Biomedical engineering

Museum application of an eye tracker

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Abstract—*The paper presents an eye tracking system specifically designed for the recording of eye movements from the visitors of a museum. Eye movements are calculated from the images of a near infra-red camera viewing the eye during the presentation of a sequence of slides. Thereafter, the same slides are displayed with the scanning paths superimposed. Servo systems, 'intelligent' image processing algorithms and interactive procedures have been implemented so that the eye tracker can operate on the general public without any technical supervision.*

Keywords—*Eye movements, Eye scanning paths, Instrumentation*

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1 Introduction

Eye movement scanning paths have been studied for many years in research laboratories and have been shown to reveal basic mechanisms of visual perception and cognition (Brandt, 1940; Levy-Schoen, 1967; Jeannerod *et al.*, 1969; Stark and Ellis, 1984). The purpose of the present work is to provide the public visiting a museum with a direct experimental demonstration of how saccades and fixations contribute to the process of vision.

A desirable method for recording eye movements from the general public should require minimal subject training, co-operation, discomfort and set-up time. It should not limit significantly the free natural head movements and the visual field of the subjects. Among the numerous methods available (Young and Sheena, 1975), these constraints restrict the choice to optical methods which separate lateral and rotary motion of the eye and provide a measurement of eye orientation independent from head translations.

The measurement of the relative position of the corneal reflex and pupil images is such a method. It has been implemented into several instruments dedicated to research applications (Merchant *et al.*, 1974; Baudonniere *et al.*, 1978; Fourcy *et al.*, 1980; Charlier and Hache, 1982; Levine and Schappert 1984). The background section of this paper reviews the basic features of this technique, which have already been described (Charlier *et al.*, 1985): the optical setup and the image processing algorithms implemented for the reduction of artefacts due to masking of the pupil with eyelids or eyelashes or parasitic reflections.

The rest of this paper addresses more specifically the problem of using this technique without any technical supervision. For this purpose, the measuring system should adapt to the physiological parameters of each individual. For instance, the relationship between the eye orientation and the relative position of the corneal reflex and pupil images is extremely variable, depending on the geometry of the eye anterior chamber and the transverse and axial position of the eye (Paris and Charlier, 1987). Furthermore, the image contrast varies with the pupil size and with the reflectance of the eye fundus, iris and sclera. The adaptation to these individual variations has been obtained by implementing closed-loop servosystems and simple interactive procedures, which are described in the following paragraphs.

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2 Background

2.1 *Optical setup of the eye image sensor*

The eye of the visitor is illuminated with near-infra-red radiation. Part of the incident light beam is reflected by the front of the cornea and produces the so-called corneal reflection.

The boundary between the pupil and the iris, which normally exhibits very low contrast, is enhanced with the bright pupil effect: the illumination and collection apertures of the optical system are made coincident (Fig. 1) so that incident light rays are refracted back from the retina

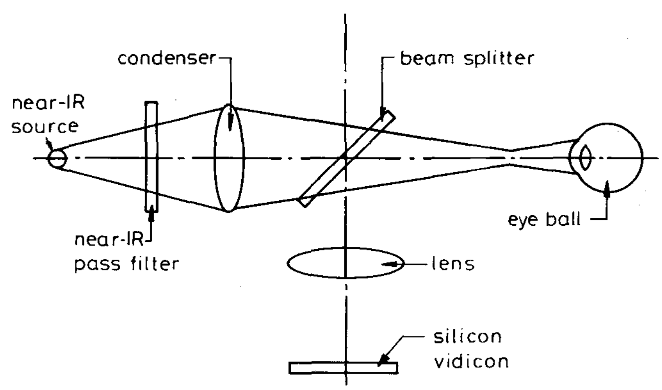

Fig. 1 *Schematic of the original eye image sensor (from* Charlier *et al., 1985)*

and back light the pupil. The resulting image of the eye (Fig. 2) shows the pupil as a bright disk against a dark background superimposed on the corneal reflection. The corneal reflection and the bright pupil images are located in two different optical planes, so that their relative position is not affected by translation movements of the eye

