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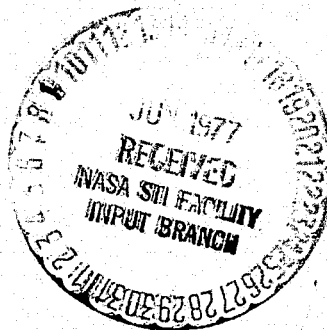
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N77-25783

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G3/54 15037

Market Study:  
3-D EYETRACKER

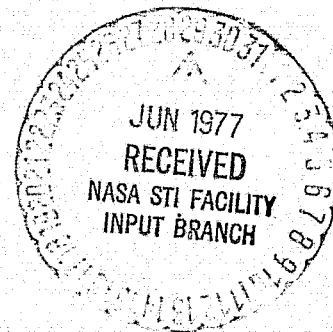


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TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION, BACKGROUND, PATENT STATUS.....	1
1.1 Introduction.....	1
1.2 Background.....	1
1.3 Patent Status.....	2
2. APPLICATION AREAS.....	3
3. TECHNO/ECONOMIC ASSESSMENT.....	5
4. NATURE OF THE MARKET.....	6
5. COMPETITIVE ENVIRONMENT.....	9
6. SIZE OF THE MARKET.....	12
7. COMMERCIALIZATION POTENTIAL.....	17
8. INTERESTED PARTIES.....	19
APPENDIX A.....	A-1
Exhibit 1 - "Comparison of Eye Movement Measuring Techniques".....	A-2
Exhibit 2 - Product Literature.....	A-5
Exhibit 3 - Excerpt from "Significance of the Proposal".....	A-59

# 1. INTRODUCTION, BACKGROUND, PATENT STATUS

## 1.1 Introduction

This report documents the findings of IITRI's market study of a proposed version of a 3-D eyetracker developed at Stanford Research Institute (SRI) for initial use at NASA's Ames Research Center. The objective of the study has been to ascertain the commercialization potential of a simplified, less expensive 3-D eyetracker. Primary focus on present and potential users of eyetrackers, as well as present and potential manufacturers has provided an effective means of analyzing the prospects for commercialization.

## 1.2 Background

The steady growth of scientific interest in the relationship of eye movements to various aspects of human performance, has led to an increased need for instrumentation capable of documenting these relationships. Several organizations have competitive eye movement monitoring instruments on the market which vary with respect to technical specifications, subject involvement, operator training, form of output, and cost.

Providing an alternative for eye movement researchers over the past few years has been an eyetracker developed at SRI, which is regarded as being the most accurate yet available. The most recent version of the SRI eyetracker is a 3-D eyetracker which not only measures the movement of both eyes simultaneously, but also provides for concurrent measurement of the state of accommodation (focus), of both eyes using an optometer previously developed at SRI. Another important distinction is that their instrument does not require contact with the eyes in order to achieve the specified accuracy. Many professionals in the field recognize that this particular combination of features provides an important tool for the future continued study of eye movements in a variety of applications.

A proposal has been submitted to NASA by SRI which defines development of simplified, cost-reduced version of the 3-D eyetracker. The objective would be to thereby offer an eyetracker with optometer which would still have many competitive technical advantages, but which also would be more cost competitive. It is perceived that such a unit would be accepted over a broader base of applications, including various clinical areas, where simplified, efficient techniques at a reasonable cost are prime considerations. The scope of this study is to consider the potential of this proposed version of the SRI 3-D eyetracker in light of its capabilities and the nature of the market place which it would serve.

### 1.3 Patent Status

The development efforts encompassing the eyetracker at Stanford led to several items which have been patented, or are being reviewed for patents. Some of these patents have been assigned to NASA, while others whose status is currently pending may be jointly assigned to NASA and Stanford. The 3-D eyetracker has been described in the literature and several publications document its capabilities.

## 2. APPLICATION AREAS

The study of eye movements is found to be applicable to a broad spectrum of areas where the levels of human performance in response to visual input is important. The following is a listing of general categories where eye movement studies would be facilitated by a simplified 3-D eyetracker.

- Basic Medical Research
- Applied (Diagnostic) Medical Research
- Reading
- Aviation
- Highway Safety/Driving

Each area has distinct requirements in terms of the accuracy of the measurements of eye motion, the freedom permitted the subject, and the form of the output which best serves the purposes of the research activity. As a result various eye movement measuring devices have been developed and most are commercially available to serve the needs of each particular market area.

The Stanford 3-D eyetracker also has features which orient its applicability to certain types of eye movement study. Recognized as one of the most accurate non-contact devices in use, the SRI unit provides an attractive alternative to commercially available instruments.

This is particularly true in the medical area where fine movements in the eye require high resolution and accuracy in order to obtain significant data. Some distinction should be made between medical research and applied clinical diagnosis. The former must precede the latter in order for substantial data to be accumulated so that diagnostic principles and procedures can be defined for use by neurologists, ophthalmologists and related professional disciplines in clinical applications.

The other application areas listed above are considered to hold opportunities for an eye movement instrument such as that proposed by

Stanford. Present competitive units have greater penetration in these areas than in the medical, but if accuracy and cost are competitive, the simplified SRI 3-D eyetracker can be effectively positioned to attract users of competitive equipment as well as first-time purchasers. The accomodation feature is an important attribute which may be a deciding factor in purchase considerations in some select areas.

### 3. TECHNO/ECONOMIC ASSESSMENT

The present SRI 3-D eyetracker has offered unique capabilities to the research community because of accuracy and resolution as well as simultaneous accommodation measurement. This has been accomplished through the technique of monitoring two images reflected from the eye. The first Purkinje image is reflected at the front surface of the cornea, while the fourth Purkinje image is simultaneously reflected from the rear surface of the eye lens. Each image is monitored by discrete tracking mechanisms. The monitoring of focus or depth of field accommodation (by using an infrared optometer) provides an indication, when coupled with the two Purkinje image trackers, of the location of the point in space at which the eyes are fixating. The complexity of the optics and the electronics used to monitor the fourth Purkinje image contributes substantially to the cost of the 3-D eyetracker, priced in the range of \$40,000. Though the accuracy and flexibility of the SRI eyetracker are attractive and serve a need in research, the expense is often difficult to justify. (Present purchases are at the rate of approximately one per month).

It is for this reason that the concept has been proposed for a 3-D eyetracker which has a reduced cost of \$15-20,000, achieved by eliminating the fourth Purkinje image monitoring mechanism. The trade-off which results is on the basis of cost versus accuracy. Reduction of the double Purkinje image device to one which relies on the single corneal reflected image has the effect of reducing the accuracy to a level obtainable by a few other competitive instruments. The combination of competitive technical specifications (plus the added feature of accommodation measurement) and a competitive price would provide a basis for significant market acceptance both in present research oriented programs as well as possible future clinical applications. The added feature of accommodation measurement is a differentiating product feature which can uniquely address the needs of segments of the research community at the present time and the clinical community in the future.



#### 4. NATURE OF THE MARKET

As the market exists today, the primary users are in the field of research, and have advanced degrees in disciplines such as neurology, ophthalmology, psychology, physiology various combinations of these, as well as various specialties in engineering (e.g., biomedical, electrical). Each individual researcher or groups of researchers establishes his eyetracker needs in conjunction with the project(s) budget(s). Both independent projects as well as those tied to government grants (e.g., NIH) are undertaken, and consequently cost constraints may vary widely from one project to another depending on the resources of the research groups as well as that of any sponsoring institutions. This has implications for the rate of advancement of the study of eye movements when demand for instrumentation is limited to some extent by the funding available for research.

Aside from cost, selection of a particular device is determined on the basis of the technique used to determine movement, the accuracy desired, the mobility of the instrument and/or the patient required, the form of output obtainable. Refer to the Appendix, Exhibit 1 for a comparative presentation of the various eye movement measuring instruments.

Regulations governing instrumentation related to eye movement measurement are of significance where intimate contact is required with the eye or the head. Contact lens techniques or Electro-Oculographic (EOG) methods using electrodes are of a nature which would require satisfactory compliance with federal safety regulations. The remaining eye movement instruments are of a nature which does not require similar contact other than to provide means for supporting the head during testing (e.g., a headrest or bite board). The SRI 3-D eyetracker would fall in the latter category. Medical device regulations as established by FDA would never-the-less be a concern to any manufacturer of such instrumentation, whether of a contacting or non-contacting type.

The nature of the research market is such that there is tolerance, by those involved in the work, of

- the considerable length of time devoted to setup and calibration
- the large amount of subject influence
- the large amount of operator expertise required
- the form of output which may require additional time and effort to evaluate.

The fact remains however that researchers would welcome any versions of instruments which would permit a greater number of tests to be administered in the course of their work, and would permit a more easily managed form of output. The primary tradeoff which usually must be made is whether efficiency and ease of use justify a degradation in accuracy. Some studies may permit such a tradeoff others may not. What is certain is that any attempt to use the same procedures and instruments (having characteristics listed above) under greater constraints of time, less controlled environments, with less knowledgeable patients and operators, as occurs in a clinical situation, would not be successful. If these constraints can be satisfied, and provision made for options (e.g., a accommodation and possibly pupil diameter measurement) at a total price competitive with other units, then a very effective tool can be marketed to meet research needs today and clinical needs in the future.

Distribution and promotion occurs thru the channels established for medical research equipment. The promotional activities could be further expanded to include the clinical medical community and all associated publications and professional seminars and conferences, particularly in the area of neurology, ophthalmology and psychology. This is a normal process as data is accumulated and specific findings are reported. It is also important to maintain contact with the colleges and universities so that future specialists can be made aware at an early stage as to the practical utility of the eyetracking instrumentation.

Funding of eye movement research currently comes from a wide variety of sources, depending on the specific nature and application potential of the research. The majority of these sources or sponsors are from various government agencies whose charter encompasses the financial support and encouragement of eye movement studies. The following list is representative of the majority of funding sources.

- National Institutes of Health (DHEW)
- National Institute of Mental Health
- National Institute for Occupational Safety and Health
- National Institute for Drug Abuse and Alcoholism
- U.S. Air Force (Air Force Office of Scientific Research)
- U.S. Army
- U.S. Navy
- NASA

## 5. COMPETITIVE ENVIRONMENT

The measurement of eye movements can be accomplished thru several methods, each of which concentrates on the different characteristics of the eye which serve as indicators of motion. The methods presented in Exhibit 1 of the Appendix have each warranted development and commercial introduction by various organizations. The product characteristics representing each method serve the needs of particular segments or groups of segments in the market place. At the present time the SRI 3-D eye-tracker represents the only instrument which utilizes the double PurKinje images of the eye for measurement of eye movement, and also provides for measurement of accomodation.

The proposed simplified version of the SRI unit would be capable of competing more effectively with other instruments already on the market, including other SRI versions, because it may have price advantages while offering added measurement capability. The advantages would be attractive to users who are presently doing research in similar as well as different areas compared to the present 3-D eyetracker.

The potential for effectively positioning the simplified 3-D eye-tracker is illustrated in the following Figure 1. The various eye monitoring techniques are compared to the proposed 3-D eyetracker in terms of accuracy, frequency response, range, freedom of head movement, and price. The conclusions are that the proposed instrument can provide:

- reasonable accuracy
- high frequency response
- good range
- sufficient head movement in stationary testing
- competitive price

Figure 1

EYE MOVEMENT MONITORING INSTRUMENTATION COMPARED TO  
PROPOSED SRI SIMPLIFIED 3-D EYETRACKER

Method (Instrument) \ Attribute	Accuracy	Frequency Response	Range	Free Head Movement	Price
Corneal Reflex (Polymetric)	Comparable	Lower	Smaller	Greater	Higher or Comparable
Contact Lens	Greater	Comparable	Smaller	Comparable	N/A
Electro-Oculo- graphy	Lower	Lower	Greater	Greater	Lower
Limbus Boundary (NARCO BIOSYSTEMS)	Lower	Comparable	Smaller	Comparable	Lower (~\$3,000)
Pupil-Center- Corneal Reflection Distance (Honeywell & Gulf & Western)	Greater	Lower	Comparable	Greater	Higher * ( \$20-50,000)
Double PurKinje Image (SRI-Present Version)	Greater	Comparable	Comparable	Comparable	Higher (\$30-40,000)

\*A price at the upper end of this range would reflect substantial purchase of optional recording instrumentation.

Product literature from the major manufacturers of eye monitoring instrumentation (Honeywell Radiation Center, NARCO BIO-STSTEMS, and Gulf and Western Applied Science Laboratories (formerly Whittaker Space Systems Division)) is included as Exhibit 2 of the Appendix.

## 6. SIZE OF THE MARKET

Eye monitoring instruments can be applied to various segments in the research market or to certain segments in industry or the medical community. The relative importance of these market segments both today and in the future is presented in light of the proposed Stanford 3-D eyetracker.

The present market for eye movement measuring instruments is almost entirely composed of users in various programs of eye movement research either public, private, or not-for-profit. The nature of these markets was described briefly in Section 2 of this report. The size of the entire research market for eyetracking instruments is greater than has as yet been penetrated. A primary reason is the expense of the instrumentation. Also the field of eye movement research is still growing which increases the demand for advancements in pertinent research tools.

The interest in eye movement research is based on the perception by specialists in a variety of fields that the study of the eyes, and in particular eye movements, will permit the understanding, diagnosis, and treatment of several human functions and dysfunctions which have heretofore been either undefinable or unquantifiable. Based on the specific projections in certain areas of the medical field such as neurology, psychology or ophthalmology, there are indications that certain disorders and anomalies may be diagnosed by observation of eye movements. As the data accumulates to substantiate these projections, the clinical use of eye movement instrumentation will become a more quantifiable entity. At the present time it can only be suggested that the potential exists for a significant future clinical utilization of this type of instrumentation in the specialized areas mentioned above.

The area of basic eye movement research encompasses studies of the following representative conditions:

- pursuit and saccadic eye movements
- nystagmus

- vergence and muscular imbalance
- amblyopia
- size and form perception
- peripheral vision
- fixation and gaze avoidance
- control of eye movements
- strabismus
- eye-head coordination
- dominance

Major medical centers, universities specializing in ophthalmology or optometry are typical users of eye monitoring instrumentation for this purpose. There are those in various other disciplines who also conduct eye movement research in these areas.

Related to these efforts in a more applied sense are studies of human performance as determined by environment:

- stress vs. workload
- night vision
- man-machine interface
- industrial inspection
- fatigue
- anxiety
- radiographic techniques

The nature of these particular activities has drawn researchers from a broad range of disciplines. These would include psychologists, physiologists; human performance experts, industrial engineers, aerospace engineers in addition to neurologists and ophthalmologists. There are university, government and commercial programs that engage in the studies. Each may lead to advancements in the way we develop technology toward improving human performance and productivity. A simplified 3-D eyetracker would aid in accelerating progress in these areas.



The area of medical diagnosis is related to that mentioned above. However, there is a distinction in that diagnostic research in neurology, physiology, ophthalmology, and psychology is aimed at utilizing eye movements as indicators of other bodily disorders. An example is presented in the Appendix, Exhibit 3 from the field of neurology where specific disorders are indicated as being linked to and diagnosable by movements of the eyes. There are also active programs involved in diagnosing the effects of alcohol and drugs by means of eye movement measurements. Again as in the case of general eye research the medical centers and universities are primary users of eyetracking instruments for this purpose. The potential exists for the simplified eyetracker to find future demand linked to practicing neurologists and possibly ophthalmologists in either medical center referral locations or in individual private practice.

The above areas related to medical research and diagnosis constitute the primary market segment for a simplified 3-D eyetracker. An indication is that there are over 150 individuals conducting research in eye movements from the perspective described in preceding paragraphs. Many of these individuals are interested in the advantages of a simplified 3-D eyetracker and would be potential purchasers. Still others not involved may be attracted by the cost/performance of the eyetracker. In the long run practicing neurologists and ophthalmologists in medical centers serving as referral locations can be considered potential users of eyetracking instrumentation. This can be estimated at about 163 based on the number of residency programs in ophthalmology, and 112 based on the number of residency programs in neurology. Beyond this some penetration of individual practitioners can occur but the major demand in this area would not be realized until graduates begin purchasing instruments. At the present time there are approximately 8,000 ophthalmologists and 2,000 neurologists practicing in the United States. The market demand in this latter area would not be significant for 5-10 years or until substantial data and clinical procedures have been established.

Reading research is another area which can utilize effectively the features of an eyetracker with accurate horizontal as well as vertical measurement and quick response time, at a reduced cost over the present SRI unit. Those performing this type of research are generally psychologists, at universities or in some cases at corporations, who have an interest in reading ability. The field of research in education would be a potential user of eyetracking equipment where accuracy and cost are important. Approximately 60 individuals are engaged in eye movement research related to reading, though it is difficult to project the potential of eyetracking instruments in this field as it relates to education and reading improvement programs.

The field of aviation encompasses several studies which relate to measurement of eye movements: aircraft display design, simulator design, training and evaluation of aircraft pilots, training and evaluation of air traffic controllers. There are other eye monitoring instruments which allow great flexibility in head movement and are thus ideally suited, indeed specifically designed for, this type of research. The nature of the 3-D eyetracker precludes gross movements of the head, but there is interest as a result of accuracy obtainable and the ability to measure accommodation which create interest among researchers in this field for possible use in static testing programs. Those conducting the research operate out of universities with government support or at military research installations. The size of the segment of the market would not be too substantial. Those now doing work in this area number about 20 at locations across the United States.

Driver and highway safety research forms yet another potential market segment somewhat analogous to that in aviation. The type of head movement freedom required has led to use of competitive instruments, however the potential exists for static testing programs (which require greater accuracy) to create a demand for the SRI 3-D eyetracker. Again the potential size is low, on the order of 10 locations, engaged in some form of research in this area. Typical users could include Department of Transportation, state drivers programs, and automobile manufacturers.

Results of this evaluation of the size of the market indicate that a potential research market size of 240 users may generate a penetration of 25% over the first five years or roughly 12 units per year. At the projected price of \$15-20,000 this would amount to \$180-240,000 in sales per year.

After 5-10 years, the penetration in the research segment would be expected to remain at about the same level. Based on specific research findings, penetration in clinical areas (mainly referral centers plus some longer range potential thru individual practitioners) could begin at a rate of 20% during the 5-10 years after introduction. This would lead to a volume of 20 per year based on about 500 potential users in referral center environments at hospitals and major medical centers as well as some commitment on the part of individual practitioners. This translates to a total long range potential after 5-10 years of 32 per year, or \$480-640,000 per year in sales.

