of the equipment used to record the eye movements: VDM, filter, camera and NIR light source, (b) reflective dot placed on the forehead of a child

The detection of the reflective dot is performed with a region-based segmentation method, using the contrast between the reflective dot and the skin. The detected points are clustered using a contiguity-based method. All points of the reflective dot are used to calculate its barycenter. In the first video frame, the whole image is analyzed. For subsequent frames, the tracking system uses the reflective dot position on the current frame, and the velocity and acceleration calculated over the last three frames to estimate its position on the following frame. The diameter of the reflective dot is used to calculate the distance to the camera, and then the 3D position of the head can be estimated.

Pupils are detected within rectangular regions located below and on both sides of the reflective dot, according to the geometry of the face (see figure 2), especially the inner canthal distance [g 4]. Pupils' detection is performed in two steps. The first step is an edge detection [h 3]. The second step is a region-based segmentation, based on the pupils' uniform luminance and the relative contrast between the pupil and the iris. The detected points are clustered using a contiguity-based method. Several criteria are used to validate the pupil detection, including the shape and the number of detected points. All the points of the pupil are used to calculate its barycenter. For the first video frame, the whole rectangular region is analyzed. For the following frames, the region considered is a small square centered on the pupil's barycenter on the last frame, and corrected as a function of head movements' data.

If the reflective dot or the pupils are not detected during one frame, the analysis is reset from the beginning. The rectangle regions used to detect the pupils are presented in real time on the video (see figure 2) to give feedback to the operator. The contours of the reflective dot and of the pupils are also shown on the video since they are detected.

The gaze orientation is obtained from the position of the two eye pupils relative to the reflective dot. The video is analyzed in real time, at 200 frames per second.

Some movements, like frowning, may create movement artifacts of the reflective dot. To minimize these effects, the reflective dot must be placed on the forehead near to the nose root (see figure 2).

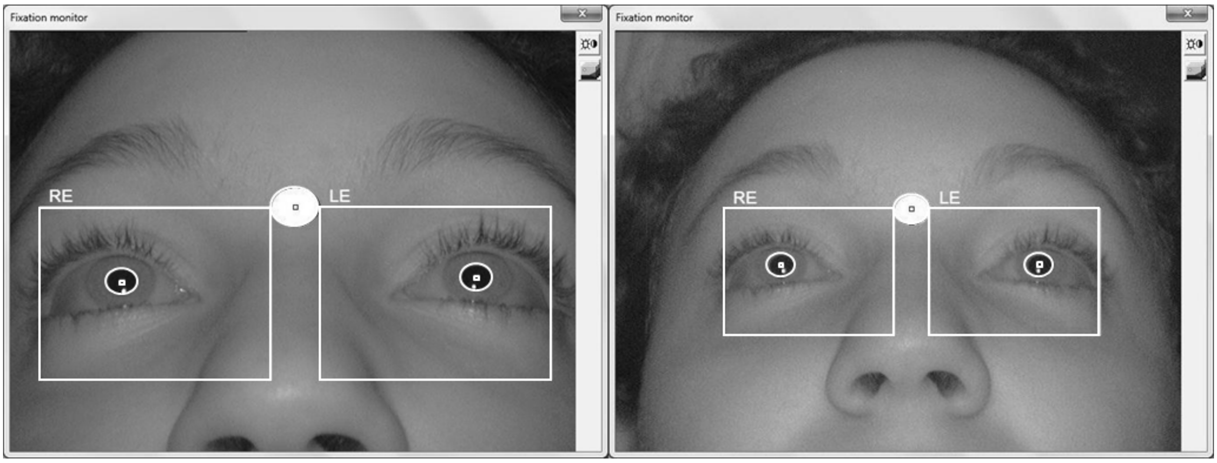

Figure 2 detection of the reflective dot and the two eye pupils as a function of the distance to the camera: (a) at 33cm, (b) at 45cm

The tracking system allows free head movements, provided that the reflective dot and the eyes are visible on the image. The working distance can be from 30 up to 50cm from the camera (see figure 2). Farther than this, the NIR illumination becomes too low to obtain enough contrast for the detection of the pupils.

For some subjects, the pupils may be covered by eyelids and eye lashes in some gaze positions. This occlusion increases with the pupil diameter and the eccentricity of gaze. To avoid these occlusions, the pupils' detection is best performed under photopic conditions when the pupils constrict to about 4 mm in diameter.

