needed is a ghost image in space. So far, the closest we have come to an indestructible target is a polyethylene target that has been developed and tested under the control of the Naval Training Device Center. This target can take 2,000 to 3,000 rounds and is reasonable in price. A quarter of a million of these targets are in the production stage at this time. In the manufacture of targets, different companies will produce targets with different responses even though the same specifications are used. Small differences in the hardness of the target make a significant effect in transferring the energy from the bullet to the target. The energy absorption characteristics of the targets are noticeable when a BB gun gets 100% response from the target while an M-16 rifle gets only 82%. The BB, not penetrating the target transfers nearly 100% of its energy down the target into the sensors while the M-16 passes through the target without losing much energy.

The Naval Training Device Center is developing a new small arms projectile device which may establish new requirements for target and target scoring systems. This device is a safe bullet - the M-16 training pellet. This may provide greater flexibility in the training of combat troops. Presently it has a range of 200 feet with a mean radius accuracy of 7 inches, and will actuate the pop-up mechanism with every hit. Eventually, it would permit the trainees to go into the training field and fire at a moving target - another trainee who is firing back. Along with the development of a light weight, slow speed bullet, a certain amount of body shielding must be provided for the vulnerable parts of the body. If noncasualty projectiles can be developed to act in the same manner as the steel projectiles, new and unique targets and scoring systems may be forthcoming.

CONCLUSION

Many areas have been investigated to produce an economic small arms scoring system. Nearly every field of science has been applied without complete success. It is within the state of the art to produce a successful economic, ideal scoring system. This could be done within a year. It is left for some group to take on the problem and do it.

THE OCULOMETER: A NEW INSTRUMENT FOR MEASUREMENT AND CONTROL

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INTRODUCTION

In the normal act of vision, the eyeball is pointed very accurately and rapidly at the target detail being scanned (typical accuracy 0.1 degree, typical speed 0.2 second). Target acquisition, tracking, designation, etc., could, in many cases, be performed, therefore, much better by eye than by hand - if a practical eye direction measuring device were available. The eye pointing action that would be utilized is not an "extra task" that the operator must consciously perform but is performed naturally, in normal vision, without any conscious effect involved.

Honeywell has developed an unattached IR eye tracker (Oculometer) capable of accurately measuring eye direction without interfering with the subject. The Oculometer can be integrated into almost any viewing arrangement, and can, if desired, be located several feet from the subject.

The Oculometer can be applied in various surveillance, target acquisition and tracking, and other control systems. It provides the advantages of:

- improved operator performance (in terms of accurate high speed control) because the eye can be used for control in place of the hands.
- reduction of operator loading
- hands free operation

The Oculometer can also be used in various ways to monitor human performance, without interfering with the task being performed. For example:

- Instrument panel evaluation
- *Pilot performance studies*
- Teaching and training machines

THE OCULOMETER

The Oculometer is an electro-optical device that measures the direction of pointing of the human eye. It is not attached to the subject, and operates with essentially invisible infrared radiation.

The basic sensing principle of the Oculometer is that eye direction is defined by the position of a corneal reflection (of the radiation source within the Oculometer), relative to the center of the pupil.

The pupil-iris boundary is illuminated by the Oculometer in such a way as to make this boundary clearly visible. By tracking this boundary, the position of the center of the pupil can be determined. This displacement of the corneal reflection from the center of the pupil is K sin θ (Figure 63) where θ is the angle between the geometric axis of the eye and the direction of the incident collimated beam (which is a reference direction, the optical axis of the Oculometer) and K is a dimensional constant of the eye. Thus by measuring the displacement of the corneal reflection from the center of the pupil, in the eye image, a measure is obtained of the direction of the geometric axis of the eye.

The displacement between the center of the pupil and the corneal reflection is independent of the position of the eye. That is, if the eye moves (with no rotation) the displacement between these two points is invariant. The displacement between the rays is solely a function of the angular direction of the eye.

