REAL TIME PATTERN RECOGNITION AND FEATURE ANALYSIS FROM VIDEO SIGNALS APPLIED TO EYE MOVEMENT AND PUPILLARY REFLEX MONITORING

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ABSTRACT

Original techniques for real time pattern recognition and feature analysis from standard video signals have been applied to the monitoring of eye movements and pupillary size during visual field examinations in routine ophthalmological practice.

INTRODUCTION

The evaluations of eye orientation and pupil size are of great interest in ophthalmology as eye movements and pupil contractions provide relevant informations on the proper operation of the visual sensory-motor system. The accuracy of fixation and the pupil size also play an important part in many visual function tests (3) including the visual field examination, since they determine the position and intensity of the retinal stimulus.

A desirable method for monitoring eye fixation, eye movements or pupil size during routine clinical examinations should require minimal subject training, co-operation, discomfort and set-up time. It should allow relatively free natural head movements and measure the rotation of the eye independently of its position. Furthermore, an eye-monitoring device should be positioned in such a way that it does not interfere with the visual examination.

Conventional intruments used for monitoring eye fixation exhibit a high sensitivity to head motion, and require frequent readjustment and reinstruction of the patient (7, 9). Some of these instruments compare the light reflection from the iris and cornea to a reference level set during proper alignment. Other instruments are tracking the position of the iris or the corneal reflection. Both types of instruments do not separate lateral and rotary motions of the eye. An eye rotation of 1° can be shown to be equivalent to a head transverse motion of only 0.17 mm (4). Maintenance of the head fixed within such limits is difficult, uncomfortable and not suitable for clinical examinations lasting for more than 10 minutes.

In a previous work (2), we described a new instrument for monitoring eye fixation and pupil size during visual field examinations. The major

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features of this instrument will be reviewed in the background section. The eye orientation was determined from the position of the corneal reflection relative to the bright pupil. Standard video equipment and LSI circuitry were used.

Intensive clinical evaluation for 3 years and over more than 6000 eyes indicated satisfactory performance in about 60% cases. The remaining 40% of cases resulted from severe perturbations of the ocular video image including partial occlusions of the pupil with eye lids and eye lashes, amplitude fluctuations of the video signal and parasite light reflections. In order to increase the performance of the instrument to an acceptable range, new developments were undertaken which will be presented in this paper.

BACKGROUND

The optics of the instrument have been described previously (2, 8, 10). The eye of the patient is illuminated with near i.r. radiation obtained from a tungsten filament lamp filtered to the 800–900 nm band, which is sufficiently far into the i.r. region to be almost invisible.

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 systems are made coincident (Fig. 1) so that incident light rays are refracted

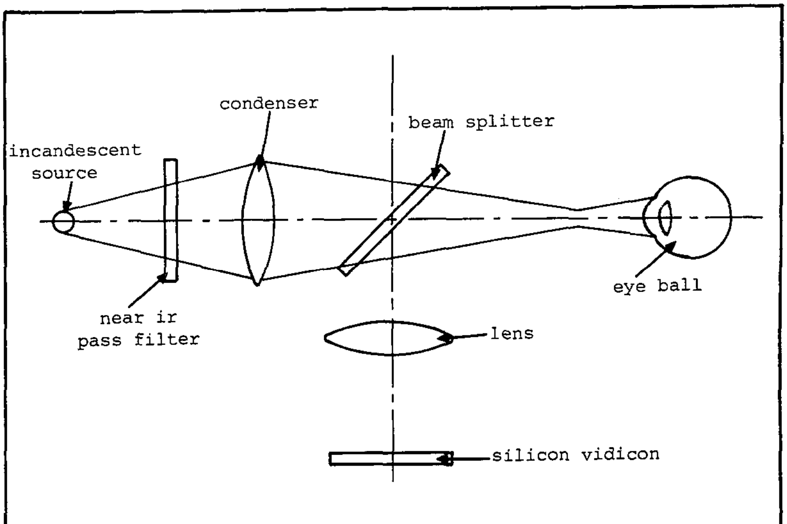

Fig. 1. Schematic of the optical system.

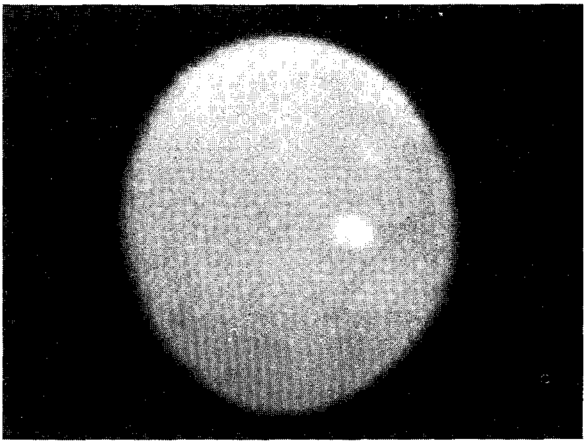

Fig. 2. Video image of the eye.