For subjects wearing eyeglasses, the reflective dot is preferentially placed on the eyeglasses frame. Some eyeglasses may disturb pupils' detection because there are reflections on the glass that can hide the pupils. These reflections can be avoided by changing the angular position of the eyeglasses.

For some subjects, the frowning movements can cause artifacts of the reflective dot in the vertical direction. For these subjects, the reflective dot can be placed over a frame (figure 3).

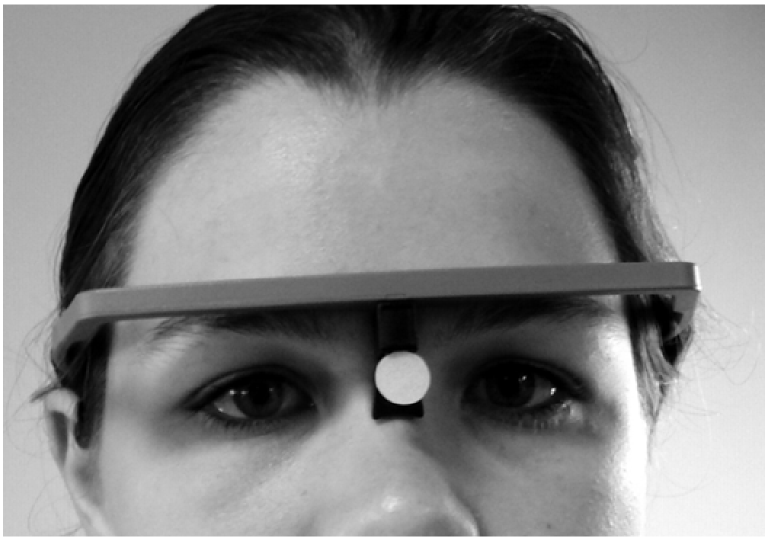

Figure 3 subject wearing a frame, over which the reflective dot can be placed

2.1 Comparing the limits of detection

In order to establish a comparison, tests were performed to measure the limits of the detection of the two methods: the reflective dot and pupils’ method (RD&P), and the corneal reflex and pupils’ method (CR&P).

Four normal subjects with different face morphologies, skin and iris colors (S1: Latin, S2: Caucasian, S3: Chinese, and S4: Afro) were tested with both methods, under binocular conditions. The test was performed under photopic conditions; the subjects' heads were placed on a head rest.

Points were presented along a gaze direction with eccentricity increasing by steps of 5 degrees, starting from the center to the periphery. The directions tested were: up, down, right, left and four oblique directions.

If the detection was performed correctly for the point, the subject looked to the next one, and so on, until the limit of the fixation field. If the reflective dot/ corneal reflex or pupils' detection failed, we considered the previous point as the limit of the detection for the given direction.

3. Results

3.1 RD&P's method

This technique uses the reflective dot and the pupils to calculate the eye gaze direction. For the comparison test, the reflective dot was correctly detected in all directions of gaze. Indeed, the position of the reflective dot does not depend on eye movements, but rather on head movements.

For all subjects, the two pupils were correctly detected until the limits of the fixation field for all gaze directions. The representation of these limits for the 4 subjects under binocular conditions is shown in figure 4.

