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Medical Progress through Technology

A New Instrument for Automatic Subjective and Objective Perimetry

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I. Introduction

The visual field examination has been used in the ophtalmic clinic for hundreds of years [5]. Until recently, the evolution of instrumentation was linked to a better understanding of the physiology and the pathology of the visual system. The resulting instruments (Goldmann, Tubinger, Etienne perimeters) are complex and sophisticated machines which can only be handled by intensively trained practicians.

However, recent developments in the technology of large scale integrated circuits have considerably lowered the cost of data processing. Thus we have been able to automate many functions of the perimeter without altering significantly the cost of equipment.

Furthermore, we have introduced some features necessary for future clinical developments toward objective perimetry including specially designed stimulation and eye monitoring units.

II. Background

Perimetry is one of the most valuable techniques available for the diagnosis of tumoral, neurologic, inflammatory and vascular affections of the visual system. The basic idea of the visual field examination is to reveal characteristic deficiencies of the threshold of light perception. The patient is fixing the central point of a uniformly lighted hemispherical screen. Mapping of the visual field is then obtained through several procedures:

- in static perimetry the stimulus is fixed and its luminance is increased until the patient perceives it.
- in kinetic perimetry, a spot with specified luminance is moved from the periphery toward the center of the screen until it is detected.

In all cases, the examination is plagued by a number of factors limiting the value of its results.

1. The complexity of the instrumentation and of the tasks performed by the operator requires intensive training for the practician and represents an important source of error.
2. A number of uncontrolled parameters can influence the results: the existing devices for the control of fixation are affected by head movements, and the pupil size which determines the stimulus intensity is not taken into account.
3. The subjectivity of patient responses diminishes considerably the value of the method with the introduction of psychologic factors [6].

Recent developments in instrumentation provide a partial answer to these problems. Perimeters have been introduced on the market which include automatic stimulus presentation, infrared monitoring of fixation and automatic recording of responses (Field Master, Octopus, Perimetron).

1. Automation results in a reduction of the perimetrist's involvement and in a better standardization of procedures. However it also reduces the flexibility of the examination as compared with manual perimetry. For instance, the Field Master and the Octopus are limited to static perimetry and the Perimetron's programs of kinetic perimetry lack fine details that would be included by a skilled operator [10]. There is such a variety in the pathologic patterns of the visual field that direct manual control can still be necessary. This feature is not included in actual automatic perimeters.
2. The existing eye monitoring units are based on coincidence measurements of the eye position. They are very sensitive to head movements and require frequent readjustments [10].

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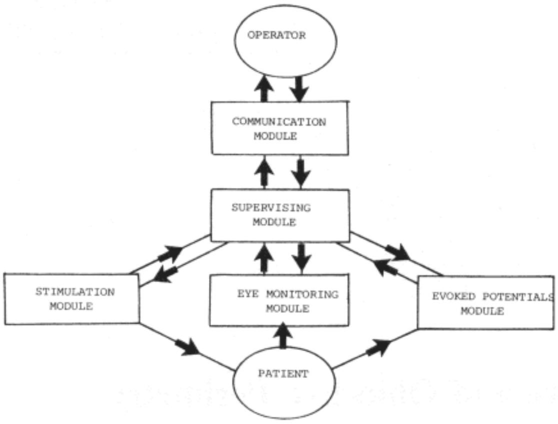