A novel illumination technique is employed in the Oculometer in which the eye is irradiated with IR radiation to show the pupil as a bright uniform disc. (See Figure 64)

An image of the eye, showing the pupil against a virtually black background with a small super bright corneal reflection, (as in Figure 65) is formed at the plane of an F4011 image dissector photocathode. The angular direction of the eye is proportional to the linear displacement of the corneal reflection from the center of the pupil. The Oculometer uses an electro-optical tracking system to measure this corneal reflection displacement.

Electrons are emitted from the image dissector photocathode in proportion to the incident IR radiation in the eye image. These electrons are accelerated towards an aperture plate having a small central circular aperture. The electrons are magnetically focussed onto this plate to form an electron image of the eye.

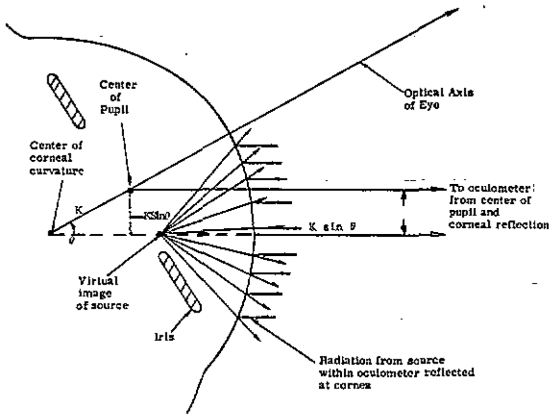


Figure 63. Basic Sensing Principle

Figure 64. Eye As Seen By Oculometer

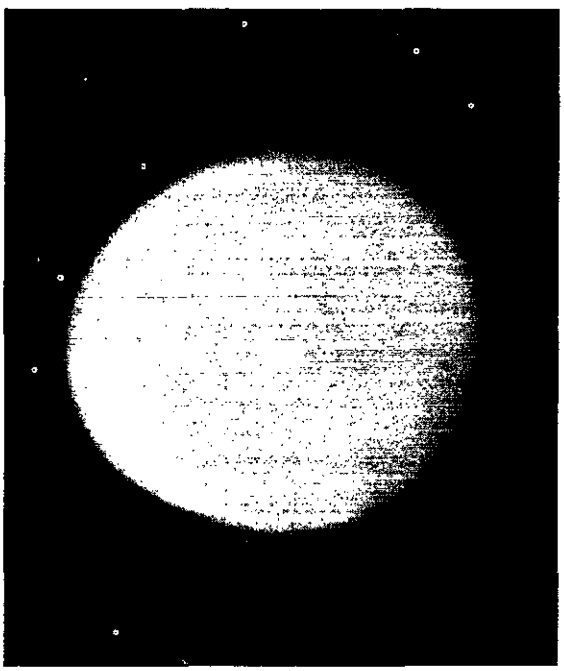
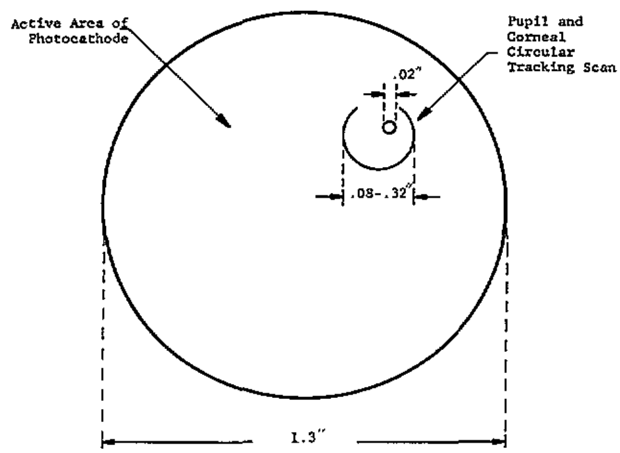


Figure 65. Eye Image At Image Dissector Tube



(All dimensions are in inches and are referred to the Eye Space)

Figure 66. Pupil and Corneal Tracking Scans

The electron image at the aperture plate can be deflected in two dimensions by magnetic fields applied by the deflection coil. In this way the clear aperture can be laid over any part of the eye image. The electrons falling onto this clear aperture pass through to the multiplier section of the tube having a gain of about 3 x 10^6. The output current from the image dissector is thus proportional to the average intensity of that region of the optical image at the photocathode corresponding to the aperture. The position of this region in turn, is determined by the currents flowing in the x and y deflection coils.