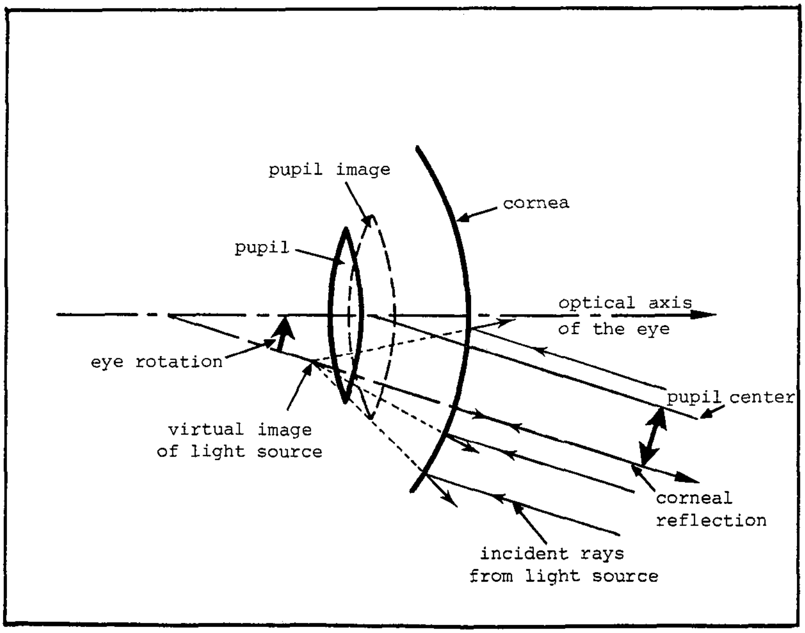

Fig. 3. The origin of the bright pupil and corneal reflection.

back from the retina 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 upon the corneal reflection. The corneal reflection and the bright pupil images are located in two different optical planes. Their relative position is not affected by translation movements of the eye and is only related to its rotations (8) (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 approximative 2 cm by 2 cm image area at the eye.

Eye orientation and pupil size are extracted from the camera video signal. Eye orientation is evaluated from the displacement of the corneal reflection relative to the pupil center.

FEATURE SELECTION

Previous design. In a first design (2), processing of the video signals involved two major steps. A preprocessing interface determined over each scanning line the co-ordinates of the beginning and end of the bright pupil as well as of the corneal reflection. Further calculations were carried out by a Motorola 6802 microprocessor.

The processing interface included amplitude threshold detectors which triggered a 5 MHz clock counter at the leading and trailing edges of the bright pupil and corneal reflection. The pupil center was calculated as the barycenter of the detected points which were likely to belong to the pupil perimeter.

This first design has been in the Lille ophthalmologic clinic for three years. More than 6000 examinations including visual fields and pupillary reflex evaluations have been performed. The instrument is found to be very convenient for routine clinical examinations in about 60% of the subjects. In these cases, it does not require any training, co-operation of discomfort. The error in measurement of eye orientation is typically less than ± 1 degree. Head movements within 10 mm amplitude do not affect the results significantly. The examination can be interrupted at any time and still no initiation of the eye monitor is needed when the examination is resumed. Pupil surface area is measured with satisfactory accuracy and recordings of pupillary contractions have been used for the clinical investigation of the pupillary light reflex (6).

Ocular video image perturbations. The remaining 40% of cases result from severe perturbations of the ocular video image involving several types of problems.

Pupil contour detection. The bright pupil intensity depends upon the pupil aperture and the opacity of ocular media. The contour of the pupil can hardly be detected when the contrast of the bright pupil is low. This situation is found when the pupil is less than 2.5 mm in diameter, as in glaucomatous patients treated with pilocarpine (Fig. 4) or when the ocular media are opaque, as in patients with cataracts. In some patients wide fluctuations of the pupil diameter require periodic readjustment of the amplitude detection threshold.

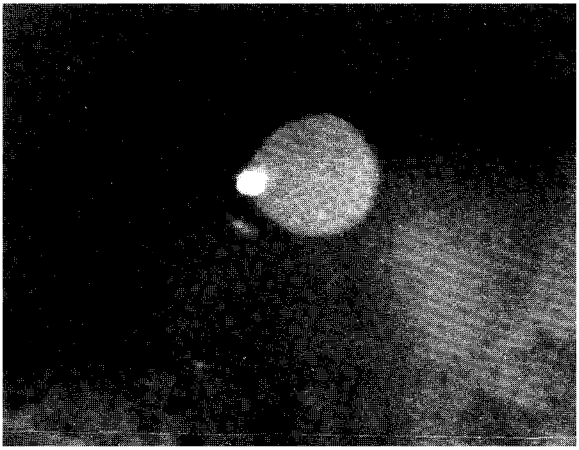

Fig 4 Low contrast pupil.

