AD-A056 791 NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA F/G 17/2
DISPLAY SYSTEM VARIABLES AFFECTING OPERATOR PERFORMANCE IN UNDE--ETC(U)
JUN 78 R L PEPPER, R E COLE

UNCLASSIFIED NOSC-TR-269 NL

1 OF 1
AD A056791

END
DATE FILMED
9-78
DDC

LEVEL II

NOSC

NOSC TR 269

Technical Report 269

DISPLAY SYSTEM VARIABLES AFFECTING OPERATOR PERFORMANCE IN UNDERSEA VEHICLES AND WORK SYSTEMS

by R. L. Pepper, Code 512
Naval Ocean Systems Center

and R. E. Cole
University of Hawaii

June 1978

Prepared for:
Engineering Psychology Programs
Psychological Sciences Division
Office of Naval Research
Arlington, Virginia 22217

Approved for public release; distribution unlimited.

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA. 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

RR GAVAZZI, CAPT, USN
Commander

HOWARD L BLOOD, PhD
Technical Director

ADMINISTRATIVE STATEMENT

The research work described in this report was conducted at the Naval Ocean Systems Center, Hawaii Laboratory, and sponsored by the Office of Naval Research, Psychological Services Division under work unit number 196-150.

Released by
JAMES K. KATAYAMA, Head
Ocean Systems Division

Under authority of
J. D. HIGHTOWER, Head
Environmental Sciences Department

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NOSC TR-269
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)*: Display System Variables Affecting Operator Performance in Undersea Vehicles and Work Systems
5. TYPE OF REPORT & PERIOD COVERED: Technical Report Aug 1977 - Mar 1978
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): R. L. Pepper, R. E. Cole
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Ocean Systems Center, Hawaii Laboratory, P. O. Box 997, Kailua, Hawaii 96734
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Prog Element 61153; Proj No. RR04207; Task Area RR040901; Work Unit NR 196-150
11. CONTROLLING OFFICE NAME AND ADDRESS: Office of Naval Research, Engineering Psychology Programs, Code 455
12. REPORT DATE: June 1978
13. NUMBER OF PAGES: 22
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*
15. SECURITY CLASS. *(of this report)*: Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

stereo viewing; high resolution viewing; television; manipulators

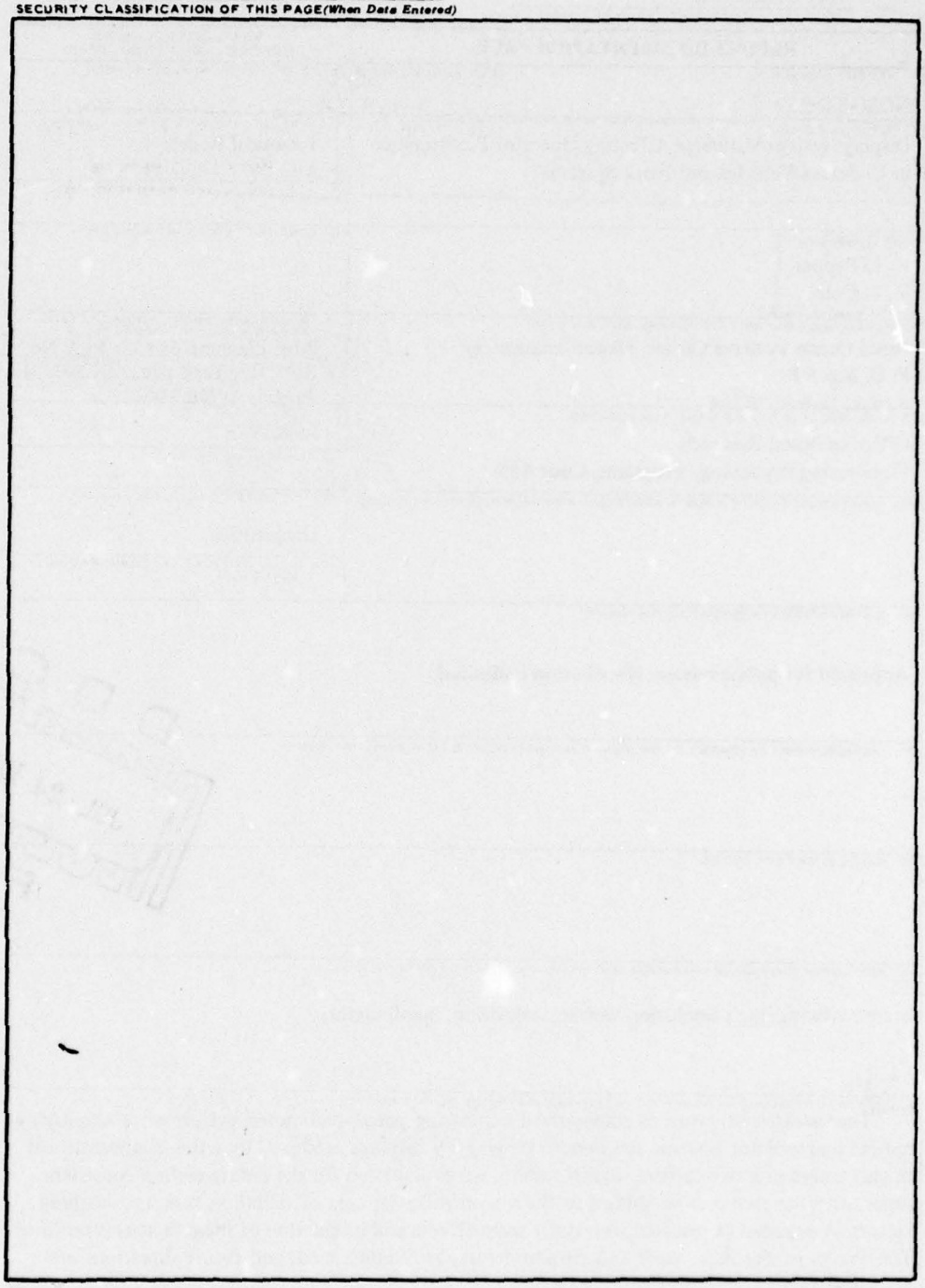
20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The research literature is summarized comparing perceptual-motor performance employing remote manipulator systems and remote viewing TV displays produced by either a conventional single camera or a two camera, stereo system. An explanation for the failure to find consistent superiority for stereo is attributed to the uncontrolled effects of visibility, task and learning factors. A program of research to test the main effects and interaction of these factors is outlined. The results of the first year's and current efforts are summarized, and future directions are discussed.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*



ACKNOWLEDGEMENTS

The authors extend their appreciation to Mr. Gerald Malecki and Dr. Martin Tolcott of ONR for their constructive advice during the conduct of this research.