## 7. COMMERCIALIZATION POTENTIAL

The commercialization of a simplified 3-D eyetracker is most critically dependent on the advancements and commensurate needs of the eye movement research community, whether in the public, private, or not-for-profit sectors, on a contract basis or in independent studies. As interest and activity increases in this field the need for efficient, accurate, reasonably priced instrumentation will increase. In many areas of research the ability to measure accommodation in conjunction with vertical and horizontal eye position will be a serious purchase consideration. The SRI unit would offer significant opportunity by researchers to purchase an accurate, flexible instrument at a price comparable to other available instruments. Thus the simplified 3-D eyetracker would be an important complementary product to the more complex double Purkinje image 3-D eyetracker presently being used.

The transition to clinical diagnostic applications requires the firm establishment of a reliable data base which will establish the utility of the 3-D eyetracker to practitioners. What is generally believed is that initial clinical usage would be found at referral centers at major hospitals and clinics or major medical centers affiliated with universities. Only after this stage, where the instrument has established its worth in a diagnostic environment, can individual practitioners be expected to express interest to the point of willingness to purchase. What must initially be established is that the diagnostic process can be aided by an eyetracking instrument in various fields. Then it must also be shown to be efficient and sufficiently easy to operate and interact with to be of practical value in a professional medical practice environment. Cost is measured not only in terms of dollars, but also in terms of time, operator training, patient involvement, instrument calibration and maintenance. The objective of any commercial venture in this field should be to minimize all of the above.

At each stage of the introduction process, promotional considerations would be oriented toward literature and pertinent conference vehicles. This would generate interest and constructive criticism in addition to educating practitioners and increasing their awareness of the utility of monitoring eye movements thru instrumentation such as the 3-D eyetracker. Education and information programs should also be conducted and encouraged in the various neurology and ophthalmology residency programs as well as the major psychology and physiology education centers. This is where future researchers and practitioners will be emerging from and thus forms an important means of creating familiarity with the practical aspects of monitoring eye movements.

The commercialization process described here is confirmed by ophthalmic goods manufacturers. There is concern based on limited potential market sizes in the research area coupled with the uncertainty of clinical diagnostic acceptance without a substantial data base. There is recognition, however, that the capabilities of the SRI 3-D eyetracker warrant serious consideration as a new product prospect. Reduction of costs thru use of advanced electronics (e.g., microprocessors) and production design evaluation would do much to increase the commercial viability of the 3-D eyetracker.

In an effort to assure proper positioning of the 3-D eyetracker in the market in terms of product characteristics and price, it is recommended that a formal survey be conducted of scientists engaged in eye movement studies. Their comments and perceptions would be beneficial in commercialization of the instrument by creating awareness and stimulating interest among those professionals most influential in making a purchase decision. The "Interdisciplinary Directory of Scientists Engaged in the Study of Eye Movements" compiled by Dr. Richard Morty and B. Diane Eberly at U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland provides an excellent basis for a product survey in eye movement research and application.

8. INTERESTED PARTIES

The following people have specifically requested to be informed on future developments of the 3-D eyetracker:

Dr. Robert Henderson  
Department of Transportation  
Washington, D.C.  
202/755-8753

Dr. Robert Hennessy  
932 N. Patterson Avenue  
Santa Barbara, California 93111  
213/889-4750

Dr. Richard A. Monty  
Behavioral Research Directorate  
U.S. Army Human Engineering Laboratory  
Aberdeen Proving Ground, Maryland 21005  
301/278-4478

Dr. Max Snodderly  
Retina Foundation  
20 Staniford Street  
Boston, Massachusetts 02114  
617/742-3140

The following people have expressed an interest as potential manufacturers of the 3-D eyetracker:

Dr. John Merchant  
Honeywell Radiation Center  
2 Forbes Road  
Lexington, Massachusetts  
617/852-6222

Mr. Albert Harabedian  
Vice President  
Human Factors Research, Inc.  
6780 Cortona Drive  
Goleta, California 93017  
805/968-1071

Mr. Michael Reynolds  
Manager, New Products Planning  
Telesensory Systems, Inc.  
1889 Page Mill Road  
Palo Alto, California 94304  
415/493-2626

Mr. George S. Leonard  
Products Manager  
Gulf & Western  
Applied Science Laboratories  
335 Bear Hill Road  
Waltham, Massachusetts 02154  
617/890-5100

APPENDIX

<u>Exhibit</u>	<u>Description</u>
1	"Comparison of Eye Movement Measuring Techniques" (Table 1 from "Survey of Eye Movement Recording Methods" by Laurence R. Young and David Sheena) appearing in "Behavior Research Methods and Instrumentation 1975, Vol. 7(5), 397-429.
2	Product Literature <ul style="list-style-type: none"><li>● Gulf &amp; Western Applied Science Laboratories (formerly Whittaker Space System Division)</li><li>● Honeywell Radiation Center</li><li>● NARCO BIO-SYSTEMS, Inc.</li></ul>
3	Excerpt from "Significance of the Proposal" section of a proposal from Dr. Langston and Dr. Hotson (associated with Stanford Medical Center) to NIH, defining the importance of 3-D binocular eyetracking and its potential in clinical neurological diagnosis.



Exhibit 1

IIT RESEARCH INSTITUTE

YOUNG AND SHEENA

Table 1  
Comparison of Eye-Movement Measuring Techniques

Method	Measurement Range (deg)		Accuracy		Speed or Frequency Response	Interference With Normal Vision	Glasses Acceptable	Contact Lens Acceptable	Subject Variation Problems, Eye Color, Etc.	Subject Cooperation Required	Subject Frustrating, Required	Usable With Young Children
	Vertical	Horizontal	Vertical	Horizontal								
1. Corneal reflex (Mackworth Camera)												
Polymetric Lab VII64	±9	±9	.5 deg	.5 deg	Photographic rate: 12-64 frames/sec Television: 60 fields/sec	Medium	?	Possible source of error	None	High	Low	?
Polymetric Mobile VO165	±10	±10	1 deg	1 deg	Same as above	High: Weight on head; optics near eye	No	Possible source of error	None	High	Low	No
NAC-REES	±10-20	±10-20	2 deg	2 deg	Same as above	High: Weight on head	No	Possible source of error	None	High	Low	No
2. Contact lens with						High	No	Eye must accept contact lens	High	High	No	
Lamp or radiant spot coil mirror	Both ±10-30		Precision 3 sec 3 sec		High	No	No					
	Larger than others		15 sec	15 sec	High	Yes						
	±10	±10	2 sec	2 sec	High	No						
3. EOG												
	±50	±50-80	2 deg	1.5 deg	dc or .01-15 Hz limited by filtering	None	Yes	Yes	Medium: placement of electrodes and calibration is variable	Medium	Low	Yes
4. Limbus boundary												
Narco Eye Trac	±10		4 deg	2 deg	2 msec; 30 msec with recorder	Medium	Yes	Yes	Iris coloration a factor	High	Low	Yes
Narco Model 200	+10-20	±20	2 deg	1 deg	4 msec; 26 msec with filtering	Medium	No	Yes	Iris coloration a factor	High	Low	Yes
5. Wide-Angle Mackworth Camera												
Polymetric VII66	40	40	2.5 deg	2.5 deg	Same as Method 1	Medium: Subject looks through apertures; special lighted stimuli are required	?	Possible source of error	None	High	Low	Yes
6. Pupil-center-corneal-reflection distance												
Honeywell Oculometer	+30-10	±30	1 deg	1 deg	.1 sec time constant	Low	Yes	Possible source of error	Low	Low	Low	Yes
Whittaker Eye View Monitor	±15	±22 Higher possible	1 deg	1 deg	30-60 samples/sec	Low	Yes	Same as above	Low	Low	Low	Yes
U.S. Army Human Engineering Lab	30	40	2 deg	2 deg	60 samples/sec filtered	Low	No	Same as above	Low	Low	Low	Yes
7. Double Purkinje image eye tracker												
	25 deg diam	25 deg diam	Noise of 1 min		300 Hz	Low		Autocorrection possible	Low	Low	Low	Yes

# SURVEY OF EYE MOVEMENT RECORDING METHODS

Table 1 Continued

Calibration and Setup Time	Head Attachments Required	Head Stabilization Requirement*	Subject Discomfort	Subject Awareness	Pupil Dilation Output Also	Form of Output	Status	Cost of Operation	Remarks	Source of Further Information
Low	Chinrest or biteboard	High head restraint or biteboard	Medium	High	No	Photographic or videotape; low-resolution digital output	Commercially available	High for film		Polymetric Co. P.O. Box D Roseland, NJ 07068
High:	Biteboard	None	High	High	No	Same as above		High	Higher resolution digital output is possible with other instruments	
Medium:	Head-mounted optics	None	Medium	High	No	Same as above		High for film	Head-mounted TV camera	Instrumentation Marketing Corp. 820 South Mariposa Burbank, CA 91506
	band, set light source									RJES Inst. Ltd. Westminster House, Old Woking, Surrey, United Kingdom
High:	Contact lens		High	High	No	Photographic or electrical	Some commercial devices available	Lens grinding may be costly	Negative pressure application may be hazardous	
	must be filtered	High								
		Low								
		Low								
High:	Yes, 2-6 electrodes	Low	Low	High	No	Electrical record	Commercially available	Low	More suitable for eye motion than eye position	LT Instruments 4604 Osage Houston, TX 77036
	requires electrode stabilization and light adaptation									Grass, Inst. Quincy, MA 02169 ICS, 129 Laura Dr. Addison, IL 60101
Low	Head bracket and chinrest	High	Low	High	No	Analog and digital	Commercially available	Low	Vertical position of eyelid is used to approximate vertical eye position	Narco BioSystems, Inc., Biometrics Div. 7651 Airport Blvd. Houston, TX 77017
Low	Spectacles	None	Low	High	No	Analog and digital	Commercially available	Low		Narco (also see ICS)
Low	Viewing through aperture	Medium, head must be kept still	Low	High	No	Photographic or videotape; low-resolution digitizer available	Commercially available	High for film	Point of regard output without head motion artifact	Polymetric Co. (see above)
Low:	None	Mark II: head free, 1 in. <sup>3</sup> Mark III: head free, 1 ft. <sup>3</sup>	Low	Low	Yes	Digital, analog, and fixation pointer on TV image of scene	Commercially available	Low	Computer-based system	Honeywell Radiation 2 Forbes Rd. Lexington, MA 02172
higher for maximum linearization									Mark III tracks head motion and has auto focus	
Low	None	Head free up to 1 ft. <sup>3</sup>	Low	Medium	Yes	Same as above	Commercially available	Low	Tracks head motion and has auto focus available	Whittaker, Space Sci. Div., 335 Bear Hill Rd. Waltham, MA 02154
Low	None	1 ft. <sup>3</sup>	Low	Low	Yes	Digital, analog, videotape, and graphic	Research laboratory	NA		U.S. Army/HFL Aberdeen Proving Ground, MD
Low	Chinrest or biteboard	None Head free 1 cm <sup>3</sup> Biteboard for high precision	Low	Medium	No	Analog output	Small production	Low	Has auto focus; field and operation are dependent on pupil size suitable for image stabilization	Stanford Research Institute Menlo Park, CA 94025

\*To make measurement, not to obtain fixation point.

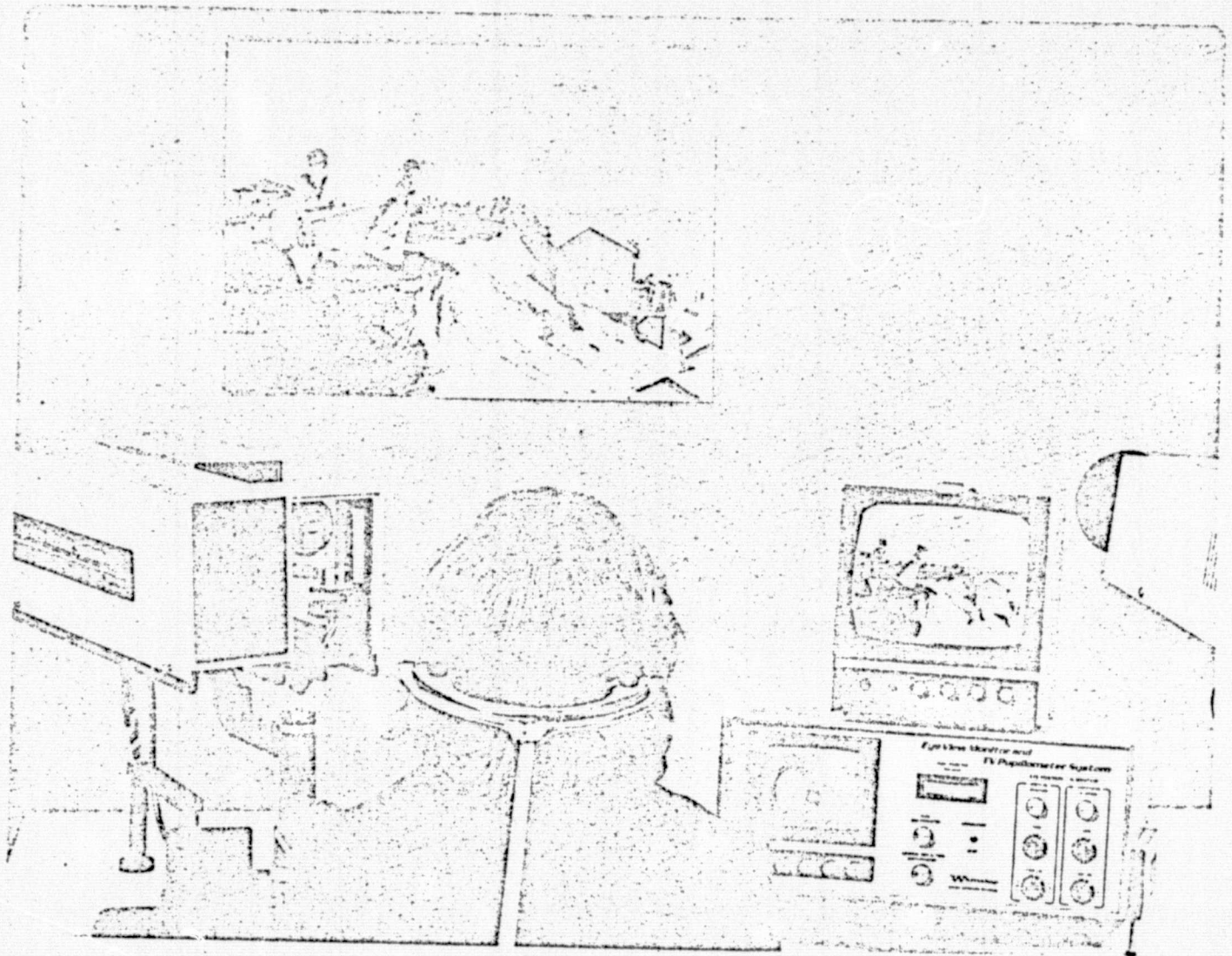
Exhibit 2

IIT RESEARCH INSTITUTE

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## *Eye View Monitor and TV Pupillometer System*

Series 1900



The Series 1900 Eye View Monitor is a complete system for measuring a subject's eye position and pupil diameter while allowing relatively free head motion. The output is provided in a number of convenient formats and allows easy correlation of pupil diameter with fixation points.

Applied Science Laboratories  
335 Bear Hill Road  
Waltham, Massachusetts 02154  
(617) 890-5100

George S. Leonard  
Products Manager

**GW**  
A GALT • WESTERN MANUFACTURING COMPANY

## APPLICATIONS

There has been a great interest for a long time in measuring eye position for various clinical, research, and commercial applications. The Series 1900 Eye View Monitor provides a convenient means for quantitative analysis of eye movement, especially where this information must be directly related to the point of gaze of the subject. The output is particularly suitable for computer processing eliminating the necessity of tedious measurement of photographs frame by frame.

Changes in pupil diameter which indicate arousal or interest may be recorded along with eye position to correlate such a psychological response with exactly what the subject is viewing. Pupil diameter appears to be a more sensitive, reliable, and practical measure than traditional parameters such as galvanic skin response or heart rate.

Clinical and psychological applications include measurement of pursuit and saccadic eye movements, nystagmus, measurement of vergence and muscular imbalance (if positions of both eyes are recorded), reading studies, testing effects of training, stress and workload, drugs or various diseases. Television viewing, perception research and image scanning are easily performed with the Eye View Monitor

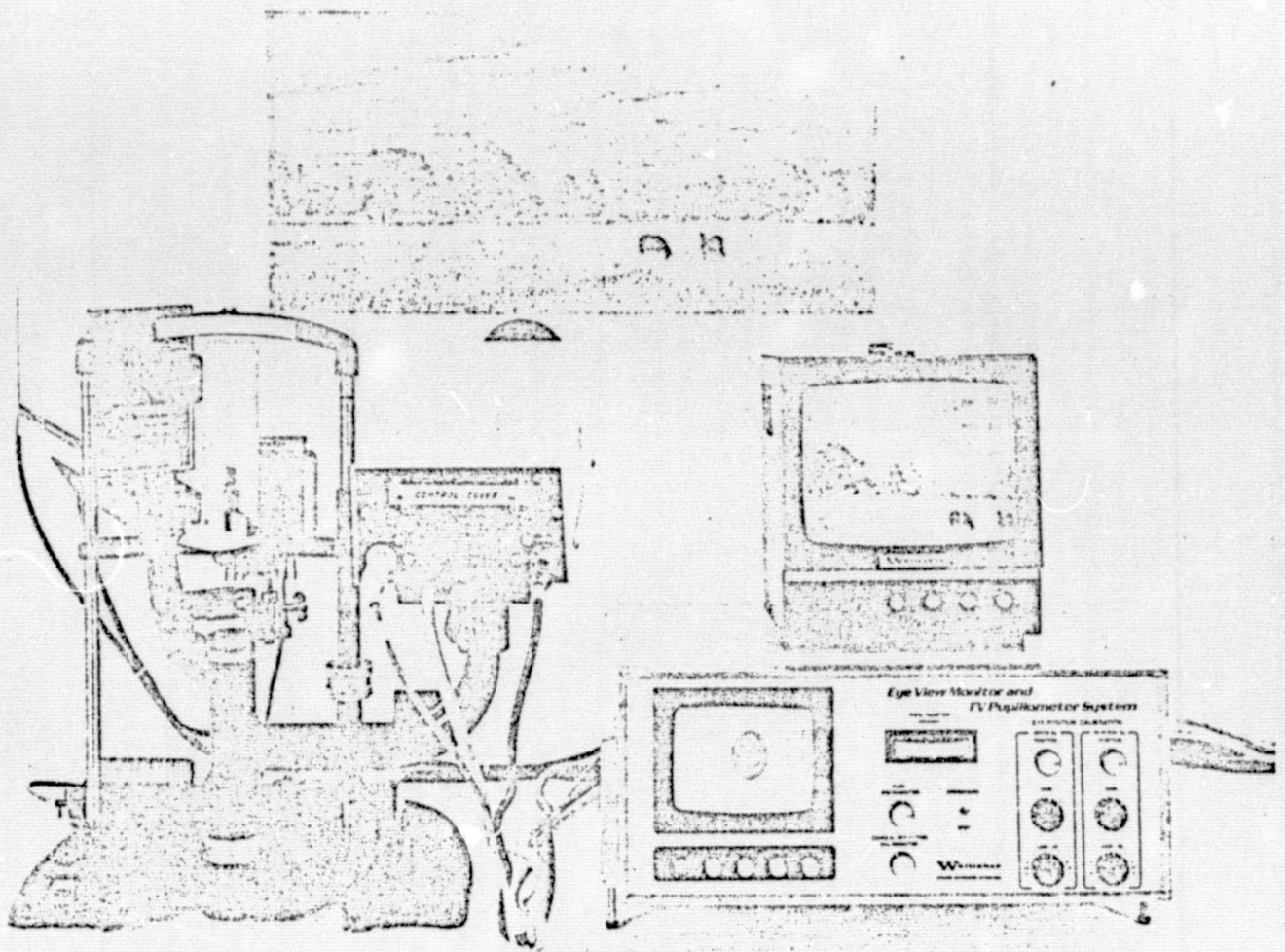
Commercial applications include human factors design of control panels or other equipment and preparation of advertisements and presentation material. Measurement of eye position and especially pupil diameter can indicate the amount of interest the subject shows in a particular picture, what he is fixating and for how long.