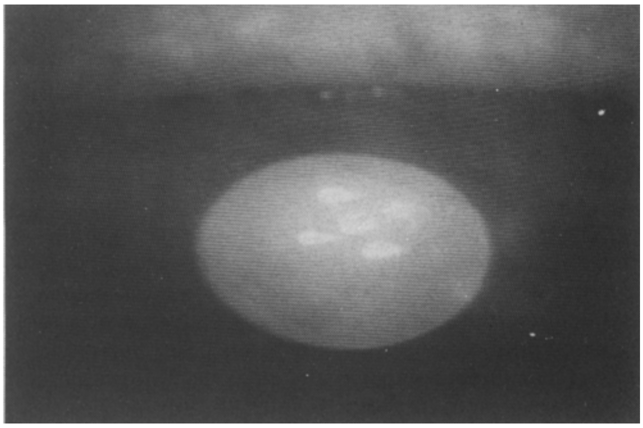

Fig. 2 *Video image of the eye (from* CHARLIER *et al., 1985)*

and is only related to its rotations (Fig. 3). A standard 625 interlaced scanning lines, 50 frames per second, television camera is used as an image transducer. The resolution of 312 lines per frame allows for a precision of one degree of eye angular motion with an approximate 15 mm × 15 mm image area at the eye.

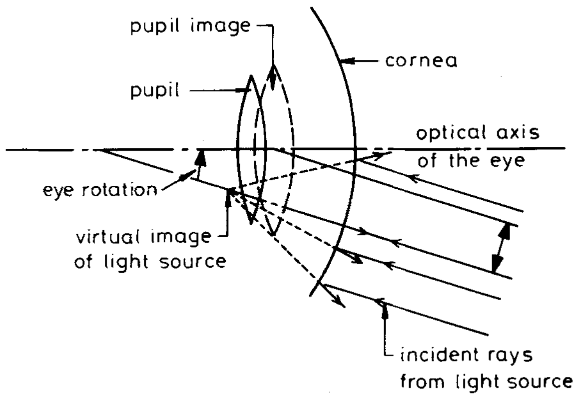

Fig. 3 *Origin of the bright pupil and corneal reflection (adapted from* YOUNG *and* SHEENA, *1975)*

2.2 *Image-processing algorithms*

The basic scheme involes, in a first step, the extraction of pupil boundary and corneal reflection from each video scanning line and, in a second step, the determination of the pupil centre and the calculation of the relative corneal reflection displacement.

A shape detector circuit extracts the corneal reflection and the leading and trailing edges of the pupil from the video signal (Fig. 4). Using the detection of shape instead of amplitude level or amplitude variation improves performance significantly with low-contrast images. It eliminates the problems associated with variations of the detection thresholds with pupil size fluctuations. It provides a better discrimination of the corneal reflection which is usually sharper than parasitic reflections. The horizontal and vertical co-ordinates are extracted from these signals by sampling from two video dot clock and video line counters and stored in random access memory.

Further processing is carried out on a Z80 microprocessor. The points detected as pupil contour are clustered in data chains which are scored according to their contour continuity and curvature consistency. The resulting score is compared to a preset threshold to eliminate the data chains produced by parasitic reflections or eyelash interference. The pupil centre is calculated as the centre of the circle which fits the selected data chains with a minimum distance error.