Fig. 1. Functional diagram of the perimeter

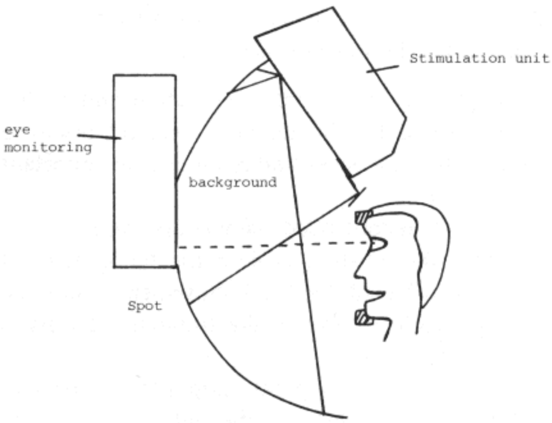

Fig. 2. General configuration of the perimeter

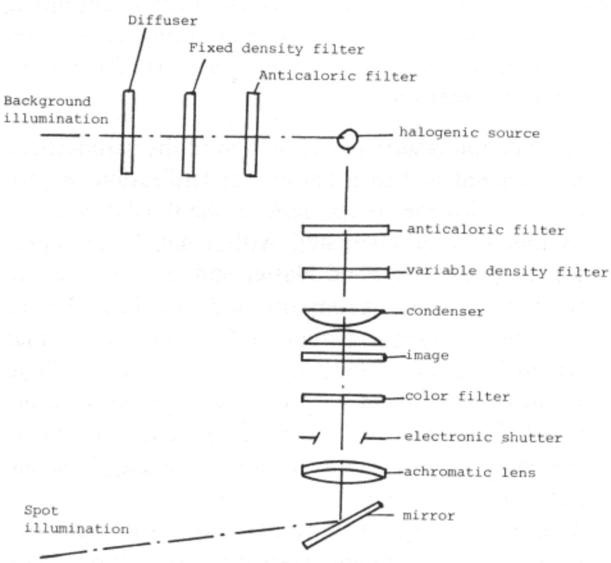

Fig. 3. Stimulation unit – optical design

3. Several attempts have been made toward the development of objective methods. Promising clinical results have been obtained with various physiological signals including the visual evoked potentials [1, 9], the pupillary reflex [2, 8] and the oculomotor reflex [3,7].

During the design of our instrument, we tried to realise a synthesis af all previous considerations. Our approach has been functional (Fig. 1) and has resulted in a set of four separate modules: one for the stimulation, one for the eye monitoring, one for the communication with the operator and a last one for the supervision of the system. A fifth module will be added later on for the acquisition and treatment of visually evoked potentials.

III. The Stimulation Unit

It is designed in order to provide stimuli for both subjective and objective perimetry. The stimulation unit is placed inside the coupola right over the head of the patient. It cannot be perceived since the visual field is limited in the upper region to 60 degrees (Figs 2 and 3). This arrangement results in two important features:

1. Images up to 10 degrees large can be projected allowing for instance the projection of a toy as a stimulus for a baby but also the stimulation with patterns in objective perimetry.
2. A unique halogenic source is used for the background and the spot illumination. Therefore a constant ratio is maintained between the relative light intensities of the two stimulus components and the need for a light source regulation is eliminated.

The spot can be displaced all over the visual field thanks to a small mirror which is positioned with two motor units. The light intensity of the spot can be adjusted over a range of three logarithmic units with a variable density filter controlled by another motor unit. An electronic shutter allows the presentation of the spot for a duration adjustable from 20 ms to infinity. This shutter operates very quietly and can be used as a chopper with frequencies up to 50 Hz.

All the functions of the stimulation unit are controlled by the supervision unit. All features of conventional perimeters are obtained plus the stimuli used for objective perimetry (pattern, chopped and modulated stimulations).

IV. The Eye Monitoring Unit

As indicated in the background section, the eye monitoring units existing in automatic perimeters are very sensitive to head movements and require frequent