## DESCRIPTION

The Series 1900 Remote Eye View Monitor is a complete system for unobtrusive measurement of a subject's eye position and pupil diameter at a distance while allowing relatively free head motion. The output is provided in a number of convenient formats and allows easy correlation of pupil diameter with fixation points.

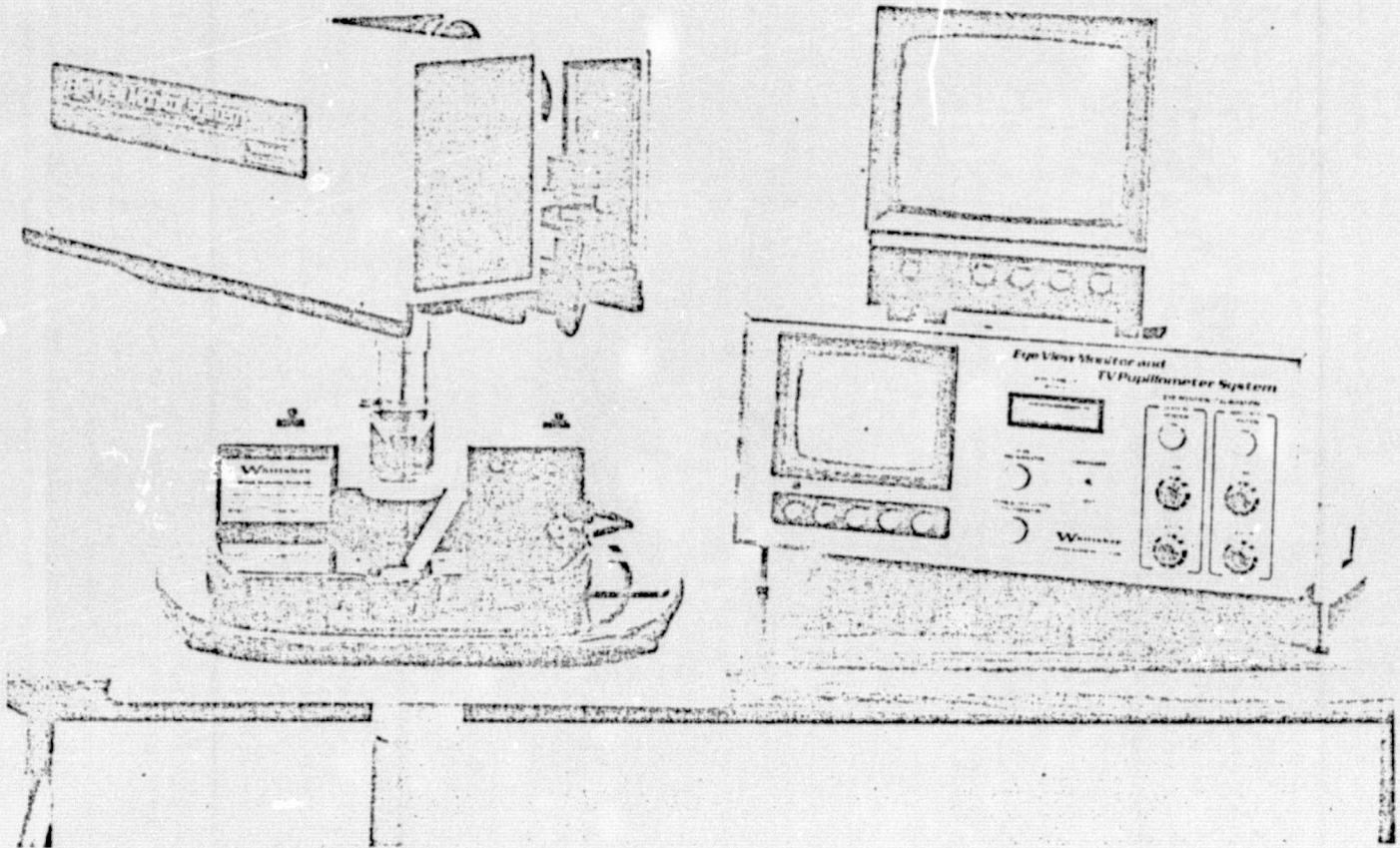
The subject sits with his head in a head rest (Remote System) or chin rest (Standard System). His eye is allowed to be in a volume of space up to about a cubic inch. The optical system can be up to 2 feet or more away from his eye and out of his field of view. He is physically and psychologically unencumbered, and he is less aware of the fact that his eye motion is being measured. This allows him to talk, makes for a more natural experimental situation, and results in more useful data.

Larger head motion can be accommodated with a manual or automatic head tracking mirror.



Standard Eye View Monitor System  
with Chin Rest Model 1992S





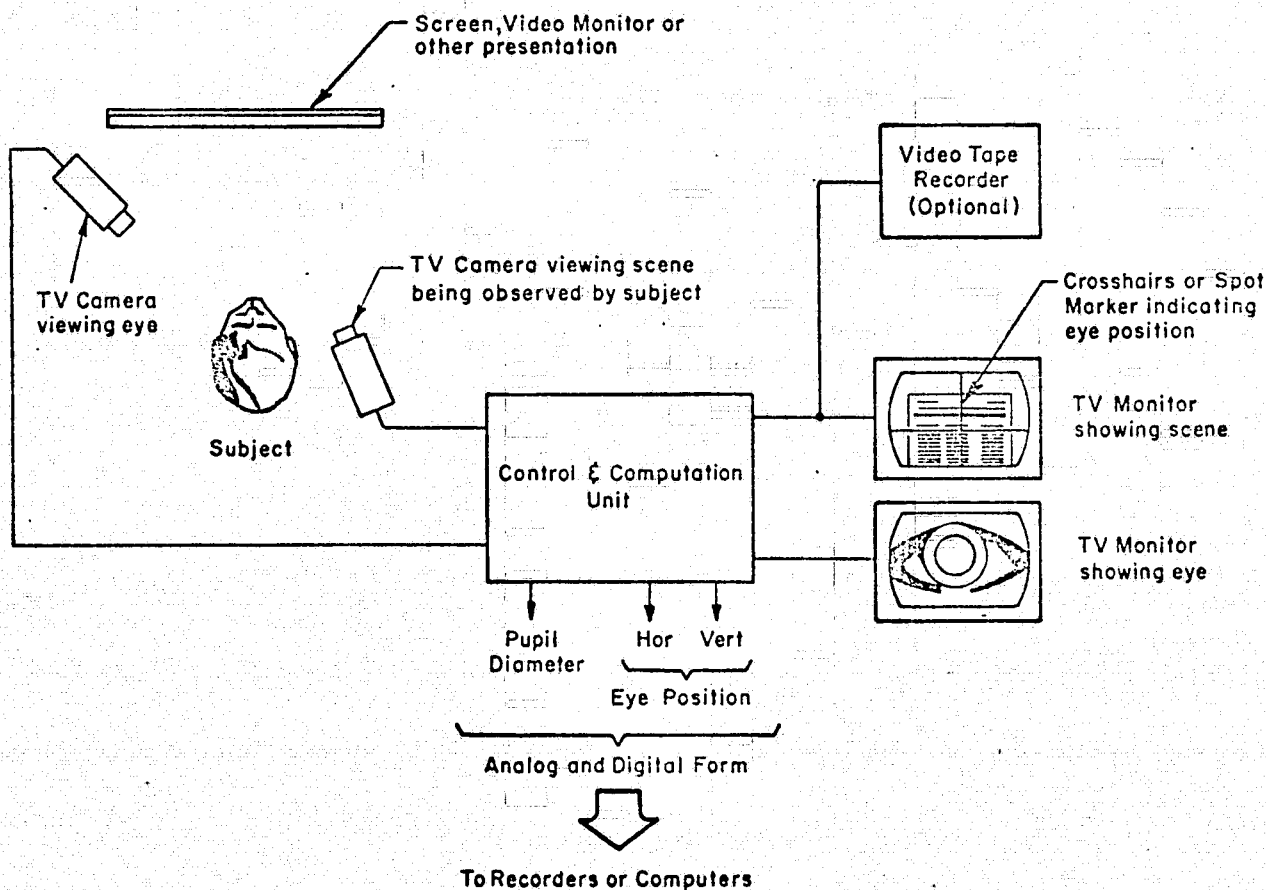
Remote Eye View Monitor System  
with Head Rest Model 1994S



## SYSTEM CONFIGURATION

The configuration of the system is schematically shown below. A television camera views one eye of the subject which is illuminated by a near infrared completely invisible illuminator. The resulting picture of the eye is displayed on a 5" TV monitor. A second camera views the scene presented to the subject.

The system uses a sensitive silicon matrix tube television camera, which functions at very low illumination, to view the eye. The Illuminator does not annoy or distract the subject. In the Remote System, the illumination is coaxial with the camera and produces an image of a backlighted bright rather than dark pupil.



Eye View Monitor System Configuration

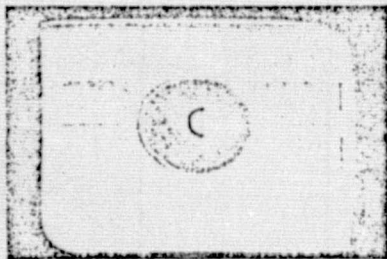
## PRINCIPLE OF OPERATION

The subject's eye rotation (as opposed to translation resulting from head motion) and consequently his point of fixation is determined by the measurement of the center of the pupil with respect to the center of the corneal reflection. The two features of the eye move together with head motion, but move differentially with eye rotation, hence the difference in their positions is indicative of the eye's point of fixation. In this way, eye position is independent of head position as long as the pupil image is contained within the field of view of the camera. This allows the system to tolerate small head motion, talking, etc, and continue the measurement without the necessity of recalibration. Without such a capability, an eyeball translation of the 0.1 mm, resulting from head motion or eyeball motion within the socket, would falsely indicate eye rotation of about 1°.

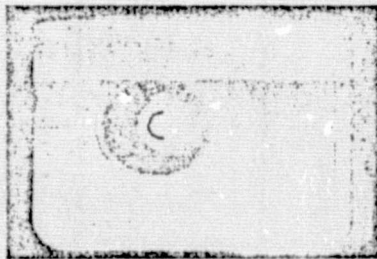
The position information is presented to the operator as a spot superimposed on a 9" television monitor image of the scene being viewed by the subject. The operator can control the position of the spot on the monitor. By asking the subject to move his eye horizontally and vertically, the operator can also adjust the gain by viewing the motion of the spot on the Scene Monitor. Once this is done the computed eye position is calibrated and may be recorded.

## SPECIAL RECOGNITION CIRCUIT

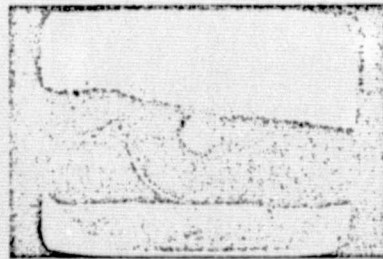
A Special Recognition Circuit detects the pupil and the corneal reflection from the video signal. The horizontal scan lines which intersect them are selected to the exclusion of scan lines which intersect the eyelids, eyelashes, or other noise. This Recognition Circuit allows operation for a broad range of subjects and under varying conditions with minimum operator adjustments. It superimposes Delimiters and other indicators on the eye TV image to show the operator that the measurement is correct without any possible doubt.



Acceptable

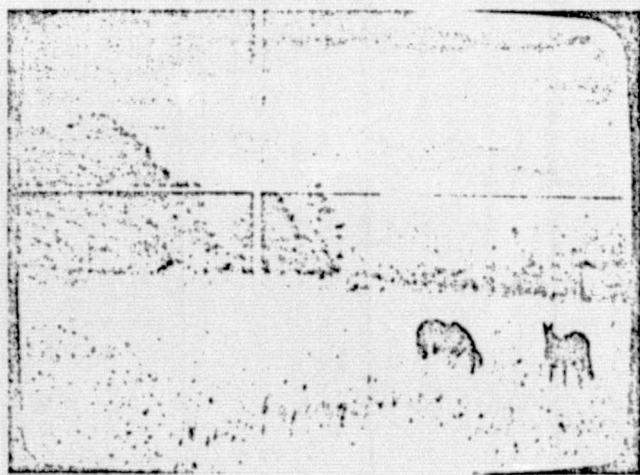
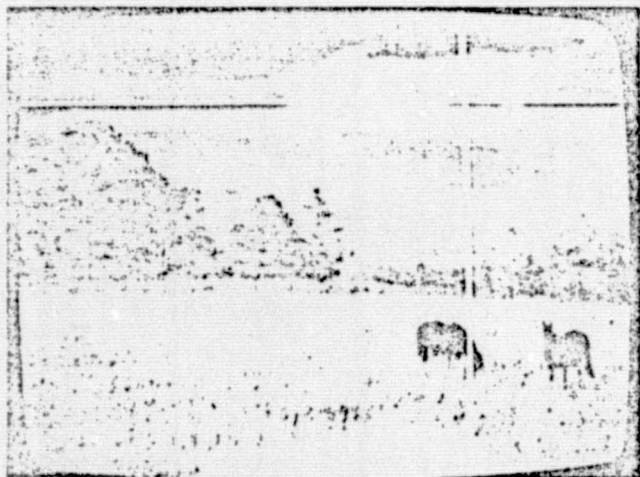


Acceptable



Unacceptable

Operator indicators superimposed on TV image of eye as a function of threshold setting showing status of measurement. Measurement is good when pupil is properly delimited.



## OUTPUTS

The output is available in digital, analog, and visual forms for recording on strip chart recorders, X-Y recorders, storage oscilloscopes, digital tape or directly into a digital computer. This data can be processed at the time of the experiment or recorded for later analysis by computer. Also provided, is a monitor showing the scene being viewed by the subject, and superimposed on this, is a spot or crosshairs indicating the point of gaze of the subject in real time; see monitor photographs. This is available to the operator both for adjusting and calibrating the experiment and as an output suitable for study or video tape recording if desired.

A scan pattern may be obtained using an X-Y recording over a picture of the scene being viewed.