Finally, the corneal reflection is selected from the

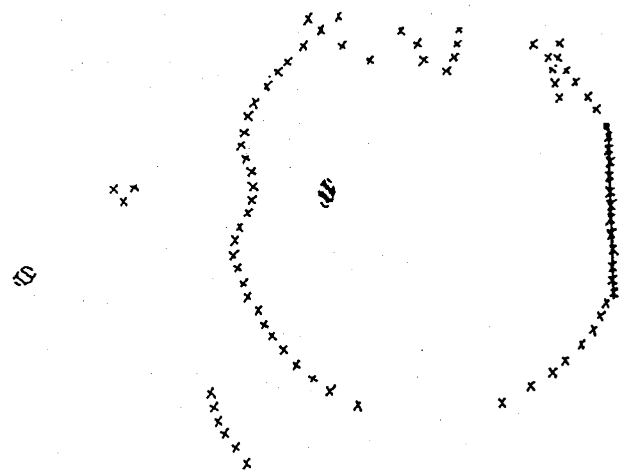

Fig. 4 *Pupil boundary and corneal reflection detection (from* CHARLIER *et al., 1985)*

detected data according to its location within a perimeter centred on the pupil. All these algorithms are implemented in assembly language so that the analysis of one image is performed within 20–60 ms, depending on the complexity of the detected features.

3 Instrumentation

3.1 *Adaptation of the eye image sensor*

Several modifications have been made on the original eye image sensor (Fig. 5). The focusing lens is driven by a stepping motor which allows the adaptation of the eye to individual axial positions. Two separate sets of near-infrared light-emitting diodes (LEDs) with a peak emission at 875 nm provide the the illumination of the eye. The first set is made optically coincident with the camera, producing the so-called 'bright pupil effect'. The second set is located at the periphery and generates a corneal reflection pattern which is identified by the image processor and improves the elimination of parasitic reflections.

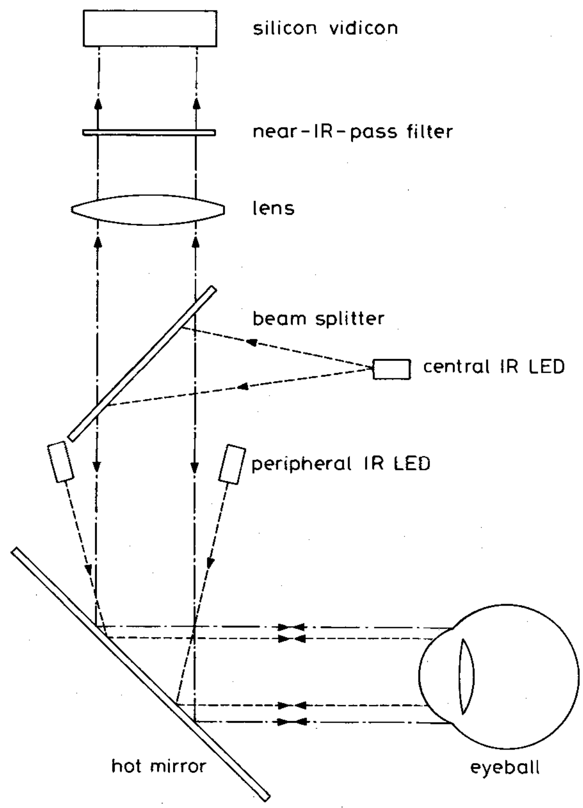

Fig. 5 *New optical schematic of the image sensor*

3.2 *General setup*

The visitor is seated and watches through an eyepiece (1) (Fig. 6). A front rest is used to reduce transverse and axial head movements. A dedicated keyboard (13) allows the visitor to select different display options. A hot mirror (2) reflects the near-infra-red light of the oculometer (3) and transmits the visible light of the screen (7).

Two slide projectors (8) generate the images and a television set (6) produces the alphanumeric, graphic and video information used for the interactive dialogue. All these image sources are superimposed with beam splitters (4) and (7). A television projector (9) and two more slide projectors (10) provide a duplicate display over a large external screen.