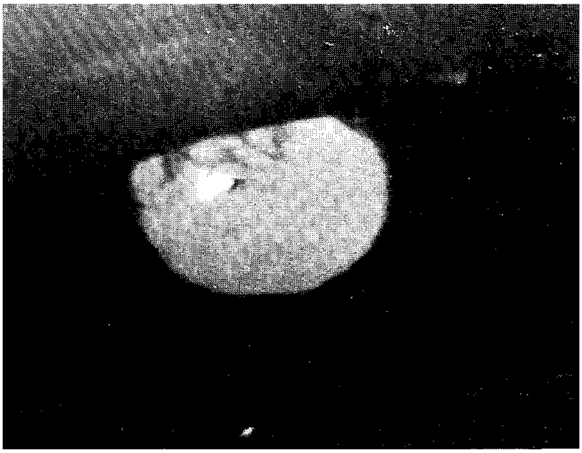

Fig. 5. Obstruction of the pupil with eye lashes.

Obstruction of the bright pupil. A large part of the pupil is often obstructed by the eyelids of eyelashes (Fig. 5). In these cases, the calculation of the barycenter leads to false determinations of the pupil center.

Corneal reflection detection. In a number of cases, parasite reflections occur on the sclera, on the skin or on optical glasses which are often needed for the evaluation of central vision (Fig. 6). These situations result in false identification of the corneal reflection.

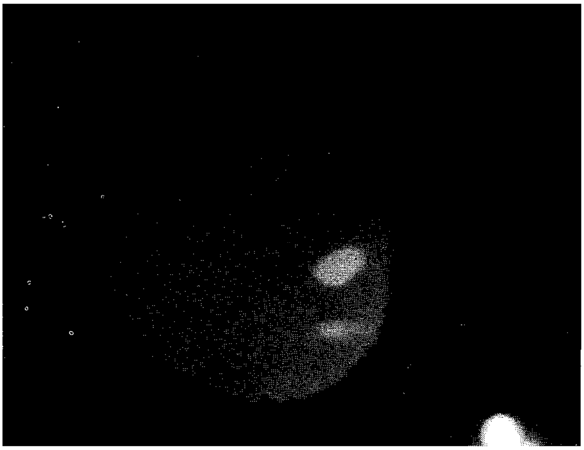

Fig 6 Parasite reflections.

FEATURE DETECTION, IDENTIFICATION AND ANALYSIS

New solutions have been developed in order to incease the performance of the instrument to an acceptable range. The basic scheme involving, in a first step, the extraction of pupil boundary and corneal reflection from each individual scanning line and, in a second step, the determination of pupil center and the calculation of relative corneal reflection displacement and pupil surface area, has been kept. It was improved significantly by the introduction for more specific ('intelligent') algorithms for feature detection, feature identification and reduction as well as feature analysis.

Feature detection. A shape detector circuitry was developed for the detection of the leading and trailing edges of the pupil and of the corneal reflection within the video signal. Figures 7 and 8 illustrate the results obtained from a sample video image. Using shape detection instead of amplitude level or amplitude variation detection improves performance significantly with low contrast images. It eliminates the problems associated with variations of the detection thresholds with pupil size fluctuations. A better discrimination is also obtained of the corneal reflection which is usually sharper than parasite reflections.

Feature identification and reduction. Further processing is carried out on a Z80 microprocessor after direct memory access of the data. Considerable thought has been given to minimizing calculation time to permit real time operation of the system, i.e., the complete analysis of each image within 20 ms. Specific, fast operating algorithms have been developed and implemented in assembly language. The present algorithms can process about

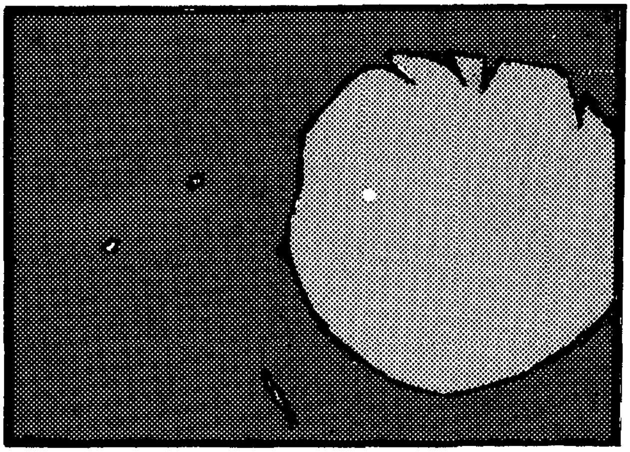

Fig. 7. Sample video image with eye lashes and parasite reflections.