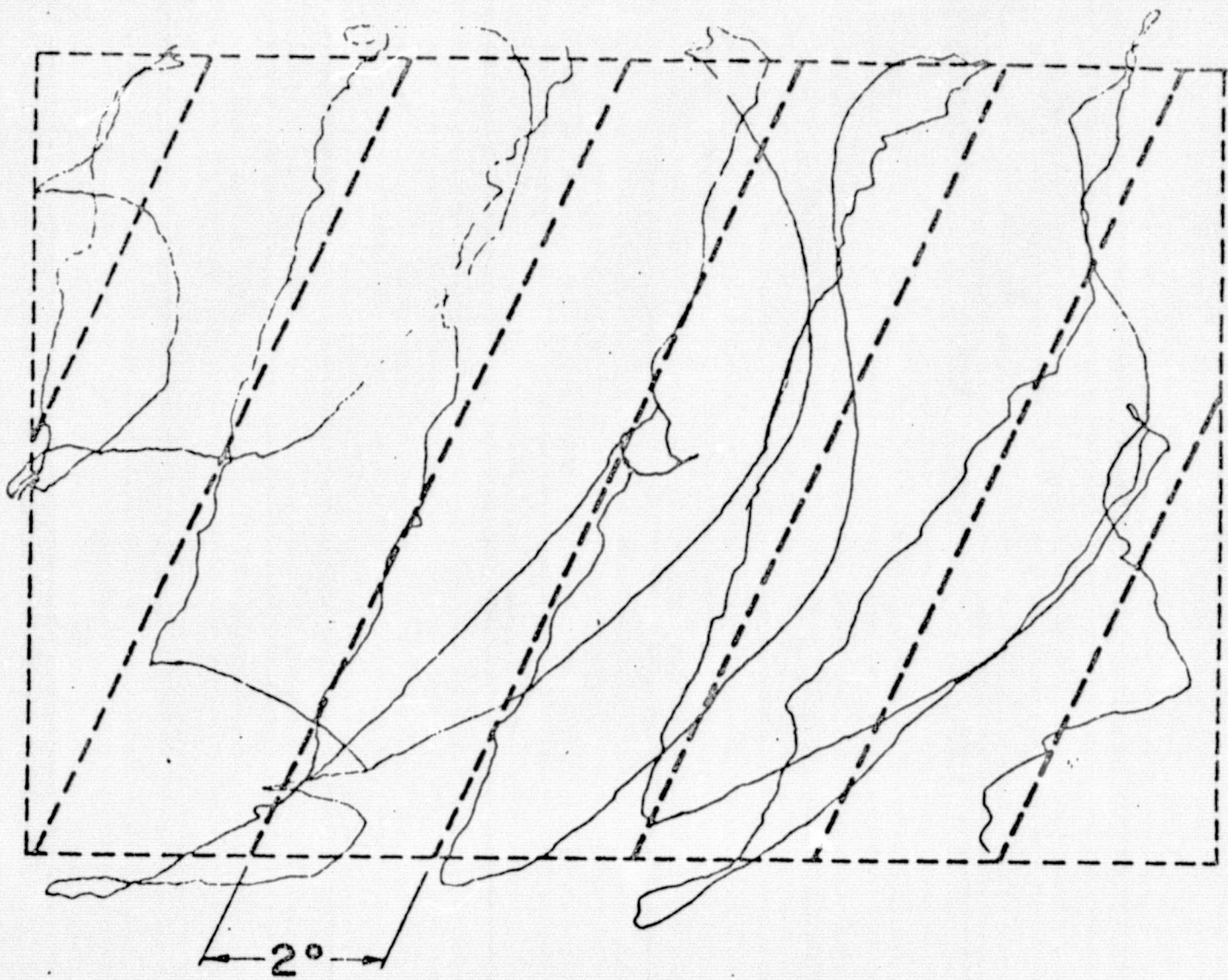


Figure 6.1. X-Y Recording of Eye Fixation as Subject  
scans a Number of Diagonal Lines

## SPECIFICATIONS

Allowable Eye Movement:	Horizontal 30°; 40° or higher with reduced accuracy. Vertical 25°; 30° or higher with reduced accuracy. Eyelids may limit this range with some subjects.	
Measurement Resolution:	Better than 1 part in 100 horizontally and vertically.	
Precision:	Better than 1/2°.	
Linearity:	Worst case spatial error between true eye position and obtained measurement is 1°. Errors are lower if only a small central field, like a TV monitor or a rear projection screen, is used. Error may increase to 2° in peripheral corners.	
Sampling Rate:	60 per second. Output is averaged every two fields; i.e., each 1/30 of a second. Non-averaged output is also available.	
Eye Position Measurement:		
Analog	±5 volts linearly related to horizontal eye position, gain and zero adjustable. ±5 volts linearly related to vertical eye position, gain and zero adjustable. Output impedance: 75 ohms	
Digital	8 bits TTL compatible representing horizontal eye position in offset binary. 8 bits TTL compatible representing vertical eye position in offset binary. Output drives up to 4 TTL loads. Logical "1" > 2.5 volts Logical "0" < 0.5 volts	
Pupil Diameter Measurement:		
Analog	Pupil measurement and display range: 2.0 to 10 mm (normal pupil diameter: 2.9 mm to 6.5 mm). Analog output signal accuracy: better than 1%. Meter accuracy: 2% of full scale. Frequency response: smoothing filter, flat from 0 to 6 Hz; may be switched out. External analog signal output: 0 to 10 volt DC. Scaling: 1.0 volt/mm of pupil diameter.	
Digital	9 bits TTL compatible representing pupil diameter in straight binary. (8 bits are generally sufficient for most applications) Logical "1" > 2.5 volts Logical "0" < 0.5 volts Output drives up to 4 TTL loads.	
Timing Outputs:	Positive strobe and busy signal are output every 1/60th of a second for transferring of data. Data is constant during strobe pulse and changing during busy signal. Strobe pulse is 1-2 microseconds; busy pulse is 0.5-0.8 milliseconds. Output drives up to 4 TTL loads.	
TV Camera:	Output impedance: 75 ohms.                      Silicon Matrix vidicon tube with 2:1 sync, 525 lines (625 lines at 50 Hz).                      1 inch faceplate.	
Illumination:	Invisible near infrared filtered incandescent lamp illumination centered at 8500 Angstroms.	
Operator Setting Indicators:	Discriminator crescents appear on monitor at edge of pupil and the corneal reflection, along with a white line through the vertical center of the pupil and a black line through the center of the corneal reflection as determined by the Recognition Circuit. The proper position of those lines indicates to the operator that no adjustment has to be made and that the measurement is being performed correctly. Delimiters are placed on top and bottom of pupil to indicate to the operator just what is discriminated.	
Power Source:	105-125 volts AC, 60 Hz 220 volts AC, 50 Hz available	
Camera to Subject Distance:	Standard	Remote
	5-6 inches	20 inches, 1-3 ft range
Allowable Eye Space:	Head in Chin Rest	Left half of pupil must be within a volume of up to a cubic inch, depending on pupil size and magnification.
Illumination Requirement:	None	Complete darkness to moderate illumination resulting in pupil diameter greater than 3.0 mm; diameters below 3 mm result in marginal performance.
Mechanical:	Control Unit Weight: 37 lbs Dimensions: 17" x 7.5" x 17" (WHD) Camera Unit Weight: 42 lbs Dimensions: 15" x 20" x 13" (WHD) Scene Monitor Weight: 9 lbs Dimensions: 8.6" x 9.2" x 8.7" (WHD)	Control Unit Weight: 37 lbs Dimensions: 17" x 7.5" x 17" (WHD) Camera Unit Weight: 50 lbs with base Dimensions: 8.75" x 7.5" x 21" (WHD) without base; Height 19" with base Scene Monitor Weight: 9 lbs Dimensions: 8.6" x 9.2" x 8.7" (WHD) Scene Camera Weight: 7.2 lbs Dimensions: 6" x 4" x 11" (WHD)

335 BEAR HILL ROAD  
WALTHAM, MASSACHUSETTS 02154  
TELEPHONE: (617) 890-5100

## DATA INFORMATION SHEET

### AUTOMATIC OR MANUAL HEAD TRACKING CAPABILITY FOR SERIES 1900 REMOTE EYE VIEW MONITOR

#### Head Tracking

In order to increase the subject head motion allowed with the Remote Eye View Monitor System, a Head Tracking Mirror System in the X-Y plane may be incorporated. (For Z axis tracking see below.)

The mirror is controlled by a head motion detector and tracking system which is integrated with and receives its control signals from the Eye View Monitor and Processor. The position of the head is determined, and when it approaches the edge of the visual field of the eye camera, the tracking mirror is commanded to reposition it to the center of the field in one or both axes as necessary.

If the head should jerk quickly and cause the eye to escape out of the field of view, special circuits will cause the mirror to re-acquire the eye in most cases.

The operator observes the subject's eye in the pupil monitor and in a wide angle view locating monitor. He uses this second monitor display, which shows a portion of the subject's face, to assist in setup positioning and in reacquisition, if the eye becomes lost. He accomplishes this positioning with remote pushbuttons or a joystick.

Acquisition of the eye is automatic as soon as a sufficient portion of it is visible to the Eye Camera.

The Manual Head Tracking Mirror gives the operator the joystick tracking capability without the automatic acquisition. This is often quite acceptable in most applications.

The tracking range of the system is dependent on the distance between the camera and the eye. System accuracy is unaffected by mirror tracking in the range of 4 square inches at a subject distance of 20 inches; and 6 square inches at a subject distance of 30 inches. Larger head motion up to 12 square inches can be handled but causes slight horizontal-vertical rotational distortion.

The Head Tracking Mirror is useful for the X-Y plane for a subject seated in a high back chair without much Z axis motion. Should subject motion in the Z-axis be needed, remote manual or automatic focusing capability can be incorporated.

The tracking mirror module may simply be attached to the front of the Eye View Monitor Camera and positioned so that the subject's eye is viewed by the mirror instead of the camera. The mirror occupies the space previously taken by the camera lens.

The Head Tracking options are:

1. Manual X-Y Mirror Head Tracking
2. Automatic X-Y Mirror Head Tracking
3. Z-axis manual focusing (Head Tracking)
4. Z-axis automatic focusing (Head Tracking)

PRICES AND SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE.

REVM-2  
1/1/77

**SERIES 1900 EYE VIEW MONITOR  
AND TV PUPILLOMETER SYSTEM**

Item	Description	Price
1	Model 1992S Complete System Including:  Silicon Matrix Tube TV Camera for viewing the eye with invisible illumination  Control and Computation Unit with TV Monitor for eye image  TV Camera for viewing scene being presented  9" Monitor showing scene with crosshairs indicating point of fixation  Adjustable Camera Base  All Cables, Accessories and Manuals  Outputs- Digital and Analog 1) Vertical Eye Position 2) Horizontal Eye Position 3) Pupil Diameter (in milliameters)	\$17,900.00
<b>OPTIONS</b>		
2	DSP Digital Output Calibration and Presentation Unit	\$ 295.00
3	19TR-9) Digital Tape Data Acquisition 19TR-7) Recording System with experiment designation and status words	See separate List
4	Z 18-90 mm Focal Length Zoom Lens for Scene Camera	395.00
5	VTR Video Tape Recorder	995.00
6	RPS Rear Projection Screen for presenting scene for other stimuli to subjects	195.00
7	1R 1-Channel Strip Chart Recorder	1,900.00
8	2R 2-Channel Strip Chart Recorder	2,700.00
9	3R 3-Channel Strip Chart Recorder	3,500.00
10	XY X-Y Recorder	2,200.00
11	EM Event Markers:   A 1-Channel B 2-Channels C 3-Channels	150.00 185.00 225.00
12	TCEVM Traveling Cases	1,350.00
13	ASC Adjustable Subject Stool	125.00
14	50Hz For Operation at 50 Hz	695.00
15	ATV External 9" TV Monitor for viewing eye	495.00
16	RM Rack Mounting	49.00

ALL PRICES FOB, WALTHAM, MASSACHUSETTS, USA.  
LEASING AND RENTAL TERMS ARE ALSO AVAILABLE.  
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SERIES 1900 EYE VIEW MONITOR  
AND TV PUPILLOMETER SYSTEM



Item	Description	Price
1	Model 1994S Complete Remote System Including: Silicon Matrix Tube TV Camera for viewing the eye with invisible illumination Control and Computation Unit with TV Monitor for eye image TV Camera for viewing scene being presented 9" Monitor showing scene with crosshairs indicating point of fixation Adjustable Camera Base All Cables, Accessories and Manuals Outputs- Digital and Analog 1) Vertical Eye Position 2) Horizontal Eye Position 3) Pupil Diameter ( in milliameters)	\$22,500.00
OPTIONS		
2	DSP Digital Output Calibration and Presentation Unit	\$ 295.00
3	19TR-9) Digital Tape Data Acquisition. 19TR-7) Recording System with experiment designation and status words	See separate List
4	Z 18-90 mm Focal Length Zoom Lens for Scene Camera	395.00
5	VTR Video Tape Recorder	995.00
6	RPS Rear Projection Screen for presenting scenes for other stimuli to subjects	195.00
7	1R 1-Channel Strip Chart Recorder	1,900.00
8	2R 2-Channel Strip Chart Recorder	2,700.00
9	3R 3-Channel Strip Chart Recorder	3,500.00
10	XY X-Y Recorder	2,200.00
11	EM Event Markers: A 1-Channel B 2-Channels C 3-Channels	150.00 185.00 225.00
12	TCEVM-R Traveling Cases	1,950.00
13	ASC Adjustable Subject Stool	125.00
14	50 Hz For Operation at 50 Hz	695.00
15	ATV External 9" Monitor for viewing eye	495.00
16	RM Rack Mounting	49.00

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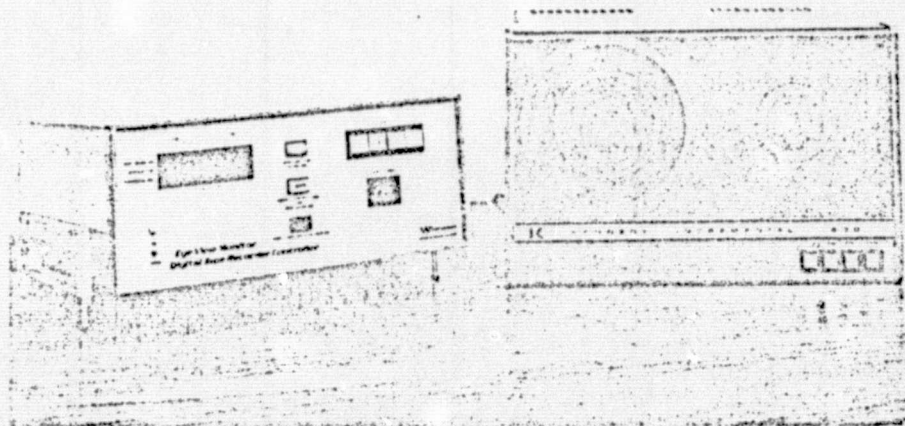
## OPTIONS

- 1) Digital Output Calibration and Presentation Unit
- 2) Zoom Lens for Scene Camera to vary field of view
- 3) Digital character display of pupil diameter on Scene Monitor
- 4) Digital Tape Recorder for data recording
- 5) Interface and Controller for digital tape recorder, slide projector, etc.
- 6) Rear Projection Screen and Intergrated Slide Projector
- 7) Large External Pupil Monitor
- 8) Binocular Measurement
- 9) Video Tape Recorder
- 10) Adjustable Subject Stool
- 11) Traveling Cases
- 12) 19" Rack Mounting Brackets

For additional literature and information, write or call

George S. Leonard  
G+W Applied Science Laboratories  
335 Bear Hill Road  
Waltham, Massachusetts 02154  
(617) 890-5100

# Digital Tape Recorder Interface and Controller

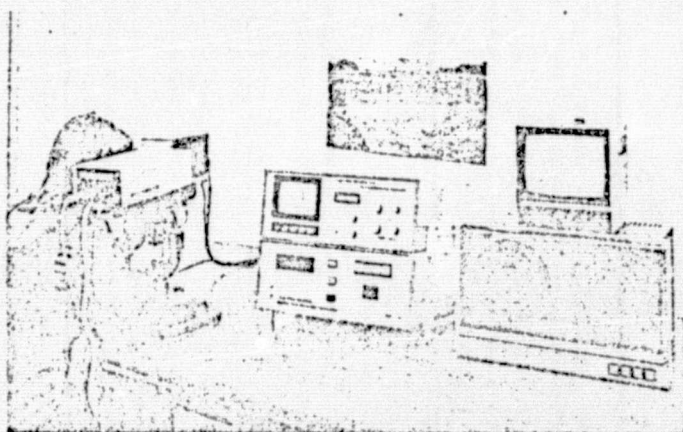


## DESCRIPTION

The tape recorder interface and controller provides the capability of calibrating the Eye View Monitor outputs and of controlling and recording experiment data and codes on a special or IBM compatible tape recorder.

The system contains calibration displays, start and stop controls, an abort control, a subject number thumbwheel switch, an experiment code, a real-time clock, a slide projector controller with a slide number counter, and a reset switch for the clock and slide counter.

Contact factory for complete specifications.



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SERIES 1900 EYE VIEW MONITOR  
WITH OPTIONAL DIGITAL TAPE  
RECORDER AND CONTROLLER

**GW** Applied Science  
Laboratories  
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MODEL 19TR-9 EYE VIEW MONITOR  
AND PUPILLOMETER SYSTEM 9-TRACK  
DIGITAL TAPE RECORDER INTERFACE  
AND CONTROLLER

SPACE SCIENCES DIVISION  
335 BEAR HILL ROAD  
WALTHAM, MASSACHUSETTS 02154  
TELEPHONE. (617) 890-5100

Description

The tape recorder interface and controller provides the capability of calibrating the Eye View Monitor outputs and of controlling and recording experiment data and codes on a special or IBM compatible digital tape recorder.

The system contains calibration displays, start and stop controls, an abort control, a subject number thumbwheel switch, an experiment code, a real-time clock, a slide projector controller with a slide number counter, and a reset switch for the clock and the slide counter.

Specifications

- Tape Recorder: Supplied by customer; or Kennedy Company, incremental or synchronous, Digital 9-track tape recorder (see options)
- Data Sample Output Rate: 60 per second
- Tape Record Format: Each sample taken in 1/60th of a second will be arranged in eight (8-bit) bytes as follows:

Word	1	2	3	4	5	6	7	8
Channel or Track	1	2	3	4	5	6	7	8
MSB 0	0	C16	C <sub>8</sub>	PD <sub>8</sub>	V <sub>8</sub>	H <sub>8</sub>	ECA	SN2 <sub>4</sub>
1	0	C15	C <sub>7</sub>	PD <sub>7</sub>	V <sub>7</sub>	H <sub>7</sub>	ECB	SN2 <sub>3</sub>
2	ABORT	C14	C <sub>6</sub>	PD <sub>6</sub>	V <sub>6</sub>	H <sub>6</sub>	ECC	SN2 <sub>2</sub>
3	RUN	C13	C <sub>5</sub>	PD <sub>5</sub>	V <sub>5</sub>	H <sub>5</sub>	ECD	SN2 <sub>1</sub>
4	SS4	C12	C <sub>4</sub>	PD <sub>4</sub>	V <sub>4</sub>	H <sub>4</sub>	SN3 <sub>4</sub>	SN1 <sub>4</sub>
5	SS3	C11	C <sub>3</sub>	PD <sub>3</sub>	V <sub>3</sub>	H <sub>3</sub>	SN3 <sub>2</sub>	SN1 <sub>2</sub>
6	SS2	C10	C <sub>2</sub>	PD <sub>2</sub>	V <sub>2</sub>	H <sub>2</sub>	SN3 <sub>2</sub>	SN1 <sub>2</sub>
LSB 7	SS1	C9	C <sub>1</sub>	PD <sub>1</sub>	V <sub>1</sub>	H <sub>1</sub>	SN3 <sub>1</sub>	SN1 <sub>1</sub>

The ninth track is used for parity

Word 1 is written first  
Word 8 is written last

The subscript refers to the bit number with bit 1 the least significant bit.

SN1:	Subject Number	Least Decimal Digit	} each is a 4-bit BCD number
SN2:	Subject Number	Intermediate Decimal Digit	
SN3:	Subject Number	Most Significant Decimal Digit	
ECA:	Experiment Code bit A	} equals 1 when lit - true 0 when off - false	
EDB:	Experiment Code bit B		
ECC:	Experiment Code bit C		
ECD:	Experiment Code bit D		
H:	Eight-bit Horizontal Position		
V:	Eight-bit Vertical Position		
PD:	Eight-bit Pupil Diameter		
C:	16-bit real-time clock which increments continuously every 1/60th of a second, reset to zero by RESET button. Clock is continuous and recycles automatically.		
SS:	Four-bit Slide Counter reset to zero by RESET button and incremented by Subject Slide Advance switch.		
RUN:	Single bit which is on for the first 12 samples of the first record of any recording sequence - started with a RUN command.		
ABORT:	Single bit which is on in the last sample of the record before stopping with an ABORT command.		