We also wish to acknowledge the support of various people within and outside the NOSC Perception Laboratory who contributed their expertise. David Smith for the engineering support; John O. Merritt for advice on human visual performance and for comments on an earlier draft of this manuscript; Malia Kamahoahoa for her diligence in gathering the data; the Graphics Branch (Rodney, Paul and Walter) for their hard work and patience in preparing the photos, figures, and tables; and Donna LaRue for her diligent typing skills.

Special thanks are in order for Clifford Chocol and Robert Tewell of Martin-Marietta Aerospace, Denver, Colorado for their assistance and material support during the early phases of our work.

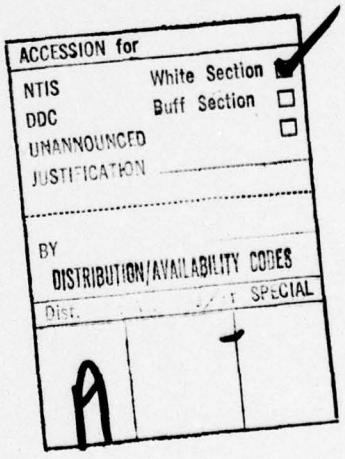


TABLE OF CONTENTS

FIGURES

TABLES

1. INTRODUCTION

A. Review of Literature

Many studies have been conducted to evaluate the various parameters involved in displaying conventional TV information. Biberman (1973) edited and reviewed an extensive body of research on image quality which provides the background to predict the effects of resolution, field of view, contrast, granularity, signal-to-noise level, and a host of electro-optical variables on human perceptual performance.

Pesch (1967) conducted one of the first studies evaluating mono TV vs stereo TV displays for undersea applications. He used two tasks commonly found in underwater operations; the first required direct interaction with an object, i.e., cable handling with a manipulator, while the second required spatial positioning of the manipulator. His results indicated that there was no significant performance difference between mono and stereo on the spatial positioning task. An initial stereo advantage on the cable handling task washed out with repeated testing. Performance decreased under mono, but not stereo condition, when visibility conditions were degraded. Pesch concluded that the advantage given by a stereo display is task dependent, is directly related to the visual environment, and may be sensitive to the repetitive nature of the task.

Hudson and Culpit (1968) conducted a study to assess size and distance judgments using mono and stereo TV displays at different signal-to-noise ratios. Their main results indicated that with highly practiced subjects, there was no significant stereo advantage for targets located 20 to 200 feet from the observer.

A number of studies were supported by NASA to evaluate mono TV and stereo TV displays under visibility conditions encountered in space exploration. In the first of these, Huggins, Malone and Shields (1973) measured detection and recognition thresholds with a mono TV system and compared performance on a distance estimation task using both mono and stereo TV systems. Their results indicate that for a standard 525-line system, the smallest object detectable requires about 2 TV scan lines and subtends about 5 arc-minutes. For form recognition, angular targets are easier to recognize than circles or hexagons; image size must be 25–35 arc-minutes. On the distance estimation task, best performance was obtained with two orthogonal cameras located in the horizontal plane. Both mono and stereo performance improved when they employed a camera angle 45°above the horizontal plane. No differences in performance were found for the various types of TV displays they tested.

Shields, Kirkpatrick, Malone and Huggins (1975) directed their study toward a determination of stereo range resolution using mono and stereo TV*. They found that "range resolution"(judgment of minimum offset of 2 rods for a given distance) could be improved by decreasing the viewing distance to the display, increasing the stereo baseline (camera separation), or by using longer focal length lenses. The authors argue for natural perspective stereo (or orthographic) where both the convergence angle and retinal disparity are the same for the direct view and the monitor view (however, they did not employ natural perspective in their study).

Grant, Meirick, Polhemus, Spencer, Swain and Tewell (1973) investigated display system parameters with a Fresnel stereo display. Although they did not obtain stereo comparisons with mono, important findings regarding camera separation, convergence angle, and field of view were reported. Task time was employed as a measure of performance, where the operator was required to place various blocks in a receptacle. The results indicate that performance is unchanged as a function of separation between left and right cameras for all but extreme separation positions (6-, 12-, and 18-inch separations resulted in similar task times, while 24 inches degraded performance). Field of view was tested from 5° to 30° with a convergence angle of 4.8° and a camera separation of 6 inches. Best performance occurred with 10° to 17° fields of view. The authors recommend a display system with a 2.5-inch camera separation, a 6.8° convergence angle, and a variable 9° to 54° field of view (zoom lens) for their particular space application (even though they did not evaluate camera separation closer than 6 inches).

Tewell, Ray, Meirick and Polhemus (1974) compared mono TV with a Fresnel stereo TV on a depth alignment task using different camera locations and objects of varying size and shape. The results indicated that with equal sized targets, stereo performance was better than mono performance by a factor of 2 under all camera locations tested. However, when rectangles of unequal size were aligned (i.e., when size cues were absent), stereo performance was further improved over mono by a factor of 5. In a second study, they made a comparison between a two-view mono system and the same Fresnel stereo system with variations of camera position and lighting. Tasks consisted of inserting a wooden block into a hole that was 1/16" larger than the block and placing a metal drawer into a 3/16" larger guide. For both tasks, the locations were offset 0°, 45°, and 90° to the horizontal. The authors state that they were unable to draw conclusions comparing mono and stereo performance, due to kinesthetic feedback which enabled the subjects to accomplish the tasks without any visual reference.