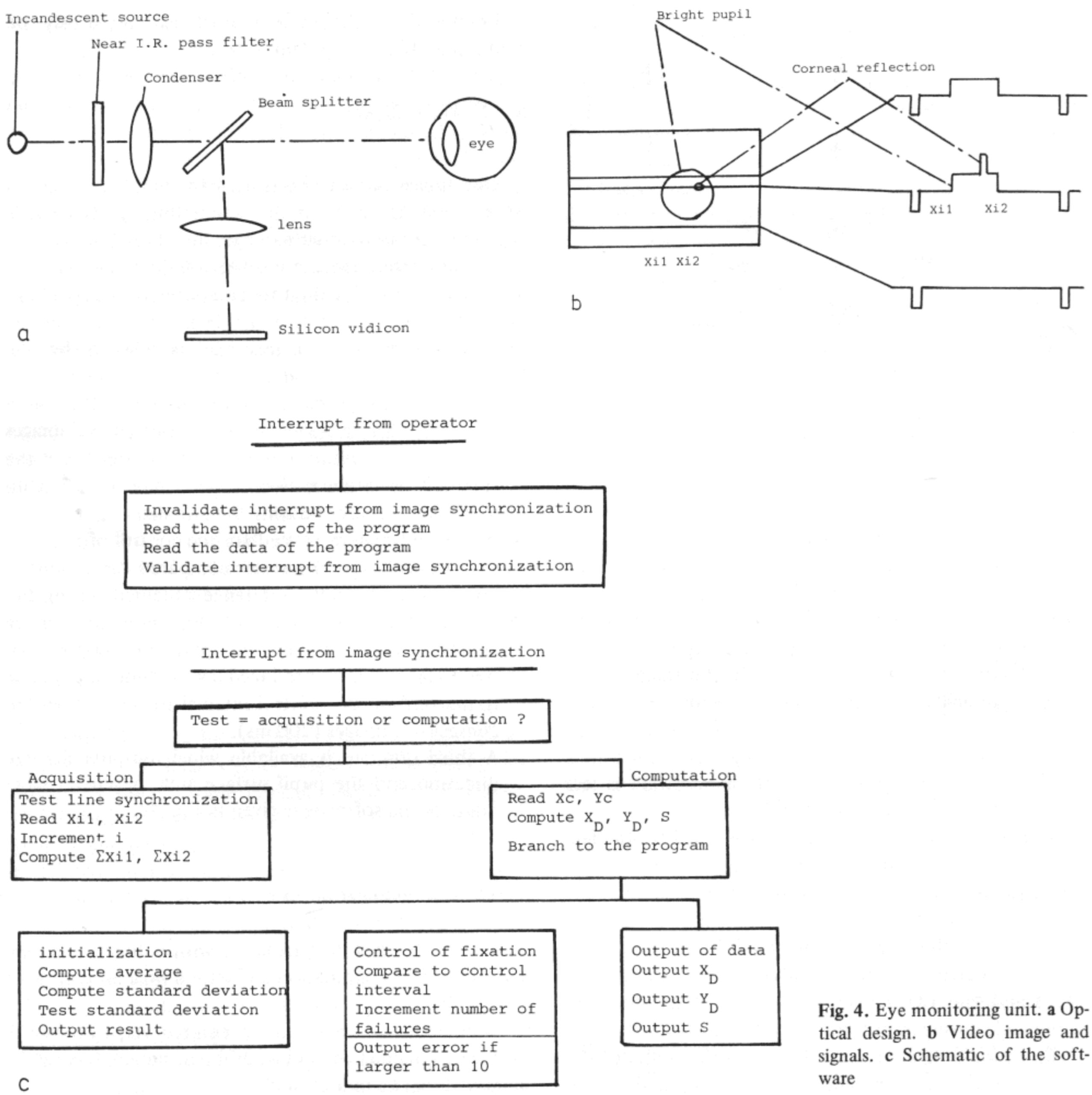

Fig. 4. Eye monitoring unit. **a** Optical design. **b** Video image and signals. **c** Schematic of the software

readjustments. With the methods tracking the position of the iris or the position of the corneal reflection, a head motion of 0.17 mm is equivalent to an eye rotation of 1° [11]. Actually it is not possible in a clinical situation to keep the head fixed within such limits.

A desirable method would allow relatively free natural head motions. It should measure the rotation of the eye independently from its position.

Such methods have recently been proposed [11].

- One measures features of the eye that only change with rotation. Variations of the apparent shape of the pupil can be used: as the eye rotates, the ellipticity of the pupil changes. Unfortunately, this method requires complex geometrical calculations which prevent an easy implementation.
- Another solution is to measure the position of details of the eye that move differently as the eye rotates. Their difference is not affected by translatory movements and is related only to rotational movements. The first and fourth Purkinje images have been used [4]. They are reflections taking place respectively at the front of the cornea (corneal reflection) and at the back of the lens. However the last one cannot be easily detected at the operating distance of the control unit (50 cm) without high illumination which can be dangerous to the eye.

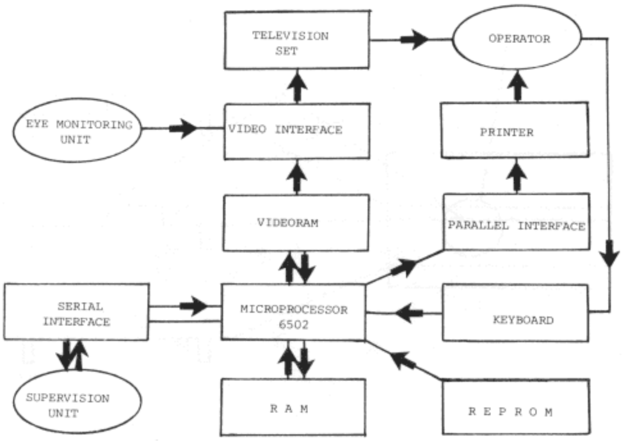

Fig. 5. Communication unit

- The corneal reflection and the center of the pupil have also been used [11]. This method has been implemented in several commercial equipments (Honeywell Oculomotor, Whittaker Eye View Monitor). However, the prices of these equipments are prohibitive (around 40,000 \$ for the Whittaker unit).

After an analysis of the costs, we decided to develop our own system in which the processing of the video picture would be made by wired logic combined to a microprocessor. The resulting cost of hardware is less than 2,000 \$, silicon vidicon included.

The schematic of the system is given in Fig. 4a. The video signal cannot be directly, analysed by the microprocessor in use in our laboratory (Motorola 6800) if the large bandwidth of the infrared camera is applied. Therefore a preliminary treatment with TTL wired logic has to be performed: the coordinates of the beginning ($Xi1$) and end ($Xi2$) of the pupil are determined by wired logic during each scanning line (Fig. 4b).