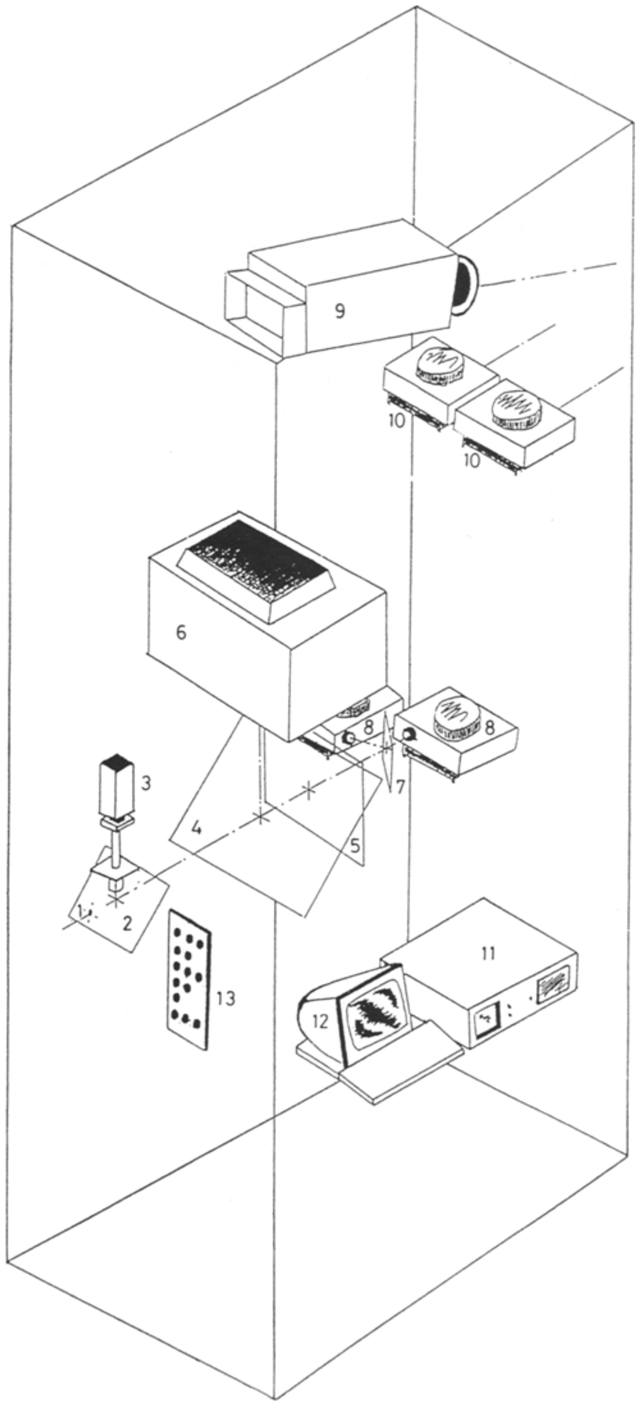

Fig. 6 *General setup of the eye tracker. (1): eyepiece; (2): hot mirror; (3): oculometer; (4): beam splitter; (5): projection screen; (6): television monitor; (7): beam splitter; (8): first set of slide projectors; (9): television projector; (10): second set of slide projectors; (11): computer and image processor; (12): computer terminal; (13): dedicated keyboard*

3.3 *Electronic setup*

The electronic setup includes a microcomputer with hard disk and floppy disk storage units and specific interfaces. Interface 1 controls the luminance of each set of near-infra-red LEDs and the stepping motor driving the focusing lens. Interface 2 achieves a real-time preprocessing of the video signal from the camera and transfers into the microcomputer memory the co-ordinates of the corneal reflection and pupil contour detected during each frame.

Interface 3 controls the luminance, forward and reverse movements of the slide projectors. It encodes the dedicated keyboard and commands light sources indicating the keys available at a given time. Interface 4 controls the television monitor. It displays under computer control the alphanumeric image used for the interactive dialogue, the graphic image representing the eye scanning paths and the video image of the eye recorded from the camera. Interface 5 transfers error codes to the museum central computer.