In the final NASA-supported study reported here, Crooks, Freedman and Coan (1975) evaluated a wide variety of display systems. Using four manipulator tasks (positioning, coupling, docking, and obstacle clearance), performance was compared with black and white mono, color mono, a two-view system in black and white mono, and an anaglyph (color separated) stereo TV system. The authors selected tasks which they reasoned were representative of all possible operator tasks. The two relevant dimensions of concern were the manipulator-object relationships and the size of the work volume. Tasks were classified

---

*The stereo system employed by this group is one of several excellent techniques for presenting a different video image to each of the two eyes, thus achieving stereopsis. A description of the technique is given in Grant, et al (1973).

into two levels of element relationship (connection/docking and transportation/clearance) and two sizes of working spaces (large and small).

A visual function analysis was conducted to determine the visual scene parameters and basic perceptual operations necessary to complete the tasks. This study is unusual in that it was the first attempt to evaluate the dimensions of the visual environment in conjunction with TV display evaluations. Using a task-analysis method to determine the scene parameters, the dimensions identified were (1) object differentiation – discriminability of objects based upon differences in brightness, color, size, shape, etc., (2) depth precision – a summary of depth cues, such as perspective, interposition, parallax, (3) reference – the cues contributing to perception of an object's orientation and spatial position within the scene, and (4) scene dynamics – primarily the amount of motion present. The results of this study indicate that the coupling and positioning tasks had smaller position errors, fewer contact errors, and required less time than the docking and clearance tasks. The use of a color TV display did not improve performance in any of their particular task-scene conditions, nor did the use of a stereo display. A significant improvement in positioning accuracy was obtained when two mono cameras were orthogonally located in the same horizontal plane. Relatively little effect was found for scene parameters, dynamics, or depth precision. The authors concluded their study by assigning a burden factor to each TV system, comparing them on the basis of cost, weight, volume, power, maintainability and reliability. Recommendations for a two-view (orthogonally positioned) black and white display system are made, based on the results of this study.

In the previously cited study by Hudson and Culpit, the authors stated that they had selected a stereo system which employed a polaroid-separation technique after having determined that the anaglyph, or color separated stereo method was ineffective due to the human eye's response to color of different wavelengths and due to the transmission characteristics of available color filters. They reasoned that a color stereo system using anaglyphs would be even less successful than the previously described system. Unfortunately, the anaglyph system is the type of stereo display employed by Crooks et al. It is not known to what extent this factor contributed to an otherwise comprehensive study. Thus, any conclusions related to stereo performance based on the Crooks, et al data must be evaluated with caution.

Zamarin (1976a), critically reviewed six studies which were concerned with stereo display applications. He concluded that a thorough parametric evaluation of stereo should include the following independent variables: viewing system (stereo TV, mono TV, direct viewing with the unaided eye), camera parameters (stereo baseline separation, convergence angle, field of view), display parameters (display size, viewing distance, resolution, brightness and contrast), stereo channel characteristics (size match, brightness match, vertical alignment, rotational alignment), perspective relationships, and subject variables.

In a second volume of this report, Zamarin (1976b) reported comparative operator performance using three viewing systems (mono TV, cross-polaroid stereo TV, and field-sequential* stereo). He also studied the effects of stereo baseline (camera separation),

*An old, well-proven technique used in map-plotting equipment with rotational mechanical shutters to alternately present left and right eye views; the equipment evaluated by Zamarin uses new electro-optics.

camera convergence angle, and field of view for the two stereo systems. His results indicated that with a 3 rod depth discrimination task, camera separation affected accuracy of performance but not response time (a separation of 7 to 10 inches resulted in the best performance). Camera convergence angle had no significant effects; that is, it made no difference if the convergence point was ahead of, behind, or on the target. Changes in the field of view (magnification of 1.0x, 1.25x and 2.0x corresponding to 28°, 22.6° and 14.25°, respectively) had no significant effects in the depth judgment task. Finally, the polaroid and the field sequential displays resulted in similar performance with both yielding an error factor that was 1/2 to 1/3 that of the mono TV display.

There was no mono field of view assessment. Direct view stereo acuity was 10 arc-seconds, while comparable TV stereo acuity was about 25 arc-seconds, or a factor of about 2.5 poorer. No comparable measures of direct mono and mono TV acuity were obtained.

Zamarin reports that the field sequential and polaroid stereo systems provided comparable levels of performance in the 3-rod depth task despite major illumination differences between them. He suggests that the Fresnel system's reduced vertical resolution (although not relevant to this rod task) may have degrading effects which would be most likely to occur when viewing a complex scene; i.e., involving more varied contrasts and shapes.

B. Implications for Research

Of the eight studies reviewed here, six directly compared task performance using stereo and mono TV displays. Four of the six concluded that stereo provides no significant performance advantage. This fact, when considered in light of other features of the review, appears somewhat contradictory. That is, the literature suggests that the state-of-the-art for producing televised images is high. One can select the appropriate physical conditions and electrical components to produce high quality images. The visual scene parameters have been determined as a function of working space, camera coverage, etc., and much experimental work has been done to understand human perceptual performance under a variety of televised conditions. Add to this the fact that a long past history of laboratory research and applied work in human visual perception clearly shows that stereopsis is a major benefit for tasks requiring spatial localization (Graham, 1965) and for search and recognition tasks where the visual scene must be interpreted and conclusions obtained (Merritt, 1977a). Thus, under televised conditions, it would appear that performance employing stereo viewing would be significantly better than under mono viewing, principally because monocular cues are reduced much more than binocular disparity, the fundamental stereo cue.

What is the basis for this discrepancy? The possibilities which present themselves are these:

(a) Comparisons of stereo-mono have been conducted under optimal visibility conditions where mono-stereo differences might be at a minimum.

(b) Because of unrealistic visual-perceptual task situations (i.e., clearly defined targets and only small differences in the plane of location), only small stereo advantages would be predicted.

(c) Failure to control learning effects which occur with repeated trials, especially with a static task scene, would ultimately result in performance relatively independent of visual feedback.

(d) Poor quality stereo displays (compared to a mono display) and the interaction of poor quality displays with (a), (b) and (c) could well result in inferior stereo performance.*

In light of the review showing that stereo displays offer no consistent performance advantage, a careful analysis of these variables associated with the remote performance of manipulator tasks is in order. We, therefore, address these factors in the following sections.