#### SYSTEM CONTROLS

Inter-record gap (IRG) and Record Length: An IRG is generated and written on tape at the end of each 512 words or 64 samples ( $64 \times 8 = 512$ ), when the RUN button is turned off, or when the ABORT button is turned on. In these cases the Controller will complete the sample which may be in progress and then write an inter-record gap. The last record of any sequence will therefore, in general, contain less than 64 samples. Record length for incremental recorder is 4096 words or 512 samples.

Inter-Record Gap Duration: Less than 70 Milliseconds (for incremental tape recorder only); no data lost for a synchronous tape recorder.

Tape Parity: Odd

#### FRONT PANEL CONTROLS

Subject Number: 3-decimal digit thumbwheel switch

Experiment Code: 4 lighted pushbuttons with two states each marked A, B, C, and D.

Reset Switch: Resets Real Time Clock and Slide Sequence Counter to zero.

RUN Switch: Actuates start and stop of recording sequence. It sets the RUN bit to one for 12 samples of the first record of any sequence (all 1st record for incremental recorder). This allows the determination of the beginning of a sequence. Turning off the RUN switch places an IRG after the last sample and stops recording.

ABORT Switch: Sets the ABORT bit to one, records the last sample, places an IRG on tape and stops recording.

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 WALTHAM, MASSACHUSETTS 02154  
 TELEPHONE: (617) 890-5100

PRICE LIST

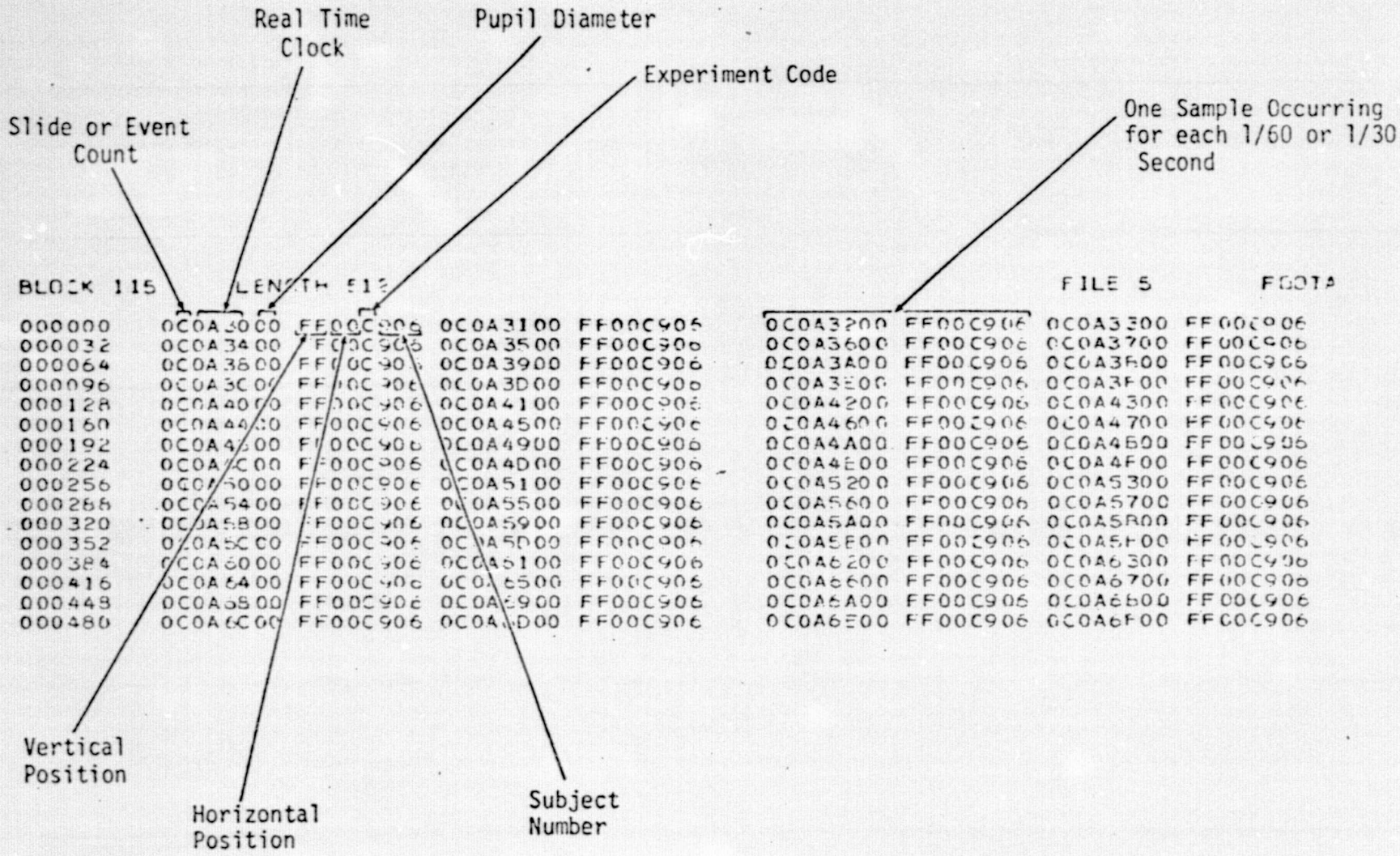
	<u>PRICE</u>
MODEL 19TR-9 EYE VIEW MONITOR AND PUPILLOMETER SYSTEM 9-TRACK DIGITAL TAPE RECORDER INTERFACE AND CONTROLLER	\$3,400.00

Options

- |  |   |          |
|--|---|----------|
| 1. Subject Number Indicator:   | A 3-digit thumbwheel switch   | 440.00   |
| 2. Experiment Code:  | 4 lighted push-button switches yielding 4-bit binary number   | 310.00   |
| 3. Event or Slide Counter:   | This is a counter to index the slide number being presented a subject. It contains 4 binary bits and this may be integrated with a slide projector system. See below. | 390.00   |
| 4a. Kennedy Model 1600/360 FG 9-Track, 800 BPI, 0-500 steps/second with Fast Gap Option  |   | 5,200.00 |
| NOTE: An incremental tape recorder is rate limited, does not allow reading after writing or prevent errors or bad writing, and loses data during an inter-record gap. A buffered synchronous tape recorder eliminates these problems. (Item b) |   |          |
| b. Kennedy Series 9000, 9-Track synchronous tape drive and buffered formatter system with read after write check.  |   | 6,490.00 |
| 5. 1200-ft reel of 9-Track recording tape  |   | 12.00    |
| 6. Intergrated Slide Projector system with proper compatibility and noise free operation   |   |          |
| a. Single Slide Projector  |   | 650.00   |
| b. Double Slide Projector with Dissolve Unit   |   | 1,290.00 |
| 7. Rear Projection Screen  |   | 195.00   |

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A-25



SAMPLE TAPE DUMP OF ONE RECORD WITH MODEL EYE

Figure 4.1



## GENERAL SYSTEM DESCRIPTION AND CONFIGURATION

	1992S	1994S	1996S	1998S
TYPE OF SYSTEM	Chin Rest Laboratory System	Remote Chin Rest or Head Rest System	Processor based free head system. Greater head motion. Greater eye motion. Greater eyelid tolerance. Greater artifact tolerance. Greater camera-subject distance.	Head tracking added to Model 1996S.
ILLUMINATION OPTICS	Indirect-Black pupil	Coaxial-Bright Pupil	*	*
ILLUMINATION CHARACTERISTICS	Invisible near infrared filtered incandescent lamp illumination centered at 8500 Angstroms.	Invisible near infrared filtered tungsten-halogen lamp illumination centered at 8500 Angstroms.	*	*
TV CAMERA	Output Impedance: 75 ohms. 525 lines (625 lines at 50 Hz). Silicon Matrix vidicon tube with 2:1 sync, 1 inch faceplate.	*	*	*
CALIBRATION	Manual	*	Automatic	*
SYSTEM COMPONENT CONFIGURATION	Pupil Camera Pupil Monitor Scene Camera Scene Monitor	* * * * Gross Eye Location Camera Gross Eye Location Monitor	* * * * * * Dedicated processor I/O devices for Processor (opt.) 4k Core (higher opt.)	* * * * * * * Head Tracker
DIGITAL DATA STORAGE AND ANALYSIS	Optional Digital Tape Recorder Interface and Controller with Digital Tape Recorder; Off-line data analysis.	*	Integrated digital tape recorder or disk for data storage in real time. Data analysis may be performed on dedicated processor.	*

\* Same as item to the left.

## PERFORMANCE SPECIFICATIONS

	1992S	1994S	1996S	1998S
ALLOWABLE EYE MOVEMENT	Horizontal 30°; 40° or higher with reduced accuracy. Vertical 25°; 30° or higher with reduced accuracy. Eyelids may limit this range with some subjects.	*	Horizontal: 40° or more. Vertical: 30° or more depending on Pupil Camera placement and eyelids.	*
ALLOWABLE EYE SPACE (Head Movement)	Head in Chin Rest	Head in Chin Rest or Head Rest	2 or more square inches in X-Y axes. 1 inch in Z axis. (Higher with reduced accuracy.)	Head tracking handled by mirror. Remote focusing capability available. Up to 1 cubic foot capability depending on configuration.
PRECISION (Measured with Model Eye)	Better than 1/2°.	*	*	*
LINEARITY	Worst case spatial error between true eye position and obtained measurement is 1°. Errors are lower if only a small central field, like a TV monitor is used. Error may increase to 2° in peripheral corners.	*	Worst case spatial error between true eye position and obtained measurement is 1°.	*
CAMERA TO SUBJECT DISTANCE	5-6 inches (12.5 - 15 cm)	18-26 inches or more (45 - 63 cm)	18-36 inches or more depending on configuration. (45-91 cm)	*
CAMERA PLACEMENT	Eye level to left of subject (right possible)	*	Variable	*
EYEGASSES ACCEPTED	Most	*	*	*
CONTACT LENS ACCEPTED	Some	*	*	*

\* Same as item to the left.

SYSTEM OUTPUTS

		1992S	1994S	1996S	1996S
SYSTEMS OUTPUTS	EYE POS.	ANA.		*	*
		DIG.		*	*
		DIS.		*	*
	PUP. DIA.	ANA.		*	*
		DIG.		*	*
		DIS. (OPT.)		*	*
	TIMING OUTPUTS		*	*	*
OPERATOR SETTING INDICATIONS		*	*	*	

\* Same as items to the left.

AN OCULOMETER NOW UNOBTRUSIVELY REVEALS  
WHAT YOU ARE LOOKING AT

JANUARY 1977

HONEYWELL  
Radiation Center  
2 Forbes Road  
Lexington, Massachusetts 02173

## AN OCULOMETER NOW UNOBTRUSIVELY REVEALS WHAT YOU ARE LOOKING AT

### The Eyes - A Window Into The Mind

Unlike a TV camera (which "sees" everything within its field of view equally clearly), the human eye must be aimed quite accurately if the detail of interest is to be seen with maximum clarity. For example, try reading a portion of this text without moving your eyes. That is, keep your eye fixed on one letter and then try to read adjacent letters and words. You will notice two things. First, the area of best vision (foveal vision) is very small - you will probably feel the need to move your eye, just to see the letter immediately adjacent to the particular letter onto which you are trying to keep your eye fixed. Second, the impulse to move your eye, to see adjacent letters, is almost irresistible.

The largely subconscious angular movement of our eyes reveals what it is that we are attending to - how we are absorbing visual information from our environment. It is, after all, a matter of common experience that our eyes not only let us see out, but allow others to "see" into us.

### The Remote Oculometer

By looking at another person's eyes, you can tell where he is looking. An electro-optical device, called an Oculometer, can now do this automatically - generating a continuous measure of the x-y coordinates of a subject's instantaneous point of fixation, together with a continuous measure of his pupil diameter.

The Oculometer, developed by Honeywell Radiation Center for the USAF Aerospace Medical Research Laboratory, is remote from the subject (several feet away, or more). Eye direction is measured whenever the eye is within a designated cubic foot volume of space. This cubic foot of "eye space" coverage of the Remote Oculometer is sufficient so that, in many applications, the subject is free to move in a completely normal fashion. The subject may not, necessarily, even be aware that his eye direction is being measured. The fact that the Remote Oculometer does not interfere with the normal activities of the subject makes it particularly useful for human factors research - for example, the flight research now being performed by NASA at their Langley Research Center.

NASA scientists have installed a Remote Oculometer in the cockpit of an aircraft simulator. The output signals from the Oculometer define the coordinates, on the instrument panel, of the pilot's point of fixation at any instant. From the

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<sup>1</sup> "Remote Measurement of Eye Direction Allowing Subject Motion Over one Cubic-Foot of Space," John Merchant, Richard Morrisette, James L. Porterfield, IEEE Transactions on Biomedical Engineering, Vol. BME-21, No. 4, July 1974, pp 309-17.

<sup>2</sup> "Preliminary Report on Airline Pilots Scan Patterns During ILS Approaches," Amos A. Spady, Jr., pp 603-616, (In Aircraft Safety and Operating Problems, NASA SP-416, 1976).

known coordinates of the various instruments, this Oculometer data is converted into parameters such as instrument-fixation-frequencies, fixation-transfer-probabilities (between instruments), etc for detailed analysis of the pilot's visual task.

The Oculometer output can also be used to annotate a TV picture of the instrument panel with a marker dot showing the pilot's instantaneous point of fixation. This annotated TV picture can be recorded on video tape to provide a continuous, graphic record of the pilot's fixation scan. Pilot fixation data is useful because it indicates, as no other data can, how the pilot is absorbing information from his flight instruments. Flying can be thought of as a multi-degree-of-freedom manual control task. The pilot must control the angular attitude (elevation, roll, and yaw), the velocity (horizontal speed and heading, and vertical velocity) and, of course, the altitude of his aircraft.

During an approach and landing most, if not all, of these flight parameters are changing and each one must be promptly and accurately corrected. In bad weather the pilot must rely, completely, on his flight instruments for information on the current value of these flight parameters. This requires a constant, rapid, and systematic fixation scan by the pilot over his primary flight instruments.

By recording and analyzing pilot eye fixation data, NASA hopes to be able to answer questions such as:

- How should the primary instruments be arranged on the panel in front of the pilot? Are there better ways (then conventional dials) of displaying the flight data?
- How should the pilot divide his attention between the various instruments? Is there a preferred fixation scan pattern over the flight instruments?
- Can the stress on the pilot be estimated from measurements of his fixation behavior and/or pupil diameter changes?

In the near future, NASA plans to install an Oculometer in an aircraft to record the pilot's through-the-window fixations in actual flight. In this case, the Oculometer data will show what elements of real-world detail the pilot uses under VFR conditions. This will help NASA optimize the design of the visual out-of-the-window display for their flight simulator.

#### How The Oculometer Works

If you shine a flashlight at someone's eye, and ask them to rotate their eye (that is, to change their point of fixation) you will see a movement in the eye. Because the eyeball is quite small (about one inch in diameter) the amount of such eye movement, per degree of eye rotation, is very small. Even more of a problem is the fact that a similar movement of the eye occurs whenever the head is translated. How is an electro-optical eye tracker to sense the small movements of the eye due to eye rotation, and then distinguish them from the generally much larger, but similar, movements of the eye caused by head displacement?

In some eye-tracking devices this problem is (often only partially) solved by clamping the tracker to the subject's head. In the Oculometer the problem is overcome by tracking two elements of eye detail - the pupil/iris boundary and the reflection in the eye of the source used to illuminate the eye.

To demonstrate this principle, ask a subject to look directly at your flashlight. You will notice that the highlight (corneal) reflection of the light appears to be at the center of his pupil. When the subject looks away from the light, you will see that the reflection moves, correspondingly, away from the center of the pupil. It is easily verified that this is independent of head position. In other words, eye direction can be determined, independently of head position, simply by measuring the displacement of the corneal reflection (of the radiation used to illuminate the eye) relative to the center of the pupil.

To avoid dazzling the subject, the Oculometer uses near infrared (0.8  $\mu$ m) radiation to illuminate the eye. This is almost invisible - the subject sees only a dull red light in front of him.

A standard TV camera is used to sense the eye detail, and by a special optical arrangement, the pupil of the eye is seen as "bright" - not black, as in a normal view of the eye (Figure 1). (In this technique, the pupil is effectively back-lighted by the retinal image of the infrared source.) With suitable black-level adjustment of the camera video output, the TV picture of the eye generated by the Oculometer reduces to just two circular areas against a black background. One circle - the pupil yields a video level of about 300 mV. The other - the much smaller corneal (high-light) reflection - is at a video level of about 1 volt. As we have seen, eye direction is proportional to the displacement of the corneal reflection from the center of the pupil. The Oculometer electronics unit analyzes this relatively simple TV picture of the eye to deduce eye direction according to this principle.

The Oculometer electronics unit is, basically, a standard general purpose minicomputer. A special interface card, which plugs into a spare slot in the minicomputer, converts the video signal from the Oculometer TV sensor into digital format, and enters the resultant eye data directly into an area of the minicomputer memory. The specialized processing of the video eye data is then performed (in real time) entirely by software in the general purpose minicomputer.

The advantages of minicomputer processing are low cost, reliability, easy maintenance, flexibility for incorporating improvements, and processing power. The processor not only estimates the relative positions of the centers of the pupil and of the corneal reflection, it also handles special, "difficult" cases - as when the corneal reflection falls on (and thereby distorts) the pupil/iris boundary, or when the top and/or bottom of the pupil is partially obscured by the eyelids. It solves the complex geometrical equations relating "raw" eye direction and the coordinates of the intercept of the fixation vector on some specified plane. The processor also provides the means for quick, three-point, calibration for each new subject as well as compensation for the nonlinearities in the relationship between eye direction and relative corneal reflection position within the pupil.

As mentioned earlier, the motion of the eye, due to eye rotation, is small. In the effect used by the Oculometer, the scale factor is approximately three thousandths of an inch of relative corneal reflection displacement per degree of eye rotation. The resolution of the TV sensor is limited by the approximately 500-600 scan lines in the picture. It is clear that if the TV sensor is to have sufficient resolution to be able to sense eye movements to an accuracy of  $1^\circ$ , its field of view at the eye must be quite small - of the order of one square inch. It turns out that the depth of focus of the Oculometer is also about one inch. Thus, the instantaneous field of view at the eye (eye space) is inherently limited to the order of one cubic inch.