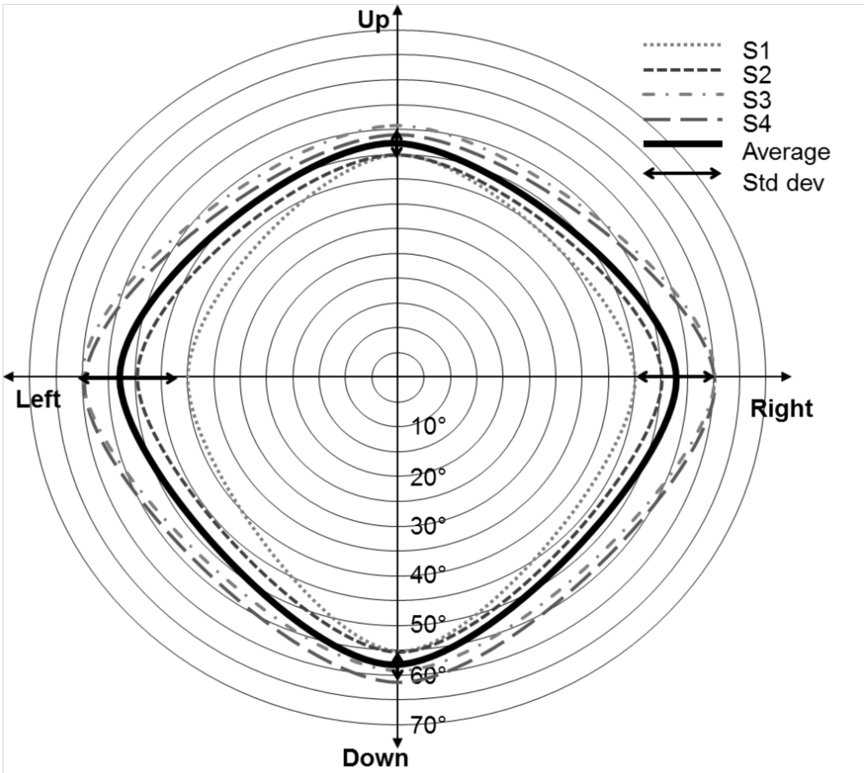

Figure 4 limits of the detection using RD&P's method for 4 subjects (S1-S4); the average and the standard deviation

3.2 CR&P's method

This technique uses the corneal reflex and the pupils to calculate the eye gaze direction. In general, and for all directions, the corneal reflex falls out of the cornea at large eccentricities: over +-30 degrees in the horizontal direction and +-25 degrees in the vertical direction.

In the present method, the NIR light source is placed below the VDM, making an angle of 30 degrees (see figure 1). In these conditions, the detection in the upward direction is reduced compared to the others directions. When the subject looks straight ahead, to the center of the VDM, the corneal reflex appears on the lowest part of the pupil (figure 5-a). As the subject looks upwards, the pupils move up, and the corneal reflex gradually appears below the pupil. Afterwards, the corneal reflex appears on the sclera where its image deteriorates until it disappears completely (figure 5-b).

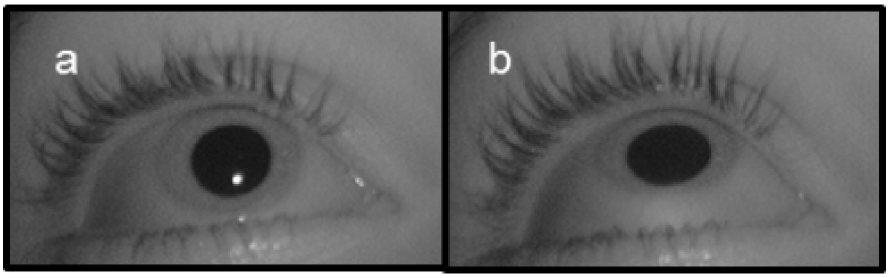

Figure 5 at left, the subject looking straight ahead, the corneal reflex is below the pupil; at right, the subject looking upward (25 degrees) the corneal reflex has disappeared

The limit of detection considered in the present study is the last point where the eye gaze direction can be calculated, using the pupil's and the corneal reflex positions. For all directions, the detection of the corneal reflex failed before the failure of the pupil's detection.

The figure 6 shows the limits of detection of the CR&P method, in all directions, for subjects under binocular conditions.

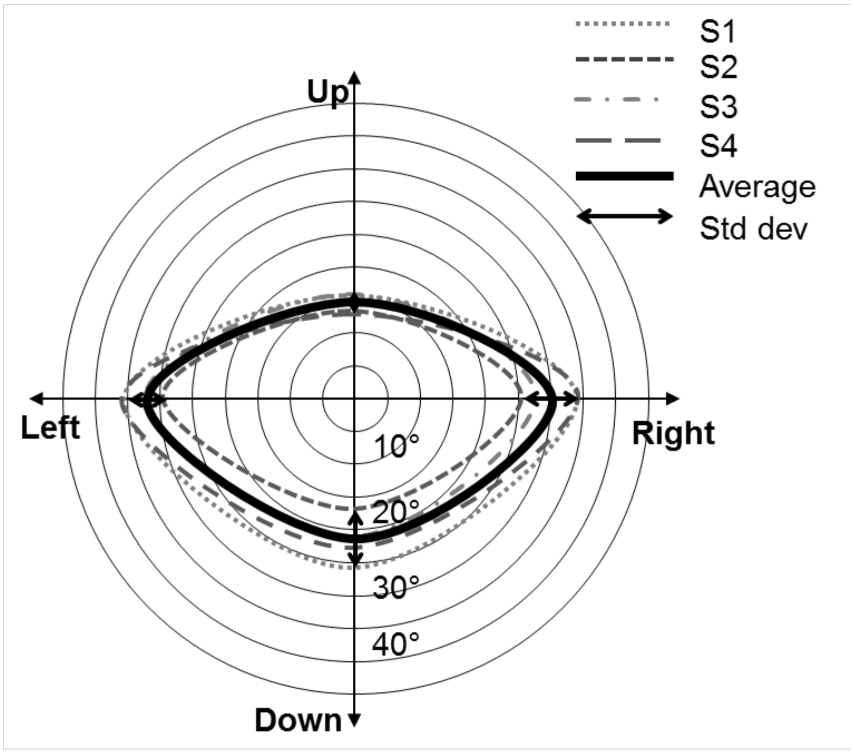

Figure 6 limits of the detection using CR&P's method for 4 subjects (S1-S4); the average and the standard deviation