2. ANALYSIS OF PERFORMANCE FACTORS

A. Visibility Factors

One of the most promising hypotheses to be tested in our laboratory is the idea that stereo TV provides a greater advantage over mono TV as visibility conditions deteriorate. This has been true in the interpretation of aerial photography, where stereo becomes essential when the imagery is degraded by haze, low luminance, graininess, and so on. Similar reductions in normal visibility can occur as a result of the particulate matter in the seawater. The back scattering of light caused by particles in water creates a condition of veiling luminance which acts to reduce the contrast between the object of interest and the scene background. Particles also create visual noise, which contributes to a reduction in picture resolution. Finally, the movement and settling of particles on the ocean floor create a cover which reduces edge and contour details of objects, essentially camouflaging them from view (Merritt, 1977b). We, therefore, have proposed a research program that will test operator performance on a number of remote manipulation tasks under three levels of visibility; (a) clear (the best image quality that could be obtained with laboratory TV systems), (b) medium visibility degradation and (c) heavy visibility degradation.

The properties of closed-circuit TV systems make the problem of specifying visibility different from the usual optical measurement paradigm. The TV operator can compensate for a low contrast image at the camera faceplate by adjusting gamma or gain in the camera, or by adjusting brightness and contrast in the monitor. This permits expansion of a light gray and a dark gray into full black and white with a contrast transfer better than 100% at the monitor screen. There is a limit to this type of contrast enhancement, however, and when a given camera/monitor system has reached its limit, a gray and washed-out image may be the best an operator has to work with. Each combination of TV camera/monitor, lighting/geometry, water properties will show a different quality of image on the monitor,

*Note: The engineering effort and optical precision necessary to maintain a good quality stereo image far exceeds that required for a conventional display. Most people are unable to recognize poor stereo or even reversed stereo, yet they are quick to notice deficiencies in conventional TVs. Julesz (1977) recently reported that in a quality control task where the operator used a binocular microscope to check for defective integrated circuits, the majority of the operators were unable to maintain appropriate stereo calibration of the microscope. To overcome this deficiency, Julesz placed random-dot stereograms on test plates of i.c.'s so that the operator could verify the binocular alignment.

and thus, a given screen image quality cannot be linked to a particular attenuation coefficient or scattering coefficient. What counts in the final analysis is the image delivered to the operator, and this is the image which we propose to vary in quality in order to determine the effects of visibility on performance. The image on the TV monitor will be measured in terms of luminance of the imaged reproduction of a known target placed in front of the cameras. Specifications for setting up the proper brightness and contrast on the TV monitor will ensure that all subjects receive the same visual input for each of the conditions.

The most promising way to relate levels of visibility used in our research to underwater optics is through the powerful and versatile method of modulation transfer function (MTF) analysis. We can assume that the MTF of the overall system is equivalent to that used by our research subjects and is given by the system's MTF curve. When a remotely manned system in the real world encounters water conditions which interact with its imaging system to produce a particular quality of imagery on the monitor, then operator performance can be predicted by the MTF of the monitor image. See Funk, Bryant and Heckman (1972) for an application of the factors affecting the monitor characteristics. Backscatter is the primary degrading factor in most remote system operations in the underwater environment, and is even more exaggerated in those systems that use their own illuminant sources. It is fairly easy to simulate and measure backscatter, since the MTF of a veiling luminance is simply a straight line showing equal contrast reduction for all spatial frequencies, regardless of the fineness of detail or the size of a dark area. Mertens (1970) provides an excellent and extensive treatment of the various component MTF's which cascade to produce the final overall system MTF in the underwater imaging situation. Since backscatter effects cause a veiling luminance which reduces contrast of both large and small detail equally, it can be controlled by means of the camera/monitor controls for gain and contrast. These can be adjusted to set the luminance levels of a white and black square calibrated by a luminance meter.

While veiling luminance conditions produce the major visibility degrading conditions underwater, other factors contribute to problems associated with scene "interpretability", or "perceptability". They are: (1) visual noise produced by large particles which are disturbed by vehicle thrusters or dislodged from objects by working manipulators, and (2) the way marine growth and siltation may camouflage objects which are being searched for visually via remote-viewing systems.

Because of these considerations, we feel it is important to go beyond simulation and performance testing of the usual optical limits of contrast transfer (MTF analysis) underwater and extend our research to consider particle noise and camouflage effects as well.

B. Task Factors

A second item of major importance in this research is the type of task that the operator must perform. For example, a major demand on the operator has to do with interpreting. or "making sense" out of, details within the scene. This is the cognitive process which occurs in making a judgment about the identification of and the spatial position of various components within the scene. (If the operator is viewing the scene in mono, the analysis of

of the scene can be time consuming and demanding.) A statement often heard from operators of remotely manned systems when using conventional TV is that, "we just couldn't figure out what we were looking at". Few of the studies reviewed considered this or other levels of analysis demanded of the operator in the sequence of tasks he has to carry out. Nearly all situations require that the vehicle operator find an object (or working area), recognize the orientation of the object with respect to the bottom and the vehicle, and then position the vehicle in such a way that operations specific to the use of the manipulator can be carried out. Thus, a general analysis might take the following form:

1. Where is the target area located in space? The answer provides the operator with information to position the vehicle or camera in order to obtain the best viewing location possible and to center the object on the visual display.

2. What is the object? This is basically a discrimination task. The operator must know the characteristics of the object and must be able to discriminate it from all other objects in the environment. The objects could be encrusted with natural camouflage; i.e., barnacles, plant growth, fish, etc.

3. What operations must be performed on the object? The answer to this question will determine the spatial positioning required to bring to bear the appropriate manipulators and specific tools at the operator's disposal.

While the problems encountered by the vehicle operator in accomplishing the first two steps of the sequence described above are not uninteresting, most laboratory research efforts typically commence at step 3. We have followed this convention, at least in the initial stages of our research.

Our approach was to conduct an analysis of the task factors involved at step 3 in order to determine the fine-grain perceptual-motor requirements imposed on the operator by the combination of the task mission and visibility conditions. We first constructed an inventory of operator tasks based on a review of the literature, evaluation of video tapes from actual undersea operations (extracted from the NOSC video tape library, including RUWS, WSP, and the integrated LOSS operations), and interviews with experienced NOSC remote vehicle operators. These tasks were then assigned to one of three categories based on commonalities of their major perceptual-motor requirements. Finally, we selected one task from each of the three categories which, based on conclusions from our work, was most representative of a class of tasks. The task categories, the three selected tasks, and selection rationale are presented below.