4 Utilisation

4.1 *Visitors' installation*

The visitor is provided with a dedicated keyboard offering a choice of five languages (French, German, English, Spanish, Italian) and five sets of slides related to different subject of interest (Scanned faces, Writings, Eye-catchers, Advertising and Art gallery).

The visitor is invited to position his eye with the help of the image from the camera displayed on the television monitor. The same image is processed by the computer to detect the pupil contour. This detection is not very sensitive to the image blur and can therefore be used without a precise focusing of the optical system. As soon as a detection is obtained within the central area of the camera field, the focusing lens is scanned and positioned according to the optimal detection of the corneal reflection.

4.2 *Calibration*

The relationship between the eye orientation and the position of the corneal reflection relative to the pupil varies greatly between individuals, due to important differences in the geometry of the anterior chamber of the eye (Paris and Charlier, 1987).

The purpose of the calibration is to identify this relationship. Five calibration points are displayed sequentially in the centre and in the four quadrants of the screen, at 10° eccentricity. The mean and standard deviation of the corneal reflection to pupil centre distance is computed for ten successive images in each of these five positions. These measurements are validated when the standard deviation is less than a given threshold, indicating that no movement occurred during the fixation. If the calibration remains unsuccessful during three successive trials, the protocol returns automatically to the visitor's installation and he is asked to reposition his eye.

If the calibration is successful, subsequent measurements are converted into screen positions by linear interpolation between the five calibration average estimations.

4.3 *Eye movements recording*

Eye movements are recorded during the presentation of the selected sequence of slides. The individual slide viewing time is set between 1 and 10 s and the total recording lasts up to 180 s. The information extracted from each image is stored in RAM memory under the following format:

(*a*) 2 bytes for the horizontal and vertical positions of screen fixation
(*b*) 1 byte for the image status, which indicates whether all features are detected or which are not identified
(*c*) 1 byte for the image timing, which contains the duration of the image analysis. This duration varies from 20 ms up to 60 ms with an average of 40 ms, depending upon the complexity of the detected features.
(*d*) 2 bytes for pupil size and luminance, which are used for the validation of recorded data.

The image status is tested throughout the recording procedure for failures in the detection of the pupil contour and corneal reflection. When an error is detected, the visitor's installation procedure is repeated to readjust the eye position within the camera field. A time delay of 400 ms is introduced for the elimination of eye blinks and eye saccades.

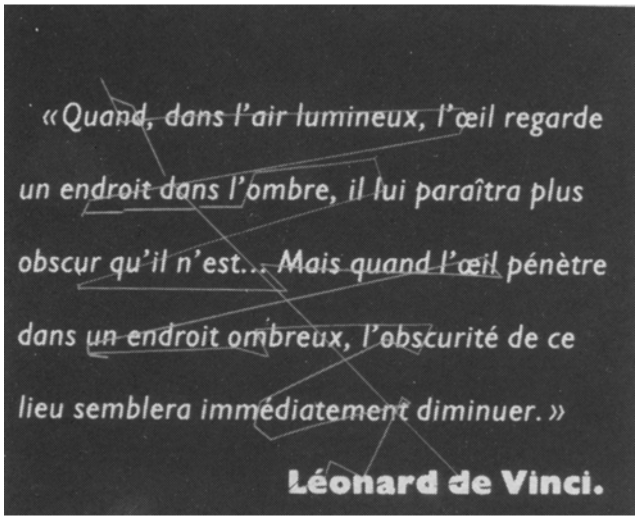

Fig. 7 *Scanning paths as seen by the visitor*

4.4 *Eye movement retrieval*

The dedicated keyboard provides commands for playing forward or backward the same sequence of slides superimposed with the scanning paths, which are visualised as segments between fixation points (Fig. 7).