In order to provide an effective eye space coverage of one cubic foot, a two-axis moving mirror system and a servo-controlled focusing lens are added to the basic Oculometer system. These opto-mechanical elements are controlled, automatically, by the minicomputer to keep the eye always centered within the instantaneous (cubic inch) eye space of the sensor, as the eye moves over the cubic foot of effective eye space. An auxiliary TV camera, with a wide-angle lens, is also located in front of the subject to provide the minicomputer with additional information for rapid acquisition of the eye and for automatic focusing of the Oculometer.

#### Installation

The angular range of the Oculometer is  $\pm 30^\circ$  (x) and  $0^\circ$  to  $+30^\circ$  (y) relative to a line joining the eye to the Oculometer. This means that, for maximum angular coverage, the Oculometer should be placed at the bottom center of the fixation field. It may not always be convenient to locate the Oculometer sensor (with its TV camera, IR Source, moving lens and mirrors, etc) at this point - particularly when the fixation field is the crowded instrument panel of an aircraft simulator. For this reason the Indirect Remote Oculometer (Figure 2) has recently been developed. The path length from the eye to the sensor has been increased to 90 inches. With this system, it is necessary to locate only the moving mirror in front of the subject. The Oculometer sensor itself can be located behind or to the side of the subject, "seeing" the eye by reflection in the mirror. There is generally more room for the Oculometer sensor away from the fixation field and, of course, the sensor will not then obstruct the subject's view of the fixation field.

In future developments, the conventional (vidicon) TV camera in the Oculometer Sensor may be replaced by the much smaller CCD (solid-state) TV cameras that have recently become available. This will make it easier to install the Oculometer in confined areas, such as the cockpit of an aircraft. The CCD camera will also make it possible to integrate an Oculometer into a pilot's flight helmet, using the parabolic visor to reflect rays from the miniaturized Oculometer sensor onto the pilot's eye. A helmet mounted Oculometer would permit the eye direction of the pilot to be measured with unlimited angular and linear motion of the head.



### Other Applications

The Remote Oculometer has been used to record driver eye fixations in an automobile. The output signals from the Oculometer were used to annotate a TV picture of the road, generated by a camera mounted just behind the driver. A video tape recording of this annotated driver's-eye-view of the road ahead allowed researchers to study how their test subjects performed the visual tasks involved in driving.

The Oculometer has also been used to study how people look at TV commercials. An Oculometer was set up near a TV set in a shopping mall and shoppers were invited to watch a series of 10 30-second commercials (Figure 3). The Oculometer determined which section of the TV screen the test subject was looking at, at each instant. In the course of a week the TV fixation data from 200 subjects was recorded for subsequent statistical analysis. As the data was being recorded, the advertising researchers were able to see an annotated version of the commercial being viewed by the test subject at that time (Figure 4). The annotation mark showed the subject's instantaneous point of fixation. In this way they were able to see, immediately, what features in the commercial people tended to concentrate on, and what features people tended to ignore - potentially important information for those trying to capture the viewer's fleeting attention and concentrate it on the product being advertised.

### Eye-Control

The ability of the Oculometer to measure a subject's eye direction, without interfering with the subject, offers the interesting possibility of using the eye for control, in place of the hands.

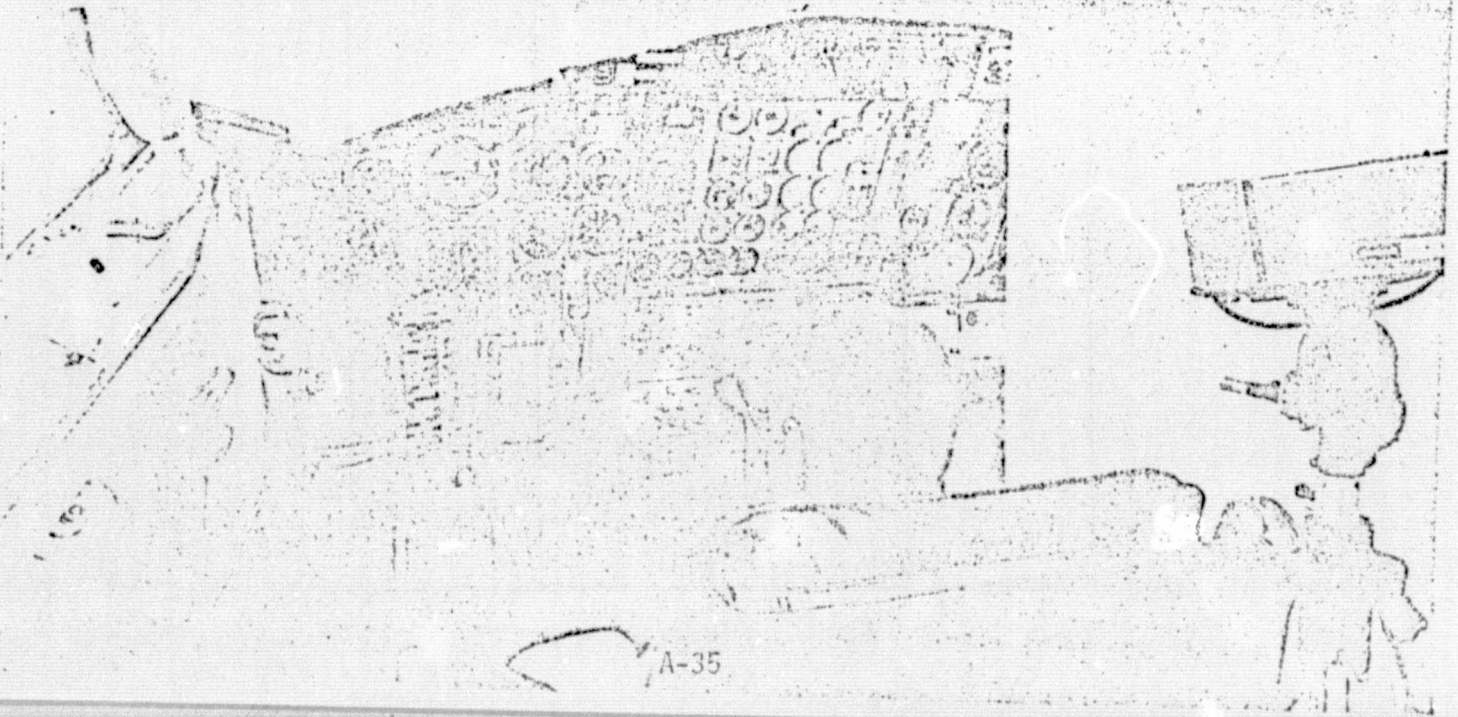
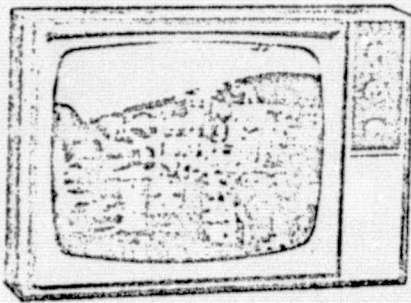
The angular direction of the eyeball is controlled by a sophisticated neuromuscular system. In addition to freeing the hands (for other tasks) eye-control might offer faster reaction than conventional manual control - particularly for aiming tasks in which the eye must be aimed, anyway, as part of the normal act of vision.

### Conclusion

There are two basic aspects of human performance in any man/machine system - what sensory information is he receiving, what motor action is he generating? The motor (output) from the man is relatively easy to record. The Remote Oculometer - by unobtrusive measurement of eye direction - now provides a practical method for recording the visual interaction of the subject with his visual environment, thereby indicating the nature of the visual information that is he absorbing. In this way the Oculometer is contributing to research aimed at understanding, and improving, human performance.

# THE HONEYWELL/INDIRECT REMOTE OCULOMETER

For Eye Fixation Measurement and Recording  
with no Interference to Normal Subject Activity



## SECTION 1

### INTRODUCTION

The Honeywell Indirect Remote Oculometer determines where a subject is looking (Figure 1) without causing any interference to the subject. The Honeywell Oculometer is, therefore, ideally suited for applications where the measurement-operation itself must not interfere with the subject characteristics being measured.

Honeywell Oculometers are being used for:

- Pilot eye fixation recording and analysis.
- Automobile driver eye fixation recording and analysis.
- Evaluation of TV commercials.
- Recording and analysis of photointerpreter scan patterns.
- Evaluation of eye/head/hand tracking for control applications.

An optical head (consisting of a standard TV Camera and a filament source of virtually invisible IR illumination) generates a TV picture of the subject's eye. This TV picture is analyzed, in real time, by a standard minicomputer to extract eye-direction information. In this application, the minicomputer functions as the 'electronics unit' for the Oculometer. No computer knowledge is required to operate the Oculometer.

The use of a standard minicomputer\* for signal processing provides a number of important benefits:

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\* The computer utilized in the Oculometer is the Data General NOVA 2/10 (8K memory in the Standard version, 24K in the Automatic version). The NOVA 800, 1200 and 1220 can also be used, by special arrangement. It is not practical to use any other type of minicomputer.

Some special back-plane wiring of the NOVA is involved, but this will not interfere with other uses of the computer. The Oculometer interface, which plugs into the NOVA, occupies 3 slots.

- ① Maximum angular coverage, because the intelligence of the computer allows accurate tracking to continue even under "difficult" conditions, for example, when the corneal reflection is on the pupil boundary.
- ② Automatic correction for a number of second order effects, for example, the nonlinearity of the TV sensor.
- ③ Correction of nonlinearities due to subject - subject variations of eyeball structure. Correction factors for up to 9 subjects can be stored in the computer for immediate recall by subject number.
- ④ Many system parameters can be easily changed at the keyboard, e.g., output scale factors, output filter time constant, size of the tracking gate, etc.
- ⑤ High reliability, easy troubleshooting and fast service because the minicomputer is a standard high-volume commercial item.
- ⑥ The computer can be used for many other functions, such as:
  - Real-time sampling, formatting, and buffering of the raw data.
  - Recording eye data on magnetic tape, cassette, etc.
  - On-line stimulus generation (either open-loop or interactive).
  - Off-line processing of eye fixation (or any other) data using standard software (e.g., FORTRAN).

## SECTION 2

### SYSTEM DESCRIPTION

The general Oculometer equipment available from Honeywell is shown in Table I. Other Oculometer configurations and peripheral equipment can be provided on special order.

#### 2.1 THE INDIRECT REMOTE OCULOMETER (Items 1 and 2)

The Standard version of the Oculometer (Item 1) can be used when the subject will not be moving very much during each fixation experiment. This is typically the case when the fixation task is of short duration and involves continuous fixation of one area, for example, a TV screen.

The Automatic version (Item 2) is intended for applications where the subject may be moving during the fixation experiment, for example, continuous, long duration monitoring of an automobile driver or aircraft pilot.

##### 2.1.1 Ease of Operation

The optical head is located 90 inches  $\pm$  6 inches from the subject and views the subject via a small relay mirror (Figure 2).

The relay mirror, and the optical head, can be adjusted so as to detect the eye anywhere over a cubic foot of space centered at the nominal eye position. In the Standard version of the Oculometer, this adjustment is manual and is performed prior to calibration. It allows the system to be adapted easily to subjects of various heights and eye positions. In the Automatic version, this adjustment is performed automatically by the signal processor (Figure 3). In the Automatic version, eye direction (or fixation point coordinates) can be continuously measured as the subject moves over the full cubic foot of eye space. A head tracker (an auxiliary TV camera) provides fast acquisition and automatic focus.

##### 2.1.2 Ease of Installation

Only the small relay mirror need be placed in front of the subject. For the maximum angular range of eye direction measurement, the relay mirror should be located at the bottom-center of the fixation shield.

Table I  
HONEYWELL OCULOMETERS AND ASSOCIATED EQUIPMENT

1. Indirect Remote Oculometer with NOVA 2/10 and 8K memory. Standard version.
2. Indirect Remote Oculometer with NOVA 2/10 and 24K memory. Automatic version.
3. ASR 33 Teletype with NOVA interface.
4. LINC Tape Drive.
5. Infoton CRT terminal with NOVA interface.
6. 8-inch TV monitor.
7. Fixation Point Unit.
8. TV camera, silicon target vidicon, lens (for use with Fixation Point Unit).
9. 18" TV monitor (for use with Fixation Point Unit).
10. Video Tape Recorder (Sony AV 3650) (for use with Fixation Point Unit).
11. Conversion of Item (1) to Item (2).
12. Artificial eye and holder.
13. Carriage for artificial eye.  
( $\pm 0.5''$  in x,y,z - vernier to 0.0001"; 0.360° in azimuth and elevation - vernier to 5 arc seconds.)

INDIRECT REMOTE OCULOMETER

AUTOMATIC VERSION

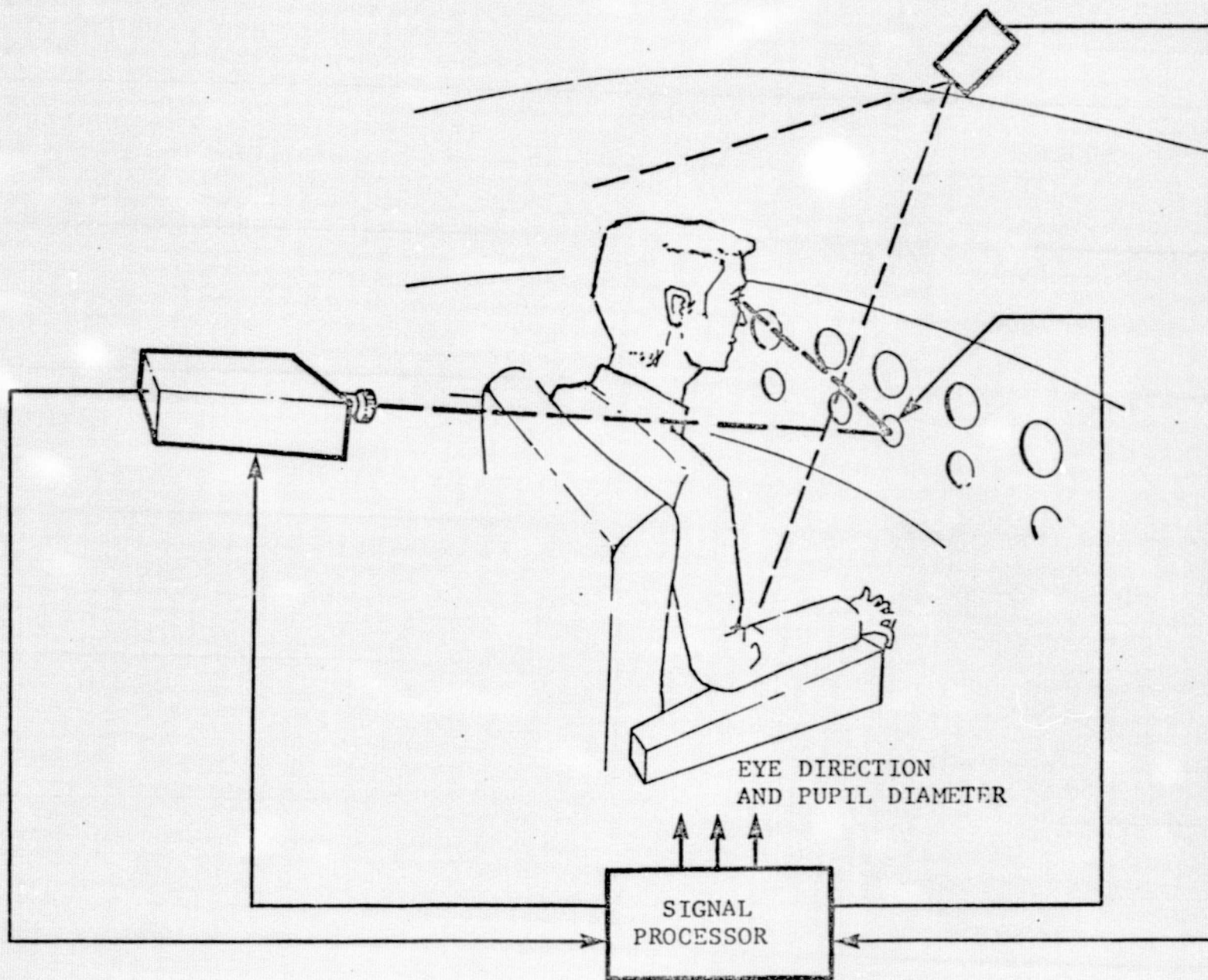


Figure 3 INDIRECT REMOTE OCULOMETER, AUTOMATIC VERSION (CONTINUOUS MEASUREMENT OF EYE DIRECTION WITH ONE CUBIC FOOT OF HEAD MOTION)

The fact that only a small mirror need be located in the fixation field is a very important advantage in the case when the fixation field is crowded - for example, an aircraft instrument panel.

The optical head can be located behind, above, or to the side of the subject - wherever is most convenient. This installation flexibility is extremely useful in situations where there may be very limited space available for the optical head - for example, the cockpit of an aircraft simulator.

#### 2.1.3 No Interference to the Subject

No bulky equipment need be located in front of the subject.

The IR illumination is almost invisible - it appears to the subject as a dull red light in the relay mirror.

A cubic foot of subject motion is permitted in the Automatic version of the Indirect Remote Oculometer.

#### 2.1.4 Signal Outputs

The Oculometer provides three analog output voltages (x,y eye direction and pupil diameter).

Digital outputs can be provided on special order.

A fixation point display option is available in which the subject's fixation point is shown as an annotation mark on a TV picture of the fixation scene.

Eye direction coordinates can be recorded on magnetic tape (LINC tape), and these recordings can be processed by the Oculometer minicomputer using FORTRAN. The necessary software can be developed by the user or can be supplied by Honeywell to the specific requirements in each case.

#### 2.1.5 Automatic Version of the Oculometer (Item 2)

In the Automatic version, the relay mirror and the focusing lens are continuously, and automatically, adjusted by the signal processor as the subject moves over the cubic foot of eye space. The computation of eye direction, or of the fixation point coordinates on any specified fixation plane, includes solution



of all the geometrical equations that relate the eye pattern data, mirror angles, and lens position, to the desired output.

An auxiliary TV camera (head-tracker) is included in the Automatic version to provide automatic focusing and fast acquisition over the cubic foot of eye space.

This camera should be located in front of the subject, at a bearing of at least 30 degrees away from the Oculometer, so as to view the cubic foot of eye space. The TV picture thereby generated is analyzed by the signal processor, in real time, to determine the position of the eye within the eye space so that the Oculometer can be pointed directly at the eye.