Category 1. Tasks in this category include drilling, stud gun firing, tapping, threading, removing bolts, and connecting-disconnecting couplers. These tasks have several common elements; they all require critical alignment of the object of interest and the end-effector. They appear to require little or no change in the sagital plane, and several of them require rotational positioning superimposed on the attitude alignment factor. The major underlying characteristic of these tasks appears to be represented by a task developed by Hill and

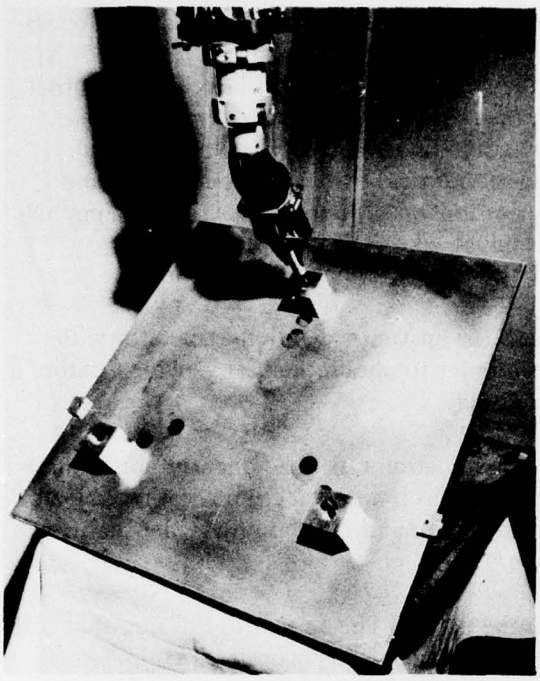


Figure 1. Peg-in-hole alignment taskboard.

his research group at SRI. (See Figure 1.) This task has been termed "Peg-in-hole", and variations can be employed which systematically increase the degree of constraint for attitude alignment, and rotational and translational movements of a fitting task. (See Hill, 1977, for further details.)

Category 2. Cutting a cable, attaching a J-hook, and attaching a cable clamp are examples of Category 2 tasks. These tasks all require relatively large movements of the end-effector or tool in the sagital plane in order to acquire the cable or attachment point. Implicit in the perfomance of these tasks is the recognition of the appropriate position point or cable, the proper alignment of the tool with respect to other objects, and the potential hazards associated with contacting the manipulator with adjacent or otherwise impeding cables, lines, or objects. This task involves the perception of changes in the sagital depth plane, as well as in the horizontal position. Selecting appropriate routes through a maze of potentially interfering components may make this task extremely difficult or impossible without the depth information conveyed by stereo. We are in the process of designing an appropriate task which includes these essential features.

Category 3. Line feeding, simple attachment, and manipulator positioning for sample retrieval are representative of Category 3 tasks. These tasks require the perception and utilization of information regarding changes in the sagital plane, as well as in the horizontal plane. While positioning requires attitude and depth alignment, the relative seriousness of conflicting visual components is not as severe as in Category 2. Therefore, the available monocular cues may be used to greater advantage without the potentially hazardous effects associated with the above described task. We have constructed a model which is composed of multiple loops arranged in a complex configuration. Pilot data from this apparatus produce satisfactorily reliable data for response time and errors.

Visibility-Task Interaction. While there are many factors which contribute to reduced visibility in the underwater world, their effects on performance are dependent on the type of visual information that is necessary to perform the specific task. Thus, poor visibility might differentially lower performance on a task that requires spatial judgment and a major difference between mono and stereo might be evidenced. However, on tasks involving scene interpretation, mono TV performance is very poor, even with good visibility. Thus, conditions which degrade visibility may well not have a measurable effect on mono performance because of a "floor" effect. In other words, if things are all that bad, they can't get worse. Performance would be expected to improve with the use of stereo in both spatial localization and interpretation tasks, especially when employing a stereo display system which does not degrade resolution and might even enhance it due to an improved signal-to-noise ratio in the fused stereo percept. In these cases, stereo might be expected to provide an excellent advantage, since in stereo, the noise is uncorrelated while the target objects are correlated; noise is not able to significantly disrupt the binocular depth percepts. The random dot stereo patterns by Julesz (1971) models the randomly distributed marine growth and siltation which camouflage objects on the ocean bottom. Just as the random elements in Julesz's stereo patterns are discarded by the brain, the randomly distributed marine growth elements will not hide objects from observers employing stereo displays. Since the observer need not recognize an object from monocular cues before seeing its shape, the stereo registration will still convey depth, curvature and shape information.

C. Learning Factors

Learning is a pervasive phenomenon which occurs under both real world and laboratory conditions. Generally, the performance improvement which results from repeated trials is attributed to learning. A careful analysis is required to describe the particular dimensions of the learning components of specific tasks. However, a general summary of the outcome of repetition would conclude that perceptual-motor links are established, motor-skills which are basic to the controller-manipulator operation are learned, and often a discrete spatial mapping of the visual task area becomes associated with the operators' actions in controlling the manipulator.

In the real world, many tasks require repetition or successive approximation simply because "trial and error" is the final irreducible strategy employed by the operator under most conditions. One must recognize that the opportunity for trial and error learning is costly (either in operating time, or in increasingly risky or unsafe operating conditions). Thus, while the learning effect is not unimportant in the real world, it is in the laboratory that special concern for this phenomenon is developed. This concern is largely due to the frequent use of repeated trial designs which contribute greatly to the reliability of the subject's data. These learning effects are usually controlled using appropriate experimental design considerations to distribute the effects across the major factors of the experiments. It is our contention, however, that both theoretical and practical considerations require a closer look at learning effects and their interaction with task and visibility parameters. As an example, Pesch (1967) reported differences in mono and stereo performances which "washed out" with repeated testing. In order to develop an appreciation for the way in which learning effects become important in research of this kind, the results of Pesch's study will be examined with particular attention focused on possible learning factors influencing performance.