The electronics system of the Oculometer can be in any one of the following states:

Pupil Track/Corneal Track
Pupil Track/Corneal Search
Pupil Search

This particular state that the Oculometer is in is determined by the corneal and pupil state sensors as a function of the signal output from the image dissector.

In the pupil track/corneal track mode the deflection coils apply a constant circular scan pattern together with pupil position and corneal position signals. The total effect is to cause the small sampling aperture of the image dissector tube to move over the eye image in a pattern illustrated in Figure 66. The top portion of the circular scan is not used for pupil tracking in order to avoid errors due to obscuration of the pupil by the upper eyelid and lashes.

The image dissector output signal is processed to generate video signals for each of the
The image dissector output signal is processed to generate video signals for each of the
five tracking loops (pupil diameter, pupil position (x and y) and corneal position (x and y)). with the computed scan position signal.

A simplified block schematic diagram of the Oculometer tracking system is shown in Figure 67.

The pupil and corneal circular tracking scans are derived from a 1 kHz sinusoidal signal, which in turn is derived from a master clock system. The video output from the image dissector is applied to pupil diameter, pupil position, and corneal position demodulators. The output from these demodulators is a signal proportional to the instantaneous scan position error, and is applied to the associated integrators. The integrator outputs control pupil scan diameter, pupil scan position and corneal scan position (relative to the center of the pupil). The various position and scan signals are assembled and applied to the image dissector deflection coil.

Let it be assumed that the scan system is exactly aligned with the appropriate eye detail. The output from all the demodulators will be zero and the integrator outputs will not change. If the eye displaces, then the video output from the image dissector will change (See Figure 68). The demodulators will generate, from this video, an appropriate error signal proportional to the existing scan position error. This error signal will cause the associated integrator outputs to change in such a way as to correct the existing error in scan position. When the error has been corrected, all the error signals from the demodulators will be zero, the integrator outputs will not change, and the scan will remain correctly positioned over the eye detail.

Eye direction is proportional to the output of the corneal integrators. These integrator outputs are applied, via electronic switches, to amplifiers which have provision for front panel individual adjustment of gain and offset.

The basic scan period of the Oculometer is 2 milliseconds; that is, the scan pattern shown in Figure 66 has a period of 2 milliseconds.

In the search modes the circular scans are suppressed and the tracking loops are disabled. A coarse raster scan is substituted for the circular scans. In the pupil search mode, the video from the image dissector is applied to the pupil state sensor. When the video level exceeds a threshold level (determined by the setting of the pupil acquisition threshold control) the logic state of the acquisition comparator changes and the system is switched to the pupil track mode.

OCULOMETER CONFIGURATIONS

There are several Oculometer configurations (designs) that can be used to monitor a subject's fixation point. The choice of the configuration for a given situation depends upon the application, size constraints, shape constraints, accuracy requirements, etc.

The basic Oculometer principle is utilized in all configurations; namely, an enhanced image of the eye is formed upon the sensitive surface of an image sensor, and the sensor output is processed by appropriate electronics. The electronic system is essentially the same in all configurations. The variation between configurations lies in the optical design. The two basic configurations are the proximate Oculometer and the remote Oculometer. The basic features of these two configurations are described below.

(1) Proximate Oculometer

The general purpose laboratory Oculometer now in use at Honeywell is a proximate Oculometer. Figure 69 shows the laboratory Oculometer monitoring the fixation point of a subject as he views a scene by looking through a dichroic beamsplitter. This beamsplitter is transparent in the visible but reflects the infrared Oculometer radiation onto the eye and back into the instrument. The subject's field of view is unobstructed, and the Oculometer itself does not interfere with the scene being viewed.