The recorded data are filtered to eliminate erroneous transient signals during saccades and eye blinks. For this purpose, the images which present rapid intermittent change in pupil size or position are eliminated.

5 Results

The eye tracker was installed in September 1986 at the Cité des Sciences et de l'Industrie de la Villette in Paris. So far, it has been used by about 9000 visitors, averaging 50 per day. The analysis of the eye tracker performance has been made from an automated printout produced at the end of each recording (Fig. 8).

The following results were calculated from 153 visitors: 84·3 per cent went successfully through the installation and calibration phases; 9·8 per cent failed during the installation phase; 1·3 per cent failed during the automated focus adjustement and 4·6 per cent failed during calibration. The same printout provides the distribution of the images according to their status, i.e. the estimated quality of detection of the pupil contour and corneal reflection. The statistics obtained from 67 944 images are summarised in Fig. 9.

Failures in detecting the pupil during installation are attributed to the visitor's misunderstanding, to the constriction of his iris or to ocular media opacities which reduce the image contrast. Failures in detecting the corneal reflection during calibration result mainly from poor cooperation or unsteady fixation.

A high incidence of absent or partial detection of the corneal reflection is noted during recordings. Partial detections do not impede the calculation of eye orientation but do affect the precision of the results. Possible causes for these errors include axial eye movements which deteriorate the sharpness of eye images and drying of the corneal tear film during prolonged viewing, which alters the optical quality of the corneal reflection.

Language selected : ENGLISH

Set of slides selected : ART GALLERY

Number of trials for the installation of the visitor : 1

Number of trials for the automated focus adjustment : 1

Number of trials for the calibration : 1

Number of slides displayed : 14

Status	Number of images	pupil detection	corneal reflection detection
0	66	yes	no
1,2,3	505	yes	partial
4,5	884	yes	yes
8	7	partial	no
9,10	7	partial	partial
12,13	19	partial	yes
32	5	out of range	no
33,34,35	14	out of range	partial
36,37	17	out of range	yes
240	81	no	no
241,242,243	20	no	partial
245	6	no	yes

Fig. 8 *Sample printout of results*

Status	frequency (%)	pupil detection	corneal reflection detection
0	25.8	yes	no
1,2,3	43.2	yes	partial
4,5	20.2	yes	yes
8	2.8	partial	no
9,10,11	0.8	partial	partial
12,13	0.4	partial	yes
32,64	0.3	out of range	no
34	0.2	out of range	partial
240	2.8	no	no
241,242,243	2.5	no	partial
245	0.2	no	yes

Fig. 9 *Image status distribution obtained from 67 944 images*

6 Conclusion

This work proves that eye movement recording techniques can be applied to a wide range of public without any technical supervision. The present application is an interesting tool for demonstrating the importance of eye movements in visual perception. Many other applications remain to be developed as the speed and accuracy of eye designation make it one of the most efficient methods in man/machine communication.

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Authors' biographies

Cathy Buquet was born in Bouvigny, France, in August 1963. She graduated from the Institut Supérieur d'Electronique du Nord in 1985 and is presently a graduate student in the Bioengineering programme of Lille university. She is preparing a Ph.D. thesis on the evaluation of eye movements in ophthalmology.

Jacques Charlier was born in France in 1951. He graduated from the Ecole Centrale de Lyon in 1974, received the M.Sc. degree in Bioengineering from the Pennsylvania State University in 1976 and the Doctorate Degree from Lille University in 1979. He is currently a researcher at the National Institute of Health & Medical Research and a consultant to the Metrovision company in Lille, France. His research interests are mainly the evaluation of visual functions in humans, including visual field, visual electrophysiology and eye movements.

Vincent Paris, was born in Paris in 1960. He graduated from the Maitrise de Génie Biologique et Médical in Toulouse in 1983 and is currently enrolled in the Bioengineering programme of Lille University. He is preparing a Ph.D. thesis on instrumentation and methods for measuring eye movements from images of the eye.