Pesch employed two tasks which differed with respect to the levels of perceptual-motor feedback required for performance. One task was a dynamic cable handling task which required the operator to make manipulator contact with the environment, while the other was a simple spatial positioning task apparently requiring little visual feedback to monitor performance. Performance for these tasks was measured under augmented and non-augmented visual conditions. The augmented feedback consisted of a visual background which included objects of known size, highlights and shadows. These cues are involved in making size and distance judgments. In the non-augmented condition, a homogeneous bottom, with uniform illumination levels, produced no shadows; only the test object was visible in the operator's view.

The results indicate that in the cable handling task, stereo performance was consistently better than mono during day one, regardless of the visibility conditions. Performance on the spatial positioning task showed no mono/stereo differences.

During the second day, stereo performance remained the same on the cable handling task (suggesting that a "ceiling effect" was operating to limit improvement), while mono performance improved under both (augmented and non-augmented) visibility conditions. The improvements in performance were not equivalent. Under augmented conditions, mono performance equalled that obtained with stereo. However, under non-augmented visibility, mono performance still remained inferior to stereo performance. This result is especially evident in the error score data, and is possibly related to the differential (mono-stereo) visual feedback conditions which facilitate learning the task.

The results of this study point immediately to the importance of understanding how learning can have differential effects on performance resulting from both task and visibility factors. They additionally indicate at least one area of interaction between these variables.

3. SUMMARY OF FIRST YEAR'S WORK

During FY 1977 a research project was initiated under ONR sponsorship. The primary purpose was to explore the utility of stereoscopic television as a visual aid in remotely manned undersea vehicle operations.

The first year effort was directed toward establishing baseline mono and stereo performance using tasks of perceptual judgment. An additional goal was the selection and development of tasks which involve hand-eye coordination and the perception of object location in space (i.e., tasks which require the operator to employ continuous visual feedback to position a manipulator appropriately).

Three studies were conducted to evaluate operator performance with conventional and stereo display systems (Pepper, Cole and Smith, 1977). The first two studies involved perceptual judgment tasks (a modified Howard-Dolman depth discrimination test, and Julesz's test of stereopsis deficiency); the third study employed a perceptual motor task requiring end-effector positioning and closure. This third task was designed to approximate components of an undersea object recovery task.

The results of studies one and two are presented in Table 1. Stereo acuity performance as measured by the Howard Dolman apparatus indicates that both stereo TV display systems provide adequate information to enhance performance over that given with a conventional mono display. Study two indicates that stereopsis thresholds obtained with Julesz patterns are equal using the Fresnel system and the Field Sequential system, and are no different from thresholds obtained while viewing Julesz patterns directly without viewer aids.

Table 1. Comparison of Stereo Acuity Performance on Two Display Systems as Measured by Random Dot (%Binocularity) and Howard Dolman (Angular/Disparity) Tasks

	%Binocularity (means of 4 subjects)	Angular Disparity in min/sec of arc (means of 5 subject)	
		mono	stereo
Direct	53.4	49.09	11.97
Fresnel	54.0	429.35	220.57
Field Sequential	51.5	426.26	191.32

In study three, conventional TV was compared with the Field Sequential stereo system in displaying a perceptual motor task. Eight males and one female were used in this study. Four of the males had prior experience using manipulators with non-stereo TVs. The female subject was employed to assess the overall effects of experience with repeated testing. A task board was fabricated to provide 11 simulated link attachment points over an area of 4,648.2 sq. cm (61.0 x 76.2 cm). Figure 2 shows the various spatial orientations and elevations of the links from 0 to 30.5 cm above the testing platform. The task board was painted a medium gray, with splatter paint and random dark splotches added to simulate visual camouflage due to marine growth and sediment.

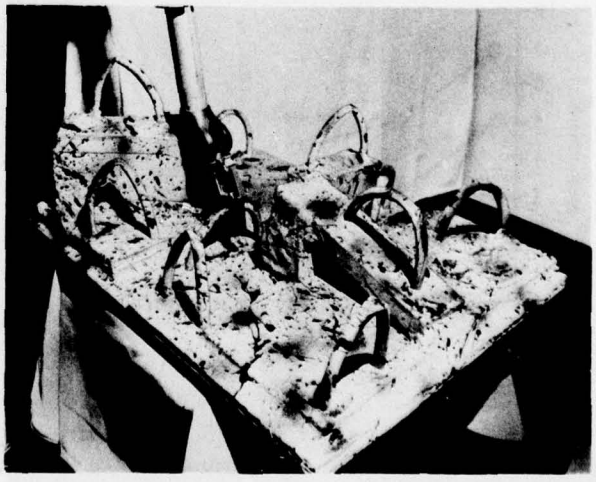


Figure 2. Link taskboard.

A CRL-Model-L master-slave manipulator was employed to achieve the appropriate end-effector positioning and closure response. Subjects were instructed to position the manipulator as quickly as possible and to grasp the link (previously indicated by the experimenter) with a minimum of errors. To reduce the opportunity for spatial learning of the link positions, the task board was systematically rotated to four different positions during the course of each 100-trial sequence. The time elapsed between "start" signal and grasping of the correct link constituted the time scores. Errors were counted as any contact with links (except grasping of the correct links), or other part of the board or incorrect closures. Mean time and error scores are shown in Table 2. Analysis of variance results indicate that the use of a stereo display significantly reduces both response time and errors on this perceptual-motor task. There was no significant difference between the experienced and the inexperienced subjects.

Table 2. Mean Task Completion Times and Mean Errors for Mono and Stereo TV Displays

	Mono		Stereo	
	Errors	Time	Errors	Time
Experienced N=4	1.75	7.20	1.23	4.31
Inexperienced N=5	2.05	7.42	0.65	4.63

The naive subject who conducted repeated tests over five days initially showed the poorest performance compared to all other subjects, but by day 5 was performing as well as the experienced operators. Figure 3 presents the five-day results. It can be seen that a learning effect does occur despite the spatial rotation of the task board and the counterbalancing procedures employed. This effect is probably due to the subject acquiring motor-