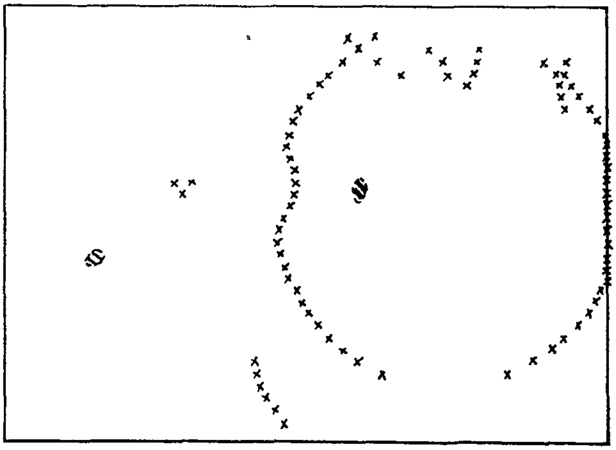

Fig. 8. Pupil boundary and corneal reflection detection.

100 detected leading and trailing edges within 20 ms. These data are clustered in data chains using algorithms based on contour continuity (Fig. 9) and curvature consistency (Fig. 10) of the pupil boundary. The data chains are scored according to these two criteria. The two data chains which obtained the highest scores are selected for further processing. This processing eliminates data chains resulting from parasite reflections and eye lashes.

Feature analysis. The purpose of feature analysis is to calculate the pupil center and diameter from the selected data chains. A fast algorithm

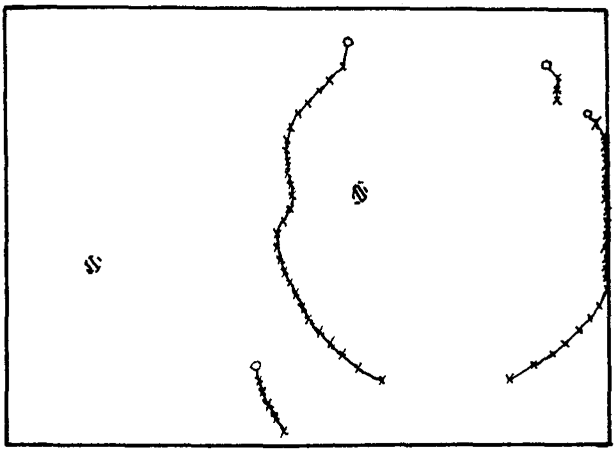

Fig. 9. Data chain extraction based on contour continuity.

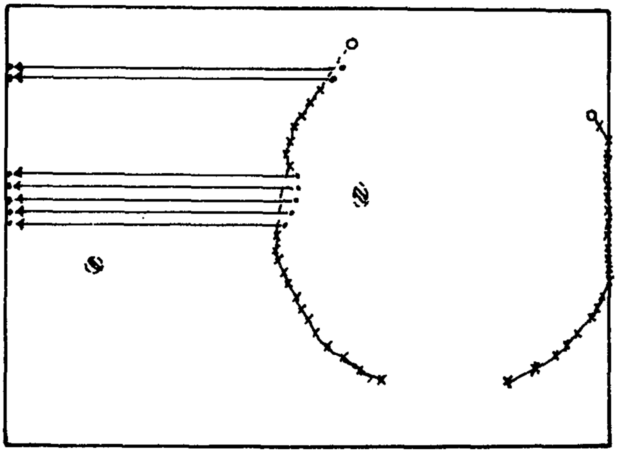

Fig. 10. Data chain extraction based on curvate consistence.

determines the center of the circle which fits the two data chains with a minimum distance error. The circle radius is computed as the average distance between the circle center and 8 data points chosen at regular intervals along the selected data chains. Finally, the corneal reflection is selected from the detected data according to its location within a perimeter centered on the pupil.

CONCLUSION

This work demonstrates the possibility of implementing fast, 'intelligent' image analysis systems providing an answer to the difficult problem of fixation and pupil size monitoring under clinical conditions.

The basic features of the resulting instrument are:

(1) The use of low-cost hardware, i.e. standard video equipment and LSI circuitry.

(2) The measurement eye orientation from the position of the bright pupil relative to the corneal reflection.

(3) 'Real time' processing and high data throughout of 50 samples per second, allowing pupillary and oculomotor reflex analysis.

(4) Specialized hardware and software permitting an adjustment free feature identification and analysis directly from video signals. Severe perturbations of the ocular video images can be handled by the system, including partial occlusions of the pupil with eye lids or eye lashes, fluctuations of amplitude levels and parasite light reflections.

Further clinical evaluation is needed in order to evaluate the improvement provided by this new design.

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