The head-tracker video information also enables range to be determined (by triangulation) so that the Oculometer can be continuously focused onto the eye.

There are two modes of operation of the head-tracker system. In one, the subject wears a headband on which is mounted a small gallium arsenide diode. In the other mode, the subject does not wear the headband. (The use of the GaAs head marker provides for faster acquisition.)

In the Automatic version, the relay mirror must be electronically slewable to enable the signal processor to automatically track the eye over the cubic foot of eye space.

The moving (relay) mirror system provided consists of two mirrors, each attached to a rotary actuator. These two mirror units are supplied mounted to a baseplate, to provide a right-angled bend in the path from the eye to the optical head (Figure 4). However, in most applications, the mirrors should be removed from the baseplate and custom-mounted on the fixation scene so as to

- interfere as little as possible with the fixation scene
- provide the appropriate bend in the optical path from the eye to the optical head, as required for the selected location of the optical head.

Other moving mirror systems can be developed on special order. For example, a single, gimballed mirror which can be rotated in two dimensions. If desired, the mirror can be specially coated so as to be transparent in the visible, thereby further minimizing any obstruction of the fixation field.

### 2.1.6 Equipment (options (see Table I)

The Oculometer, itself, is available in a Standard version and an Automatic version, the components of which are illustrated in Figures 5 and 6. In addition, a number of peripheral items are available, as discussed below.

### 2.2 COMPUTER TERMINALS AND TAPE UNITS (Items 3,4,5)

A means of reloading the Oculometer program is required, e.g., the ASR 33 Teletype (Item 3). Other suitable devices include - the LINC tape drive, paper tape reader, cassette, floppy disc. The Oculometer program is supplied on paper tape or, on request, on LINC tape.

Certain symbols in the Oculometer program, such as output scale factors, can be accessed via the NOVA front panel. This is inconvenient and a keyboard device [such as the ASR 33 or the CRT terminal with NOVA interface (Item 5)] is recommended.

The teletype has the advantage that it can be used to load the program and access symbols. The LINC tape has the advantage of much faster program loading and is also useful for program development, data recording, etc. The CRT terminal has the advantage of quiet, fast operation.

### 2.3 8-INCH TV MONITOR (Item 6)

Use of a standard TV monitor (e.g., Item 3) (to show the Oculometer sensed image of the eye) is recommended for subject alignment, system checkout.

### 2.4 FIXATION POINT OPTIONS (Items, 7,8,9,10)

Item 7 is an annotation device. It accepts an input video picture of the fixation scene (e.g., from Item 8) and also the x,y outputs of the Oculometer.

The output from the annotation device is a video picture of the fixation scene with the fixation point (as designated by the x,y inputs) shown as a white marker dot.

This annotated picture of the fixation scene can be displayed on a standard monitor (e.g., Item 9) or recorded on a video tape recorder (Item 10).

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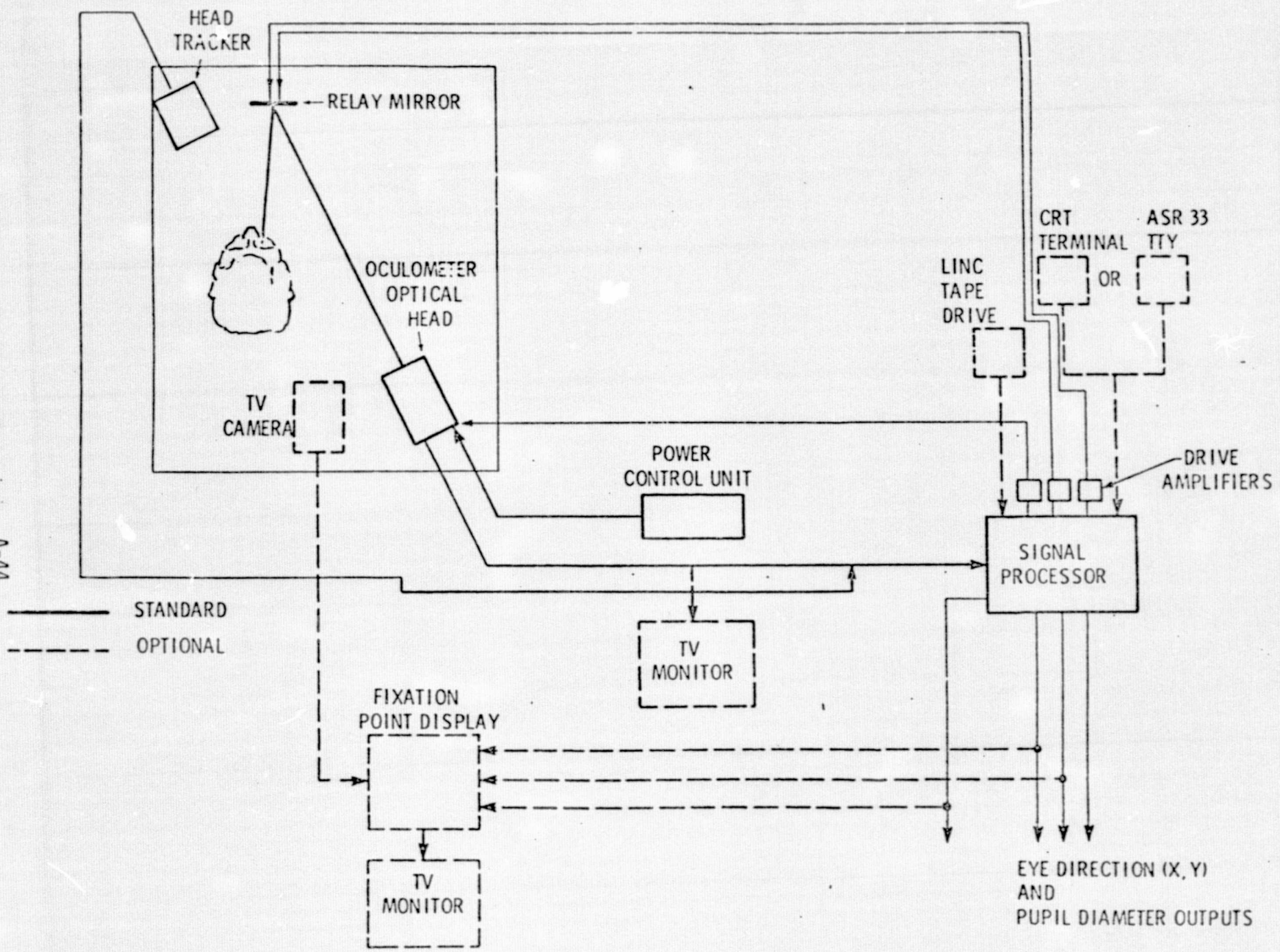


Figure 6 AUTOMATIC INDIRECT REMOTE OCULOMETER SYSTEM

The fixation point options are particularly useful when the function of the Oculometer is to indicate, qualitatively, what the subject is looking at. The stop-action and slow-motion features of the video tape recorder allow this information to be studied, as a function time (frame by frame - 1/30 second), if desired.

2.5           CONVERSION (Item 11)

A Standard version Indirect Remote Oculometer can be converted, at Honeywell, to the Automatic version.

2.6           ARTIFICIAL EYE (Items 12,13)

The artificial eye is specially designed to generate the same video signal as a human eye. The carriage allows the eye to be precisely translated in three dimensions (to 0.0001 inch) and rotated in two dimensions (to 5 arc seconds).

These items are useful for accurate testing and evaluation of the Oculometer.

SECTION 3  
OCULOMETER SPECIFICATIONS

3.1 HONEYWELL STANDARD INDIRECT REMOTE OCULOMETER SPECIFICATIONS

SYSTEM RANGE (from eye to optical head):  $90 \pm 6$  inches<sup>1</sup>  
(adjustable)

RMS NOISE LEVEL: 0.5 degree (measured with artificial eye)

SYSTEM TIME CONSTANT: 0.1 second

ANGULAR RANGE: (Horizontal):  $\pm 30$  degrees<sup>2</sup>  
(Vertical) : -10 to +30 degrees<sup>2</sup>

SYSTEM ACCURACY: within 1 degree<sup>3</sup>

OUTPUT SCALE FACTOR: adjustable 10 degrees/volt (nominal)

OUTPUTS: X eye direction,  $\pm 5$  volts max  
Y eye direction,  $\pm 5$  volts max  
Pupil diameter 0-10 volts (digital outputs  
also available)

EFFECTIVE AREA COVERAGE: one cubic foot<sup>1</sup>

ILLUMINATION: complete darkness to moderate office light  
(pupil diameter 3 mm or greater)

POWER REQUIREMENTS: 115 volts, 60 Hz; or 230 volts, 50 Hz

3.1.1 Dimensions and Weights

UNIT	SIZE (inches)	WEIGHT (lb)
OPTICAL HEAD	18-1/2 x 14-1/2 x 5-1/4	30
RELAY MIRROR <sup>4</sup>	4.1 x 3.7 x 3.1	--
POWER CONTROL UNIT	12 x 8-3/4 x 4-1/2	12
SIGNAL PROCESSOR <sup>5</sup> AND INTERFACE	10-3/4 x 19 x 24	52

CONNECTING CABLES AND OPERATING AND MAINTENANCE MANUAL PROVIDED.

NOTES:

1. The one-cubic-inch instantaneous field of view at the eye can be manually adjusted (prior to calibration) over an

area of one cubic foot at the eye by tilting the relay mirror and adjusting the focus control in the optical head. After calibration, the eye should remain within the one-cubic-inch instantaneous field of view at the eye.

2. Beyond 20-degrees horizontal or below 0-degree vertical, operation may be limited for some subjects due to tears or eyelash obscuration.
3. Over the range  $\pm 20$  degrees (X) and 0-20 degrees (Y). Contact lenses cannot be used. Eyeglasses can be used under certain conditions.
4. Supplied with an adjustable mount. Smaller mirror size can be specified depending on range and angle of intended use. Special, transparent, relay mirrors can also be provided.
5. Standard 16-bit minicomputer. 8K mirror. General-purpose software (e.g., Fortran) available.

3.2 HONEYWELL AUTOMATIC INDIRECT REMOTE OCULOMETER SPECIFICATIONS

SYSTEM RANGE (from eye to optical head):  $90 \pm 6$  inches<sup>1</sup>

RMS NOISE LEVEL: 0.5 degree (measured with artificial eye)

SYSTEM TIME CONSTANT: 0.1 second

ANGULAR RANGE: (Horizontal):  $\pm 30$  degrees<sup>2</sup>  
(Vertical) : -10 to +30 degrees<sup>2</sup>

SYSTEM ACCURACY: within 1 degree<sup>3</sup>

OUTPUT SCALE FACTOR: adjustable 10 degrees/volt (nominal)

OUTPUTS (three sets, selectable) (X,Y:  $\pm 5$  volts max;  
P<sub>D</sub>: 0-10 volts max):

- X,Y coordinates of the intercept of the fixation vector on any specified fixation plane, pupil diameter.
- Azimuth and elevation of the fixation vector, pupil diameter.
- Three direction cosines of the fixation vector relative to fixed axes.

Digital outputs also available.

EFFECTIVE AREA COVERAGE: one cubic foot<sup>1</sup>

AMBIENT ILLUMINATION: complete darkness to moderate office light (pupil diameter 3 mm or greater)

POWER REQUIREMENTS: 115 volts, 60 Hz; or 230 volts, 50 Hz.

### 3.2.1 Dimensions and Weights

UNIT	SIZE (inches)	WEIGHT (lb)
POWER CONTROL UNIT	12 x 8-3/4 x 4-1/2	12
OPTICAL HEAD	18-1/2 x 14-1/2 x 5-1/4	43 (approx)
RELAY MIRROR	See Note 4	--
SIGNAL PROCESSOR <sup>5</sup> AND INTERFACE	10-3/4 x 19 x 24	95
MOVING MIRROR AND LENS DRIVE AMPLIFIERS (3)	8-1/2 x 9 x 3-1/4 (each)	4.5 (each)
HEAD-TRACKER <sup>6</sup>	4-1/4 x 14 x 5-3/4	--

CONNECTING CABLES AND OPERATING AND MAINTENANCE MANUAL PROVIDED.

#### NOTES:

1. The instantaneous one-cubic-inch field of view at the eye automatically acquires and continuously tracks the designated eye of the subject over one cubic foot of space centered at the nominal eye position.
2. Beyond 20-degrees horizontal, or below 0-degree vertical, operation may be limited for some subjects due to tears or eyelash obscuration.
3. Over the range  $\pm 20$  degrees (X) and 0-20 degrees (Y). Contact lenses cannot be used. Eyeglasses can be used under certain conditions.
4. In the Automatic Indirect Remote Oculometer, the direction of the relay mirror is controlled automatically in two dimensions by the signal processor. The moving (relay) mirror consists of two mirrors (approximately 2.5 inches x 2.5 inches) each mounted to a 2.6-inch x 1.75-inch x 1.25-inch actuator. These two moving mirror assemblies are supplied mounted to a baseplate. The mirror assemblies

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can be removed from the baseplate for customer installation in front of the subject. Customer installation allows selection of an optimum location for the optical head and minimum obscuration of the fixation area by the moving mirror assemblies. [Special moving (relay) mirror systems can also be supplied. For example, a single, two-axis mirror (transparent in the visible) for minimum obscuration of the fixation field].

5. Standard 24-K 16-bit minicomputer. General-purpose software (e.g., Fortran) available.
6. The automatic head-tracker is a TV camera located in front of the subject. Positioning is not critical provided that the camera has a clear view of the subject's face and is at least 30 degrees, in bearing, away from the relay mirror. A small head marker is also supplied for fastest acquisition, but system will operate with no head marker. Ultra-small head-tracker (5-7/8 inches x 2-3/4 inches x 4-1/2 inches) also available.



SECTION 4  
PARTIAL LIST OF OCULOMETER USERS

- ⊙ Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio.
- ⊙ National Aeronautics and Space Administration, Langley Research Center, Langley, VA.
- ⊙ Rome Air Development Center, Rome, NY.
- ⊙ Federal Aviation Administration, Atlantic City, NJ.
- ⊙ Cunningham and Walsh Inc., New York, NY.
- ⊙ Forschungs Institut Feur Antropotechnik, Meckenheim, W. Germany.
- ⊙ Delft University of Technology, Delft, The Netherlands.
- ⊙ Naval Air Station, Patuxent River, MD.
- ⊙ Systems and Research Center, Honeywell, Inc., Minneapolis, MN.

SECTION 6  
LATEST TECHNICAL FEATURES

6.1 THREE-CHANNEL DIGITAL FIXATION POINT UNIT

This is an updated version of the fixation point unit (item 7, page 5).

The new item consists of a circuit card that plugs into the NOVA together with special software. It allows the NOVA to annotate a standard video signal.

The advantages of this unit are:

- Self-contained in the NOVA
- Shows a single (current) fixation point or the previous 120 fixation points (for example, the fixation pattern over the last 30 s at 4 points/second)
- Can also show fixed reference points
- Annotation mark can be black or white

6.2 HIGH SENSITIVITY ATTACHMENT

In its normal mode of operation, the Oculometer compensates for head motion, providing an accuracy of 1 degree with a noise level of 0.5 degree.

With the High Sensitivity Attachment the Oculometer can also be operated to provide a noise level of less than 0.1 degree, but with no compensation for head motion. This mode, in which the eye-Oculometer distance is approximately 20" (instead of 90"), is intended for studies of eye movement itself, in which the head is held still and absolute accuracy is not required.

6.3 EXTENDED RANGE STANDARD OCULOMETER

In this version, a remotely controlled moving (panel) mirror is used to extend the 1 cubic inch eye-space coverage of the original Standard System (item 1, page 5). The operator

keeps the eye within the 1 cubic inch field of view of the system by remote manual control of the panel mirror (and by manual control of focus) as the subject moves over a range greater than one cubic inch. In other words it provides some of the benefits of the Automatic System (item 2, page 5), with a simpler and less expensive system.

The Extended Range Standard Version is intended for applications in which relatively slow motion of the subject may occur over a range of a few inches, and where it is practical to use manual control. The Automatic System is recommended for applications where full accuracy is required for subject motions of up to one foot.

#### 6.4 SELF-CONTAINED ELECTRONICS

As explained on page 11, a teletype or CRT terminal is normally needed to operate the Oculometer.

In the Self-Contained Version all functions (including reloading of the program) are controlled by front panel switches on the signal processor. Neither a teletype nor a CRT terminal is required. (The signal processor consists of a standard mini-computer and a LINC tape drive.) The advantages of the Self-Contained Version are lower cost and less associated equipment to be interconnected.

The Self-Contained Version is suitable for applications in which the system will be used only as an Oculometer. For applications in which it may be desired to use the minicomputer for non-Oculometer purposes (i.e., as a general-purpose computer) some kind of terminal will be required.

#### 6.5 DICHOIC MIRROR OPTION

In the Automatic Version of the Indirect Remote Oculometer, the one-inch beam of rays (between the eye and Oculometer) must be moved automatically as the eye is moved over the cubic foot of eye-space.

In the arrangement illustrated in Figures 3 and 4, this is accomplished by a moving mirror assembly located on the fixation plane (e.g., instrument panel).