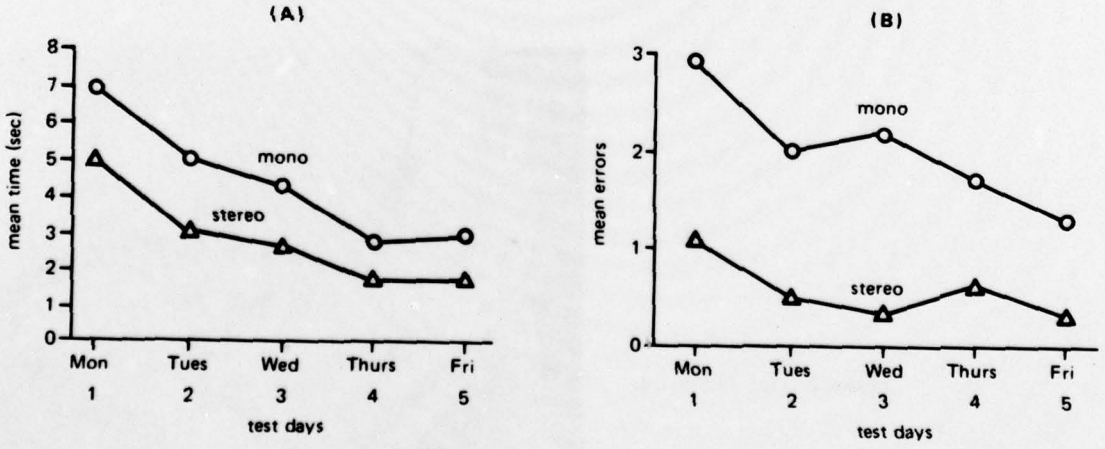


Figure 3. Mono vs stereo link task time scores (A), and error scores (B) with repeated testing.

skills with the manipulator and to learning the four positions of the board. Note that the functions described in Figure 3 evidenced no interaction effect; that is, improvement in performance occurs equally under both mono and stereo conditions.

From the first year's research activities, it seems clear that there is a loss of depth information when a three-dimensional arrangement, such as the Howard-Dolman apparatus, is televised (either in mono or stereo), but not when random dot patterns displayed on two dimensional cards are televised. Although there was no difference in performance on either task due to TV systems used, the systems differ in a number of ways. The Fresnel display appeared to give higher image resolution, thus a more sharply focused image which subjectively seemed to be less prone to a deterioration in picture quality than the Field Sequential display. This deterioration was due primarily to the result of a reduction in brightness and the flicker introduced by the glasses of the Field Sequential display. The fact that the Fresnel display required a rigid, fixed posture appeared to result in greater fatigue than the free head positioning permitted by the Field Sequential display. Although it was not a factor in these two studies, the restrictions of head position would have an additional disadvantage in perceptual-motor tasks where large arm or body movements are required. It was mainly for this latter reason that the Field Sequential display was selected for use with the perceptual-motor task in study three.

4. CURRENT EFFORTS

Our current efforts are concentrated on developing reliable controls of the visibility and task factors that were described in detail above and in adapting experimental designs and statistical analyses to permit assessment of learning effects and their interactions with visibility and task factors. The near term goal is to compare performance using mono vs stereo displays under high, medium and low visibility conditions for the three types of tasks previously described. The hypothesis underlying this line of inquiry is that conditions which degrade visibility will contribute differentially to mono and stereo perceptual performance. Figure 4 presents this prediction graphically. Regardless of how well an

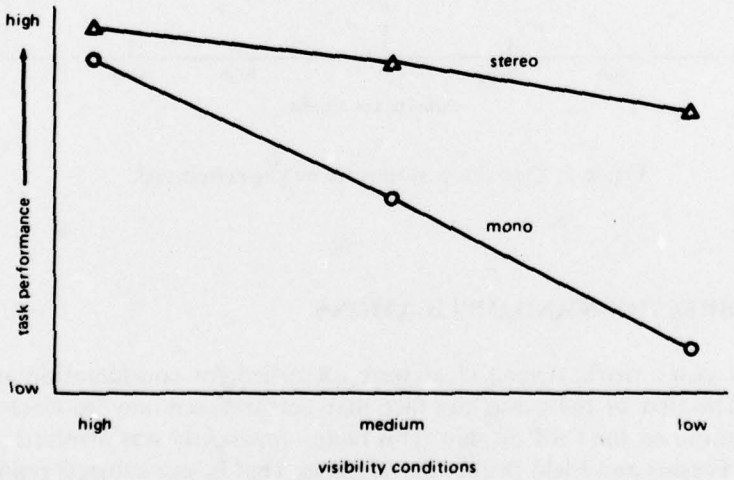


Figure 4. Predicted mono vs stereo performance under three levels of visibility.

operator might perform under clear conditions with a mono display, his performance will fall off at a greater rate than with a comparable stereo display as visibility is degraded. The basis for this prediction is the fact that mono cues of relative height and size, linear perspective, and light and shadow will be lost before binocular disparity (the cue which underlies stereo) is lost.

In a pilot experiment to test the above hypothesis, two subjects were run under conditions of high and low visibility using mono and stereo TV to position a manipulator. Fifteen trials in each condition resulted in the performance depicted in Figure 5. The data points are the arithmetic mean values for each of the four treatment conditions. These preliminary data suggest that there is an increase in stereo advantage as visibility is degraded. This result is consistent with the notion that mono and stereo performance is disrupted differentially by degraded visibility. Further exploration of this phenomenon is underway using a more complex version of the link task, a larger subject sample, and a more rigorous visibility simulation procedure. Since completing the pilot project, we have developed a method which permits a trial-to-trial change of visibility levels (contrast ratios) at the TV monitor while holding overall luminance levels constant.

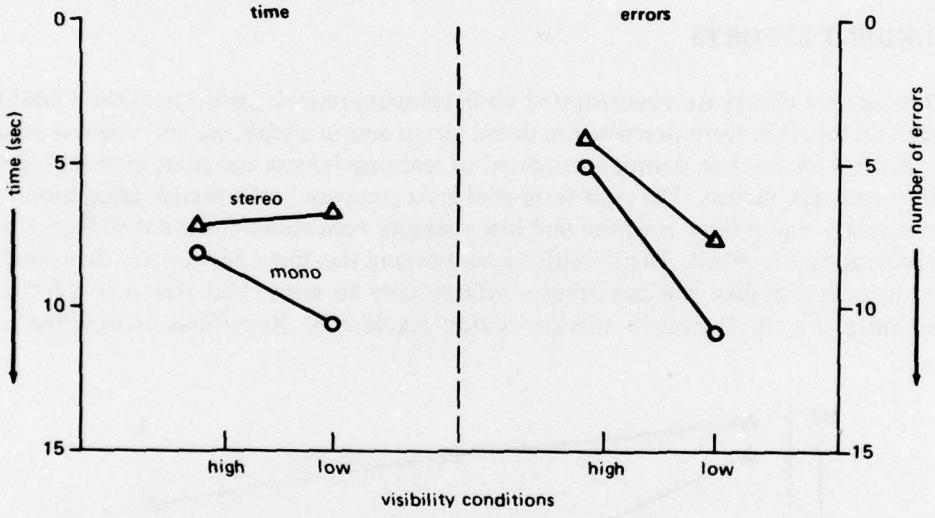


Figure 5. Operator performance on peg-in-hole task.