The proximate Oculometer also can be used with auxiliary optics to provide the subject with a magnified (or demagnified) view of the scene.

The proximate Oculometer can be designed specifically for monitoring a subject as he watches a particular display.

(2) Remote Oculometer

The remote design permits placement of the Oculometer at some distance from the subject. The distance between the Oculometer and the subject can be as great as six feet (or more if necessary). Figure 70 shows a demonstration remote unit now being made by Honeywell.

The remote configuration is particularly suited for situations where it is desired to monitor the subject's fixation point on a given screen or panel. Honeywell is currently performing a design study for installation of a remote Oculometer in an aircraft instrument panel to monitor the pilot's fixation on various instrument dials in the panel.

It can be noted that the incorporation of a two-axis moving mirror assembly into the remote Oculometer enables the monitoring of the subject's eye pointing direction for a large range of head positions. Lateral head movements of one foot or more can be allowed using this technique.

APPLICATIONS OF OCULOMETRY

The Oculometer is a new instrument with a wide variety of important and interesting applications derived from its unique ability to accurately measure eye direction in both remote and

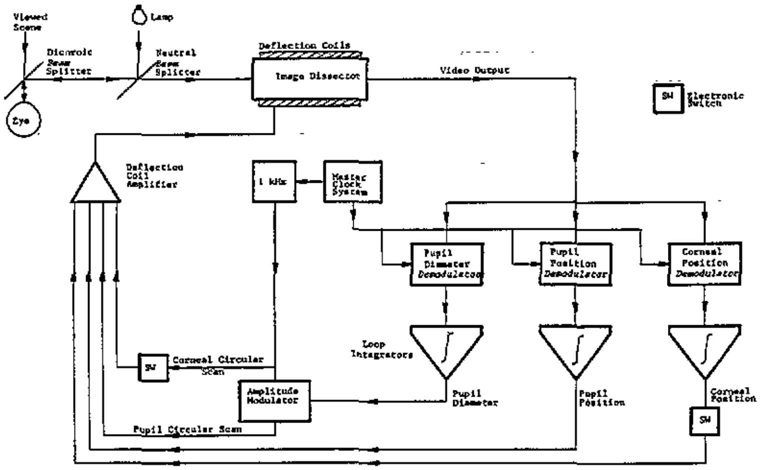


Figure 67. Oculometer Tracking System

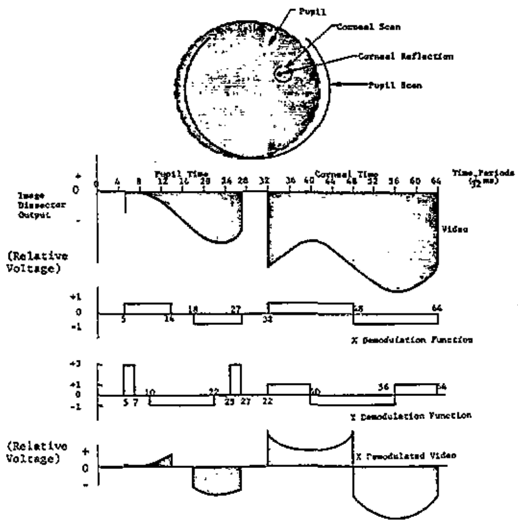


Figure 68. Position Demodulation Functions

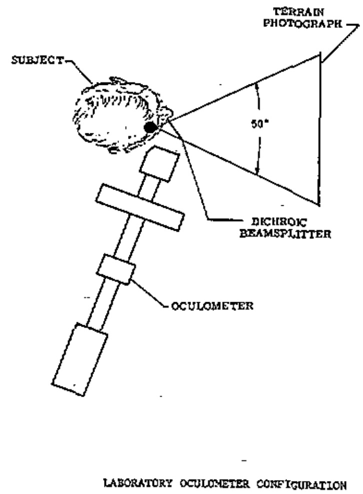


Figure 69. Laboratory Oculometer Configuration

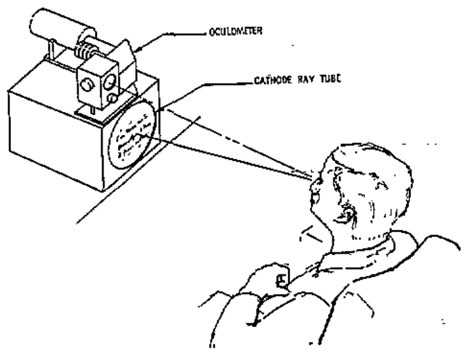


Figure 70. Remote Oculometer

proximate configuration without interfering with the subject. Some of these applications relate to the interaction between a human observer and a system with a visual display. The Oculometer can be used to monitor and study the way in which the observer uses his display. It can also be used to help the observer interact with the display system. Since the Oculometer is a device which measures where the user's gaze is directed, it is also generally useful for automating any pointing or following task now performed by the user's hands. A helicopter pilot, for example, must simultaneously control several servo loops in his craft using eye-hand feedback. Additional tasks are assigned at the peril of the vehicle and its occupants. If, for example, the pointing of reconnaissance sensors is automated, the pilot's hands will be free to fly the vehicle.

The applications of oculometry can be divided into several categories. These are as follows:

Laboratory and experimental applications
Target designation
Sensor pointing
Training aid

Each of these categories will be discussed in turn.

LABORATORY AND EXPERIMENTAL APPLICATIONS

The Oculometer is particularly applicable to studies of human subjects viewing real-time or nonreal-time displays for military reconnaissance. Many very important benefits result from such eye behavior studies, such as:

1) The visual functions of the operator, pilot, observer will be better understood so that his training and usefulness may be enhanced.