3.3 Comparison results

The limits of detection of the two methods (RD&P, CR&P) were evaluated for 4 subjects.

In general, some conditions affected both methods:

- The angular distance between subject and the video capture device (camera and NIR light source) axis was 30 degrees for both methods;
- The photopic conditions allowed the complete detection of the pupils, which were generally about 4 mm of diameter, for all gaze directions until the limits of the fixation field.

For the CR&P' method, the detection failed since corneal reflex was absent or appeared on the sclera. Thus, the eye gaze detection using this method was, on average, limited to the eccentricity of the VDM (+-30 degrees in the horizontal direction and +-25 degrees on the vertical direction), except for the upwards direction, for which the detection limit was 15° (in average) due to the angle between the eye gaze and the NIR source axis.

On the other hand, for the RD&P' method, the detection was performed correctly until the limits of the fixation field.

Figure 7 presents the average limits of detection for the two methods, under binocular conditions.

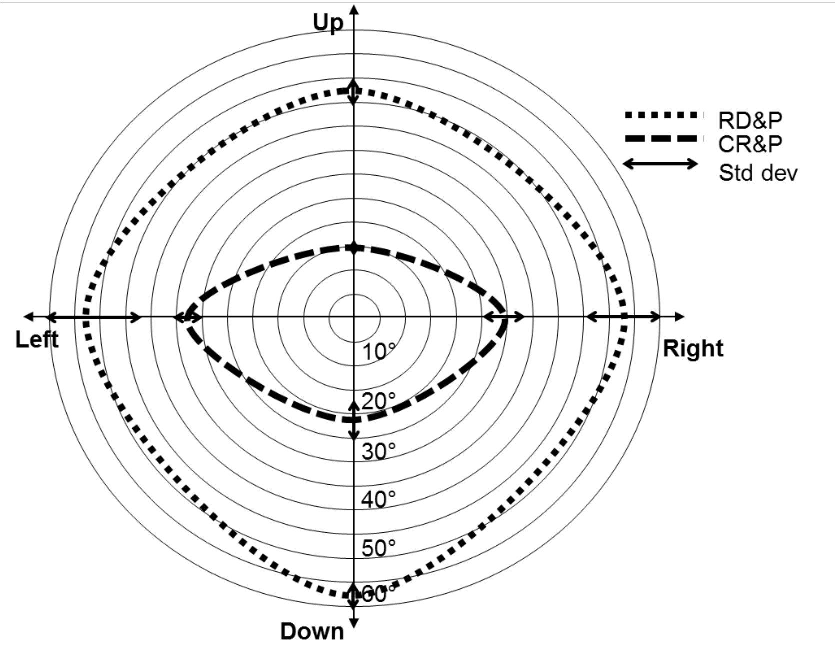

Figure 7 average of the limits of the detection using CR&P's and RD&P's methods and the standard deviation

4 Discussion

This study presents the evaluation of a new head and eye tracker that does not use the corneal reflex. This original method is based on the detection of a reflective dot and eye pupils. The first one is used to detect the head position, and the last one to calculate eye positions. The eye gaze direction is obtained from the relative position of the head (reflective dot) and eyes (pupils). This method does not require immobilizing the head.

The comparison between the proposed method and the method using the corneal reflex and the pupils was established, showing that the new method is more robust because of the size of the reflective dot compared to the size of the corneal reflex. Moreover, difficulties related to the detection of the corneal reflex, such as artifacts on tears or eye glasses, and dry eye, are absent. Furthermore, the present technique has limits of detection larger than the corneal reflex and pupils' method in all directions. These characteristics suggest that this new head and eye tracker can be used to record eye movements even when the eye gaze presents a large deviation.

Preliminary tests show that the reflective dot is well accepted by children. It is currently under evaluation in ophthalmology for the recording of eye movements in children.

KM, JFL: No Conflict of interest

JC: Research director in Metrovision Company

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