From these data, the coordinates of the center of the pupil (Xp and Yp) can easily be determined as the barycenter of the pupil perimeter:

$$Xp = \frac{1}{2i} \left[\sum_i Xi1 + \sum_i Xi2\right] \tag{1}$$

$$Yp = \frac{\Sigma i}{2} \tag{2}$$

And the distance between the pupil center and the corneal reflection (Xc, Yc) can then be obtained:

$$X_D = Xp - Xc \tag{3}$$

$$Y_D = Yp - Yc \tag{4}$$

Furthermore, the pupil surface are can easily be determined from the previous data:

$$S = \sum_i Xi2 - \sum_i Xi1 \tag{5}$$

One image out of two is used for the determination of $Xi1$ and $Xi2$ and for the summations $\Sigma\, Xi1$ and $\Sigma\, Xi2$. During the following image, the coordinates of the cornea are determined, the center of the pupil (Xp, Yp) and the distance (X_D, Y_D) are computed from Eqs. (1) to (4).

Several specific programs can be chosen by the operator:

- One is initializing the control of fixation. The values (X_D, Y_D) are averaged over a series of 32 images (640 ms). The result is used as a reference only if the standard deviation is close to zero-indicating that no movement occurred during the initialization.
- A second program is used for the control of fixation. The values (X_D, Y_D) are compared to a control interval based on the reference obtained during the initialization. The width of this interval can be adjusted, depending on the patient's cooperation. An error signal is produced every time the eye is fixing outside the control interval for more than ten consecutive images (200 ms).
- A third program is available which outputs the eye direction and the pupil surface area. A general schematic of the software is given in Fig. 4c.

V. The Communication Unit

This unit provides the practician with a direct, real time control of the examination and with a final hard copy of the results.

Alphanumeric data can be entered via a keyboard, and direct manual control of different parameters can be obtained thanks to a joystick.

A large number of data has to be transmitted to the operator: the image of the eye produced by the eye monitoring unit, plots of data corresponding to the patient responses and alphanumeric data. A color display is essential for the easy interpretation of all these informations.

All these functions are fulfilled with a slightly modified Apple II personal computer (Fig. 5). This solution is very cheap (less than 2,500 \$), including a color television set. Graphics with five colors and a resolution of 140 x 180 are obtained. Furthermore the Apple II is built around a 6,502 microprocessor which can execute the calculations relative to the presentation of results (transfer from the parameters of the stimulation unit to the operator representation).

VI. The Supervision Unit

The management of the different modules and the determination of the strategy of examination are controlled by the supervision unit. A powerful minicomputer (LSI 11 from Digital Equipment Corporation) was chosen in order to allow future clinical developments of the strategies.

The actual software includes basic modules which can be used as building blocks for the construction of complete procedures of examination.

One basic module is assigned to the command of the stimulation unit and a series of modules are programs determining specific procedures. For instance, there is a procedure used when the eye monitoring unit detects a bad fixation. First the light which should be fixed is put on a flickering mode. If fixation is recovered, the examination continues normally. If not, a buzzer is actuated and the operator intervention is waited for. Other specific procedures exist for initialization of fixation control, for linear movements of the stimulus, etc.

VII. Results

Our instrument will be installed at the Ophtalmic Clinic in the Lille Medical Center within a few weeks. We expect to obtain some clinical results before August 1979. However, the different functions of the instrument have already been evaluated in our laboratory.

1. The stimulation unit permits local stimulations over a matrix of 256 x 256 positions. The field limits extend to 100° on the temporal side, 70° on the nasal side, 60° upward and 70° downward, which is close to the natural limits of the visual field. Displacements of the stimulus with a velocity ranging from 1 to 255° per second are obtained.
2. The eye monitoring unit allows the measurement of eye direction with a precision better than 1°. This is quite sufficient for the control of fixation. However, one limit of our solution is that the pupil cannot be detected when its diameter is less than 1 mm. In fact, the amount of light brightening the pupil, i.e. the light which is entering the eye and reflected by the retina, is determined by the size of the pupil. Therefore, the bright pupil effect cannot be obtained on patients with a constricted pupil, such as the glocomatous patients. For these subjects, we have developed a program which is only taking in account the corneal reflection. As mentioned previously, this control is sensitive to head movements.

VIII. Conclusion

Most of our objectives have been fulfilled and we are looking forward to the first clinical results. We expect this instrument to allow important improvements in the diagnosis of visual affections.

Future research orientations include the development of objective methods and of strategies of examination with adaptative and specific algorithms.

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