2) Displays and data presentation formats can be designed to match the real needs and capabilities of the human operator. The Oculometer, therefore, can provide a portion of the data base with which to design much more practical and effective displays.

3) It will allow the rapid and efficient scoring and evaluation of trainee performance in examinations and tests where it is necessary to determine if the student is observing the proper search patterns, viewing tasks, and similar operations. In scanning displays and photographs, it is important to know if the student missed certain areas in the display or photograph or if he spent the wrong amount of time on certain areas at the expense of other areas.

There are numerous instances where it is necessary for one operator to indicate a point-target to another operator. It is often of value to be able to point or direct a search light beam or laser beam for landing aid or for target illumination in semiactive homing missile systems, etc. The Oculometer can be a very effective military tool for such purposes.

In command and situation displays, the commander is often required to designate a particular portion of the display. With an Oculometer and a push button, he can instantly, and automatically, indicate his point of attention. If the display is computer driven, a superimposed circle, spot, or other symbol may be inserted synthetically at the coordinates furnished by the Oculometer.

SENSOR POINTING APPLICATIONS

In any system applications where a sensor telescope or scanner is to be directed or pointed under human control, the Oculometer can free the operator's hands for other tasks and greatly improve the system dynamics. The pointing automation capability has other less obvious advantages and potentialities. For example, dual resolution systems can be configured. Energy and/or resolution can be concentrated in areas of the observer's field of view where it is most important to have such concentration. The foveal region of the retina is richly equipped with sensor cells for high resolution color vision. The peripheral sensor cells of the retina, on the other hand, provide a very wide field of view with poor resolution but excellent sensitivity to motion or light changes. The Oculometer can be used to control the pointing of a variable resolution sensor so that the system resolution can always be matched to the resolution of the retina. In this arrangement, the information bandwidth requirements of the system are vastly reduced.

TRAINING

The Oculometer could be used for a number of training applications: For example,

A remote configuration Oculometer panel mounted in an aircraft, could help pinpoint any errors committed by the pilot in executing various procedures.

An Oculometer integrated into a computer driven display could be used in reading analysis, reading training, information retrieval, teaching etc. (The film, which will be shown at the conclusion of the paper was taken by MIT showing the Oculometer in use in project MAC. It illustrates the way in which the Oculometer can be used at the interface between man and a computer display.)