In an alternative arrangement, Figure 14, a moving mirror system is located at (or close-to) the optical head and a relatively large fixed dichroic mirror is located on the fixation

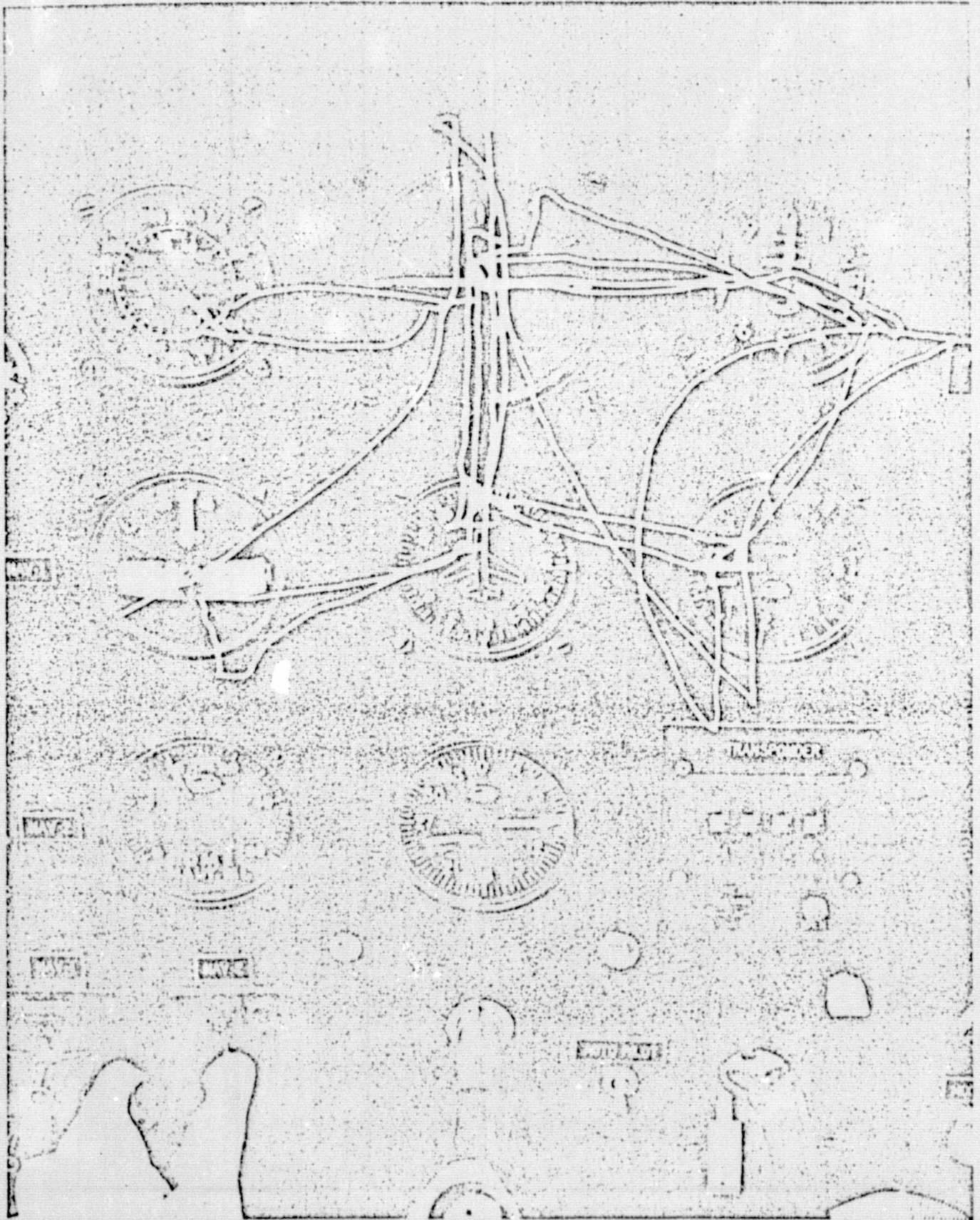
plane to reflect the moving Oculometer IR beam onto the eye. The dichroic mirror is transparent to visible radiation - it does not obscure the subject's view of the fixation plane.

The fixed dichroic mirror can be tilted to adjust the dynamic eye-space region to suit each new subject. The size of the dynamic eye-space region is governed by the size of the dichroic mirror and its distance from the moving mirror assembly and from the eye.

The advantage of the Dichroic Mirror technique for the Automatic Version of the Indirect Remote Oculometer is that no equipment of any kind, other than an (apparently) transparent sheet of glass, need to be located at the fixation plane. This simplifies installation and minimizes subject interferences.

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# eye-trac Model 200 Research Eye Movement Monitor



NARCO BIO-SYSTEMS, Inc.

A-54

# eye-trac<sup>®</sup> MODEL 200 RESEARCH EYE MOVEMENT MONITOR

Measures Horizontal or Vertical Eye Movements—simultaneously monitors both eyes.  
 High Sensitivity, Accuracy, Resolution—minutes of arc possible—millisecond response.  
 Analog and Digital Outputs Available—compatible with most display and recording devices and computerized data systems.  
 Non-Contacting Photoelectric Technique—does not require electrodes or attachment to the eye.

## APPLICATIONS

The Eye-Trac, Model 200 has many useful research applications. The front cover shows the eye movement pattern of a pilot flying under IFR conditions, in evaluation of an aircraft instrument panel design. Other uses include:

Scan Patterns	Dominance	Perception
Drug Effects	Advertising, Consumer Reaction	Tracking
Fatigue	Vigilance Testing	Others
Psycholinguistics	Anxiety	
Human Factors Engineering	Fixation & Gaze Avoidance	

## DESCRIPTION

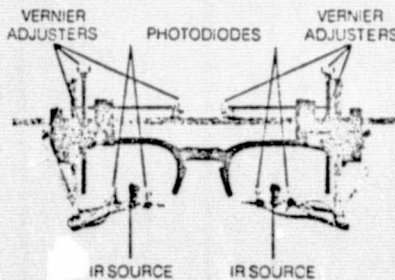
The Eye-Trac, Model 200 Research Eye Movement Monitor measures both horizontal and vertical eye movements by employing a non-contacting photoelectric technique. The outputs produced are simultaneous analog voltages (digital optional) which are direct functions of the position and movement of each eye.

The instrument consists of a sensing assembly and an associated electronics control package connected by an eight foot flexible cable.

The monitor does not require attachments to the eye or skin, nor does it significantly interfere with the subject's head movements or vision. Low level, invisible, modulated, infrared eye illumination and synchronous detection of the reflected signal minimize both subject distraction and ambient illumination artifacts.

The Model 200 measures direction of gaze horizontally by utilizing the differential reflectivity of the iris and the sclera. It measures horizontal position of the eyes over a range of approximately  $\pm 20^\circ$ , with a resolution of better than one quarter of a degree. The resolution can be improved to a few minutes of arc with a rigid head mounting fixture (bite board or good head and chin rest). Vertical eye movement recording is accomplished by monitoring either upper or lower eyelid movement. In this case, the difference in reflectivity between the lid and sclera is employed to make the measurement. Vertical range is  $+10^\circ$  (up) and  $-20^\circ$  (down), with a resolution of approximately  $1'$ .

Crosstalk between horizontal and vertical



measurements can normally be kept under 10% by careful alignment and set-up of photo-sensors. Additional electronic crosstalk reduction is provided for and is adjustable by front panel controls. The time constant of the instrument is approximately four milliseconds. Front panel "filter" switches allow the response time to be increased to 26 milliseconds in order to minimize 60 or 120 Hz interference.

A front panel selector switch allows the output signal from either channel to be presented on the monitoring meter. The analog signals from both channels are simultaneously available at rear panel binding posts and front panel jacks. These signals are suitable for direct interfacing to most recorders, oscilloscopes, magnetic tapes, and other common recording /display devices. The optional digital outputs (both channels available simultaneously) appear on a rear mounted connector. The analog and digital signals produced by the Model 200 are compatible with almost all recording and data acquisition systems.

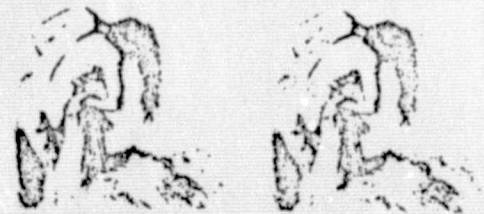
All Model 200 sensor assemblies are now supplied in the "Clip-on" configuration, and may be used by subjects with or without corrective spectacles. In addition, three-way vernier adjustment of each sensor assembly facilitates alignment and calibration procedures.

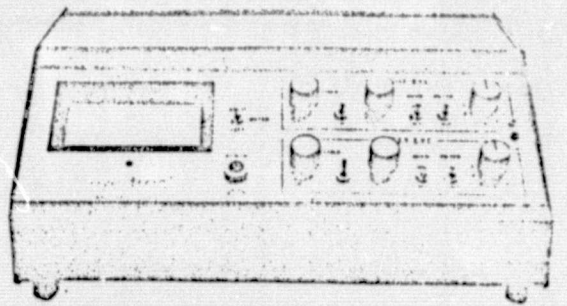
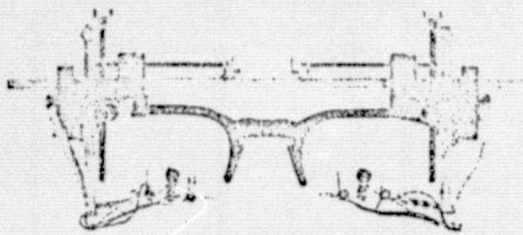
The Model 200 requires only modest set-up and calibration. Preparation consists of placing the spectacle assembly on the subject, adjusting the position of the photoelectric sensors, and setting the front panel operating controls.

## SCAN PATTERN ON X-Y PLOTTER

The Model 200 can be utilized to superimpose a subject's eye movement pattern directly on the viewed material. This is accomplished by placing a copy of the material in the bed of an X-Y recorder and connecting the Model 200 horizontal and vertical output signals to the

respective horizontal and vertical inputs of the plotter. The result of this procedure is an immediately available hard copy of the subject's scan pattern superimposed on the viewed scene.

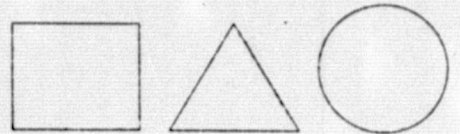




## OUTLINE TRACING

A subject's eye movements may be recorded as he visually traces the outline of geometric figures (after Yabus). This record-

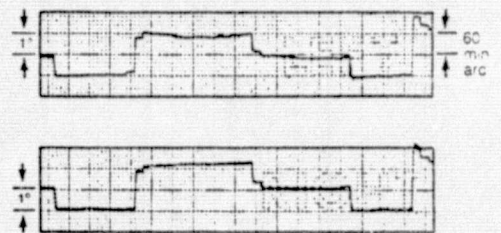
ing was made by the Model 200 Eye Movement Monitor and an X-Y Plotter set-up as described above.



## MINIATURE EYE MOVEMENTS

The Model 200 is capable of reliably measuring changes in horizontal eye position as small as a few minutes of arc. Such measurements do require effective restraint of the subject's head to prevent movement artifacts. The recording shown of a 1° eye movement was made with the subject's head restrained in a Model 115 Head Rest. This particular device

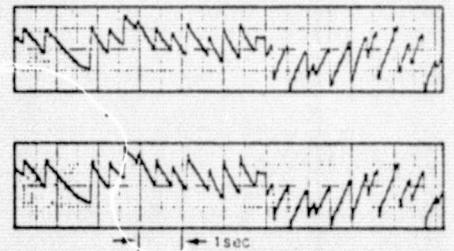
utilized a chin cup rather than the traditional bite plate. The Model 115 head restraint system is much more comfortable than a bite plate and yet fixes the head quite reliably. Furthermore, it does not require the elaborate and unsanitary dental wax impressions necessary with a bite plate.



## NYSTAGMUS

Oscillatory eye movements of both spontaneous and induced types are readily and accurately recorded with the Model 200 Eye Movement Monitor. Nystagmus recordings

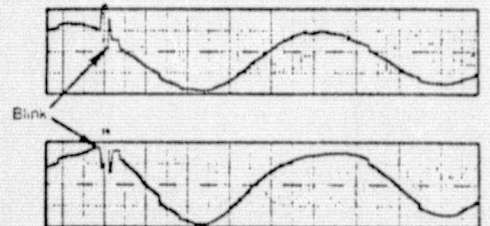
are most useful in diagnosis of neurological problems (tumors, lesions, etc.), vestibular studies, motion and position effects, inner ear malfunctions (Meniere's Syndrome, etc.), and drug and fatigue studies.



## PURSUIT MOVEMENTS

A subject's ability to track a moving target is of significant interest to neurologists, psychologists, ophthalmologists, and human factors engineers. The Model 200 provides for

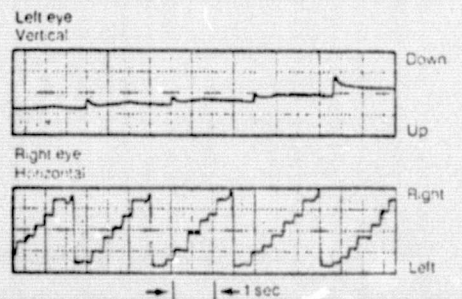
a simple, straightforward and noise-free recording of tracking performance. Pursuit movements, like nystagmus, are most useful in neurological, oculomotor, vestibular, drug and fatigue studies.



## READING PATTERNS

Eye movement patterns produced by reading activity have long been of interest to educators and psychologists. Such patterns are most useful for analysis and research on reading difficulties, learning disabilities, dominance, comprehension, perception and other

aspects of psycholinguistics. The Model 200 produces reading eye movement recordings of truly superior quality. The figure illustrates one such recording in which the left eye is being monitored for vertical movement and the right for horizontal movement.



## TYPICAL SPECIFICATIONS

	HORIZONTAL	VERTICAL	REMARKS
Range (From Center)	±20°	+10° (up) -20° (down)	
Resolution	0.25°	1°	A few minutes of arc possible with rigid head restraint
Accuracy	1°	2°	
Response Time — With Filter	4 milliseconds 26 milliseconds		
Output Signals (Both Channels Simultaneously Available)			Both outputs updated once each millisecond — busy-bit signal during updating
Analog	300 mv /degree		
Digital (Optional)	8 bit binary-DTL /TTL Compatible		
Instrument Drift	10 mv /hr.		
Crosstalk	Adjustable to less than 10%		Controlled by sensor position and electronic controls
Power Requirements	105-125V AC, 50-60 Hz		230-250V AC 50 Hz optional
Weight	8lbs.		
Dimensions	12" wide x 10" deep x 4.5" high		
Artifacts	Blinks (readily distinguished), Squinting		
Accessories & Options (Consult Factory)	Digital Outputs, Optical Sensor Filters, Head Restraint Systems (bite board and chin rests), and Recording-Display Systems		

## ORDERING INFORMATION eye-trac® Model 200

Part Number	Description
719-2001	eye-trac®, Model 200-1 Research Eye Movement Monitor. Analog output, 115V., 60Hz.
719-2002	eye-trac®, Model 200-2 Research Eye Movement Monitor. Analog and digital outputs, 115V., 60 Hz.
719-2004	eye-trac®, Model 200-1 Research Eye Movement Monitor. Analog output, 240V., 50 Hz.
719-2005	eye-trac®, Model 200-2 Research Eye Movement Monitor. Analog and digital outputs, 240V., 50 Hz.
719-2400	PhotoCell Filters, set of 4 (Suppress Fluorescent Light Artifacts).
719-1150	Table Mount Head Restraint System, Model 115.
345-0090	Bite-Board Accessory.

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- Nodine, C.F. & Lang, N.J. Development of visual scanning strategies for differentiating words. *Developmental Psychology*, 1971, 5(2), 221-232.
- Noton, D. & Stark, L. Eye movements and visual perception. *Scientific American*, 1971, 224(6), 34-43.
- Troost, B.T., Weber, R.B. & Daroff, R.B. Hemispheric control of eye movements. *Archives of Neurology*, 1972, 27, 441-452.

## NARCO BIO-SYSTEMS, Inc.



A-57

P.O. Box 12511 7651 Airport Blvd. Houston, Texas 77017  
AC 713, 644-7521 Cable: FISIO/TWX 910 881 6388



NB-S PART NO.	DESCRIPTION	PRICE
719-2001	<u>EYE-TRAC, MODEL 200-1 EYE MOVEMENT MONITOR,</u> Research Model, measures horizontal and/or vertical eye movements. Simultaneously monitors both eyes. Analog Output, Meter readout, 120 volts, 60 Hz.	\$2,935.00
719-2002	<u>EYE-TRAC MODEL 200-2 EYE MOVEMENT MONITOR,</u> Research Model, measures horizontal and/or vertical eye movements. Simultaneously monitors both eyes. Analog and Digital outputs, Meter readout, 120 volts, 60 Hz.	3,315.00
719-2400	<u>PHOTOCELL FILTERS, set of 4</u> (Suppress Fluorescent light artifacts)	
719-1150	<u>TABLE MOUNT HEAD RESTRAINT SYSTEM, MODEL 115</u>	140.00
345-0090	<u>BITE BOARD ACCESSORY</u>	80.00
719-2000	<u>EYE-TRAC, MODEL 200 SPECTA-SENSORS<sup>TM</sup>.</u> Clip-on sensor assemblies, with vernier adjustments. This item is supplied with all EYE-TRAC MODEL 200 Eye Movement Monitors as standard equipment.	815.00

PRICES F.O.B. FACTORY

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NARCO BIO-SYSTEMS, Inc./P.O. Box 12511/7651 Airport Blvd./Houston, Texas 77017/(713)644-7521

Exhibit 3

IIT RESEARCH INSTITUTE

"A systematic and quantitative analysis of oculomotor disorders is directly relevant to the diagnosis and treatment of a wide variety of neurologic disorders. Diseases affecting cerebral cortex, cerebellum, brainstem, all may lead to abnormal eye movements (Walsh and Hoyt, 1969). Accurate characterization of these movements may allow for precise anatomic localization of neurologic disorders, even when the exact nature of the disease process remains in doubt. The following brief list of examples is put forth to illustrate this point.

ANATOMIC LOCALIZATION

OCULOMOTOR DISORDERS

I. Central Nervous System

A. Cerebral Cortex

contralateral, reversible conjugate gaze paresis; disorders of saccadic refixating and smooth pursuit.

B. Cerebellum

ocular dysmetria, flutter, opsoclonus, square-wave jerks.

C. Basal Ganglia

delayed initiation of saccades, hypometric saccades.

D. Brainstem

skew deviation, gaze induced nystagmus, periodic alternating nystagmus, Horner's syndrome.

1. Midbrain

paralysis of upward gaze and convergence-retraction nystagmus; supranuclear accommodation paralysis; bilateral third nerve paresis; intranuclear ophthalmoplegia.

2. Pons

ipsilateral gaze paresis; ocular bobbing; internuclear ophthalmoplegia.

3. Medulla- high cervical cord

down-beating nystagmus.

4. Cervical cord lesions

alternating Horner syndrome cilio-spinal reflex.

II. Peripheral Nervous System

A. Third Cranial Nerve

unilateral ptosis, paresis of superior rectus (upper division); paresis of pupillary reflexes, vergence, accommodation, inferior, medial rectus and inferior oblique (inferior division).

B. Fourth Cranial Nerve

paresis of the superior oblique muscle; superior oblique myokymia.

C. Sixth Cranial Nerve

paresis of the lateral rectus.

D. Eight Cranial Nerve Vestibular Branch

contralateral horizontal nystagmus; ipsilateral impaired caloric response.

E. Neuro-muscular Junction

external ophthalmoplegia with prominent fatigue or facilitation with repetitive movement.

F. Muscle

external ophthalmoplegia with the fatigue response."