5. FUTURE DIRECTIONS AND IMPLICATIONS

In our first year's work, several ideas were identified for consideration and future investigation. The first of these was the fact that performance may be enhanced with increased resolution on the CRT display. This factor apparently was involved in the studies comparing the Fresnel and Field Sequential displays. That is, our subjects reported that the picture quality was significantly better with the Fresnel than the Field Sequential display. Grant et al (1973) indicate that a primary advantage of the Fresnel stereo display over all

other stereo displays is its inherent high illumination efficiency and high resolution capability. While the movement restrictions imposed by the narrow exit-pupil operative is theoretically limited to 6.35 cm (the interpupillary distance of the eyes) regardless of display size, a pupil-spreading technique employing a lenticular screen appears to enable vertical head motion on the order of 30 cm. This advanced stereo system has been assembled by NASA's Marshall Space Flight Center for use in the space shuttle program. To date, no experimental work with this system has been reported. We plan to obtain and evaluate this system systematically.

Implications

At this point, it is not unreasonable to ask how the results of this line of research apply to problems faced by those charged with the actual conduct of undersea assignments. The following are logical implications which need emphasis:

1. Reduced search time for location of target. This is especially the case for unfamiliar objects or those obscured by other objects or sediment.

2. Increased accuracy and reduced time for positioning vehicle (results also in reduced disturbance of bottom sediment and subsequent time spent waiting for water to clear).

3. Reduced reliance on "contact" feedback which might damage target object, put it in a more difficult recovery position, or result in dropping tools.

4. Increased accuracy of tool positioning and manipulation. We expect that all of these effects will be greatly enhanced by stereo under (a) poor visibility conditions, (b) unfamiliar or obscured targets, and (c) task conditions which require relatively large movements in the forward direction, a high degree of accuracy without "contact" feedback and single operation tasks where trial and error is unavailable to provide immediate perceptual motor learning experiences.

REFERENCES

1. Biberman, Lucien M. (Ed.), Perception of Displayed Information. Plenum Press, New York, 1973

2. Crooks, William H., L. A. Freedman and P. O. Coan, Television Systems for Remote Manipulation. Proceedings of the 19th Annual Meeting of the Human Factors Society, Dallas, Texas, October 14–16, 1975

3. Funk, G. S., S. B. Bryant and P. J. Heckman, Jr., Handbook of Underwater Imaging System Design, NUC TP 303, San Diego, July 1972

4. Graham, C. H. (Ed.), Vision and Visual Perception. John Wiley and Sons, Inc., New York, 1965

5. Grant, C., R. Meirick, C. Polhemus, R. Spender, D. Swain and R. Tewell, Conceptual Design Study for a Teleoperator Visual System, Phase 11, Final Report. Martin-Marietta Co., Denver, Colorado, April 1973

6. Hill, J. W., Study to Design and Develop Remote Manipulation Systems. SRI Contract Report to NASA, January 1977

7. Hudson, D. E. and G. Culpit, Stereo TV Enchancement Study. Final Technical Report. Kollsman Instrument Corp., Syosset, New York, February 1968

8. Huggins, C. T., T. B. Malone and N. L. Shields, Jr., Evaluation of Human Operator Visual Performance Capability for Teleoperator Missions. Remotely Manned Systems, E. Heer (Ed.). Cal. Tech., 1973

9. Julesz, B., Recent Results with Dynamic Random-Dot Stereograms. Proceedings of the 21st Annual Symposium for the Society of Photo-Optical Instrumentation Engineers. San Diego, CA., 21–26 August 1977

10. Julesz, Bela, Foundations of Cyclopean Perception. The University of Chicago Press. by Bell Telephone Laboratory, Inc., 1971

11. Merritt, John O., Analysis of Turbidity Simulation Techniques. Human Factors Research, Inc., Goleta, California, May 1977a

12. Merritt, John O., A Review of Photo-Interpretation Problems. Personal Comm., August 1977b.

13. Mertens, L. E., In-Water Photography: Theory and Practice. Wiley Interscience, 1970

14. Pepper, R. L., R. E. Cole and D. Smith. Operator Performance Using Conventional or Stereo Displays. Proceedings of the 21st Annual Symposium for the Society of Photo-Optical Instrumentation Engineers. San Diego, CA, 21–26 August 1977

15. Pesch, A., Behavioral Cybernetics Theory Applied to Problems of Ship Control and Manipulator Operation in Small Submarines. Proceedings of the 2nd Marine Systems and ASW Conference. Los Angeles, California, August 1967

16. Shields, N. L., M. Kirkpatrick, III, T. Malone and C. T. Huggins, Earth Orbital Teleoperator Visual System Evaluation Program. Essex Corp., Alexandria, Virginia. Under NASA contract NAS8-30545, 1975

17. Tewell, J. R., A. M. Ray, R. R. Meirick and C. E. Polhemus, Teleoperator Visual System Simulations. Journal of Spacecraft and Rockets, Vol. 2, June 1974

18. Zamarin, D. M., Use of Stereopsis in Electronic Displays. Part 1 - Review of Stereoscopic Characteristics and Application of Stereo Viewing Systems. Douglas Aircraft Co., Report NO. MDC J7084, December 1976

19. Zamarin, D. M., Use of Stereopsis in Electronic Displays. Part II - Stereoscopic Threshold Performance as a Function of System Characteristics. Douglas Aircraft Company. Report No. MCD J7410, December 1976