Laboratory Oculometer (Proximate): NASA Unit . . . . Completed May 1968
Laboratory Oculometer (Proximate): Honeywell Unit . . . . Completed August 1968
Demonstration Remote Oculometer: NASA Unit . . . . Scheduled November 1968
Remote Oculometer for Aircraft Use: NASA Design Study . . . Completed October 1968

PERFORMANCE	Present	Projected	OUTPUTS AVAILABLE
Noise Level	0.3°	0.05°	Eye Direction x
Repeatability	0.5°	0.1°	Eye Direction y Pupil Position x
Response Time	< 20 ns	20 ns	Pupil Position y Pupil Diameter R Blink Occurence

Figure 71. Oculometer Status

Figure 72. Oculometer Optomechanical Unit

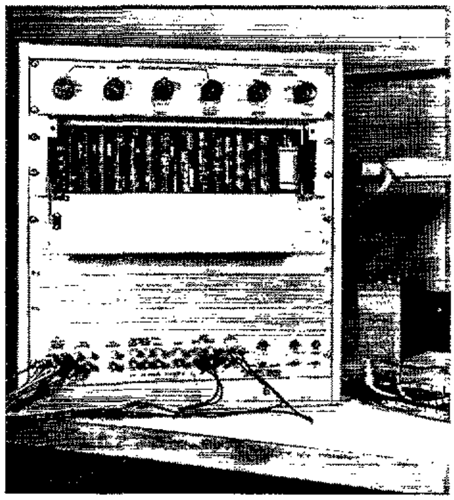


Figure 73. Oculometer Electronics Unit

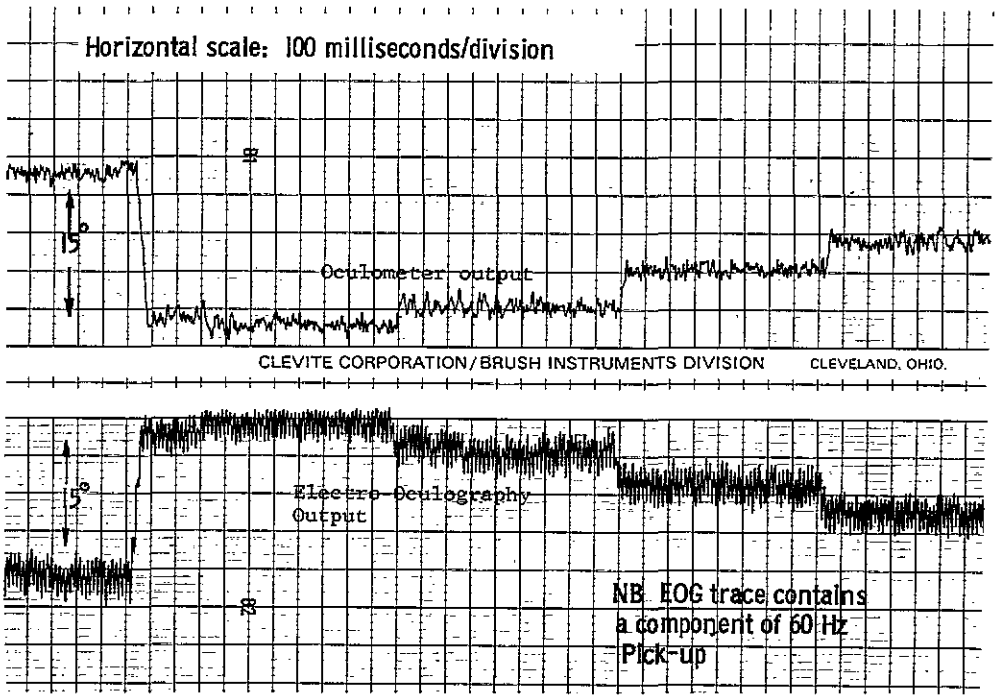


Figure 74. Comparison of Oculometer with Electro-Oculography

STATUS

The status of our Oculometer development is summarized in Figure 71. The laboratory (proximate) Oculometer is shown in Figures 72 and 73. Figure 74 shows a typical Oculometer recording, together with a simultaneous EOG trace.