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IMAGE INTENSIFIER RECOGNITION EXPERIMENT

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ABSTRACT

This report describes an experiment to determine the potential for improvement of the visual performance of a human observer in a recognition task at low ambient light levels using an image intensifier system. The task of the observer was to identify known familiar ship images which had been optically degraded and then subjected to Poisson noise. The experimental variable was the signal-to-noise ratio of the observed images. The observer's performance is compared with the calculated performance of an "ideal detector" utilizing the same input data available to the observer.

CONTENTS

1. INTRODUCTION

Improved image intensifier tubes incorporated in low light level devices, such as the United States Army's Starlight Scope, have caused dramatic improvements in the visual performance of observers using such equipment. Further research and development will undoubtedly continue. In order to effectively control the research and development efforts we must be able to determine the potential performance improvements from the work and the fundamental performance limitations which are imposed by the statistical nature of light.

The Visibility Laboratory recently completed a detection experiment* which experimentally determined the performance of an observer using a Starlight Scope and then compared that performance with the theoretical limit achievable by an ideal detector. The result was a quantitative evaluation of the efficiency of the man/device combination in performing simple detection tasks. The study showed that the man/device does not achieve a performance approaching the fundamental limit, at least in a detection task.

Recognition is a higher order visual task than detection. Is there the same potential for improvement in recognition performance as there seems to be for the detection task?

This report describes the effect of the signal-to-noise ratio upon the performance of an observer in a recognition task at a low light level. A digital computer utilizing the modulation transfer function of a low-light-level device (specifically the United States Army's Starlight Scope) was used to make computer-generated, Poisson noise degraded movies which were then used in the psychophysics experiment. Theoretical calculations were made to predict the performance of an ideal detector which used the same images that were presented to the human observer.

* Image Intensifier System Detection Experiment," by Richard L. Ensminger, Robert F. Howarth, Alma L. Shaules, SIO Ref. 72-60, June 1972.

2. DESCRIPTION OF THE EXPERIMENT

2.1 GENERAL

To simulate the dynamic effect of an actual low-light-level device, the digital computer was employed to generate, frame by frame, a movie film of the degraded noisy target for eventual presentation to the observer. Appendix A provides the details of the preparation of these computer-generated movies. A luminance level of 4×10^{-2} foot lamberts was selected as being typical of the phosphor screen luminances of such devices. In all the psychophysics experiments herein described the observer has been dark adapted to 4×10^{-2} foot-lamberts.

The task of the dark adapted observer was a forced choice identification of the optically degraded, noisy image that is visually presented to him. The targets selected for use in the experiment consisted of scale models of four United States Navy ships; a tanker, a cruiser, and two different classes of destroyers All images were range adjusted to provide the same angular subtense to the observer so that relative size is not an effective clue to correct recognition. The films were generated and shown to the observer in groups of twenty: a two-second presentation followed by a two second response period. All presentations on a film were at a known signal-to-noise ratio. Each of the four known and familiar ships was presented five times in each film in a random order of presentation. A range of signal-to-noise ratios was used in an attempt to insure that the observer's results would vary from chance to being 100% correct.

The original, undegraded, noise free images are shown in Fig. 1. Figure 2 shows the optically degraded images after being subject to the modulation transfer function of the low-light-level image intensifier device.

Each of the degraded, noisy images of a particular target which are generated at a specific signal-to-noise ratio will have the same statistical parameters but will show great variations from frame to frame in luminance values at any specific point. The presentations made for the psychophysics test consists of 32 such unique images which were generated by the computer, preserved on film and then projected to the observer at 16 frames/second. Figure 3 shows, for one such unique frame at each signal-to-noise ratio, the effect of the signal-to-noise parameter. It should be remembered that the reader is viewing one static frame from a movie sequence.

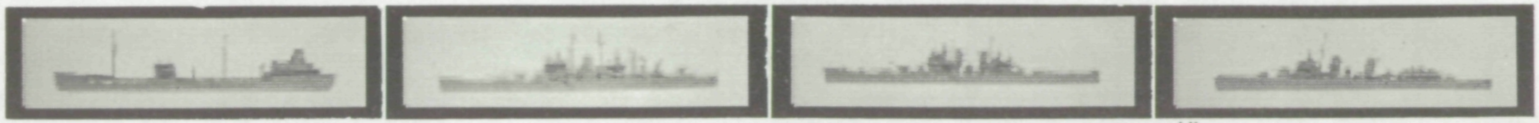
2.2 EXPERIMENTAL TECHNIQUE

A forced-choice technique was used. The observer is informed of the difficulty level of the task prior to each run. After viewing a two-second presentation of the degraded noisy ship's image, the observer has a two-second period in which to verbally record his decision. During the two-second response period the target area is filled with the non-noisy background luminance of 4×10^{-2} foot-lamberts.

A single sequence of a two-second presentation followed by a two-second response period constitutes one trial for one ship at one signal-to-noise ratio. Fifty trials were made for each of the four ships at five different signal-to-noise ratios. The computer calculated the decision for the ideal observer for each of those trials.

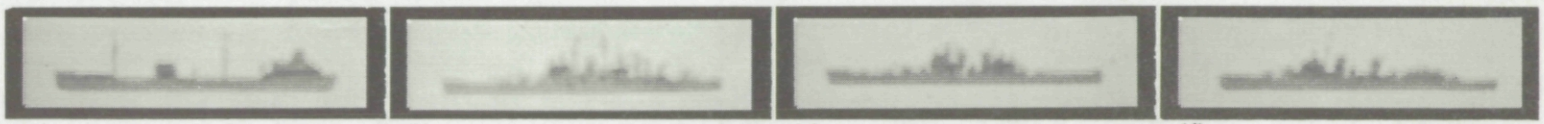
The resulting curves were based upon the performance of one experienced observer with emmetropic vision. In fact, the same observer was used in the "Image Intensifier System Detection Experiment."

Ship No. 1 | Ship No. 2 | Ship No. 3 | Ship No. 4



(a) (b) (c) (d)

Fig. 1. Original, noise-free, relative luminance map of targets.



(a) (b) (c) (d)

Fig. 2. Noise-free, relative luminance map after operation of the modulation transfer function of a low-light level device.

S/N = 3

S/N = .75

S/N = .375

S/N = .15

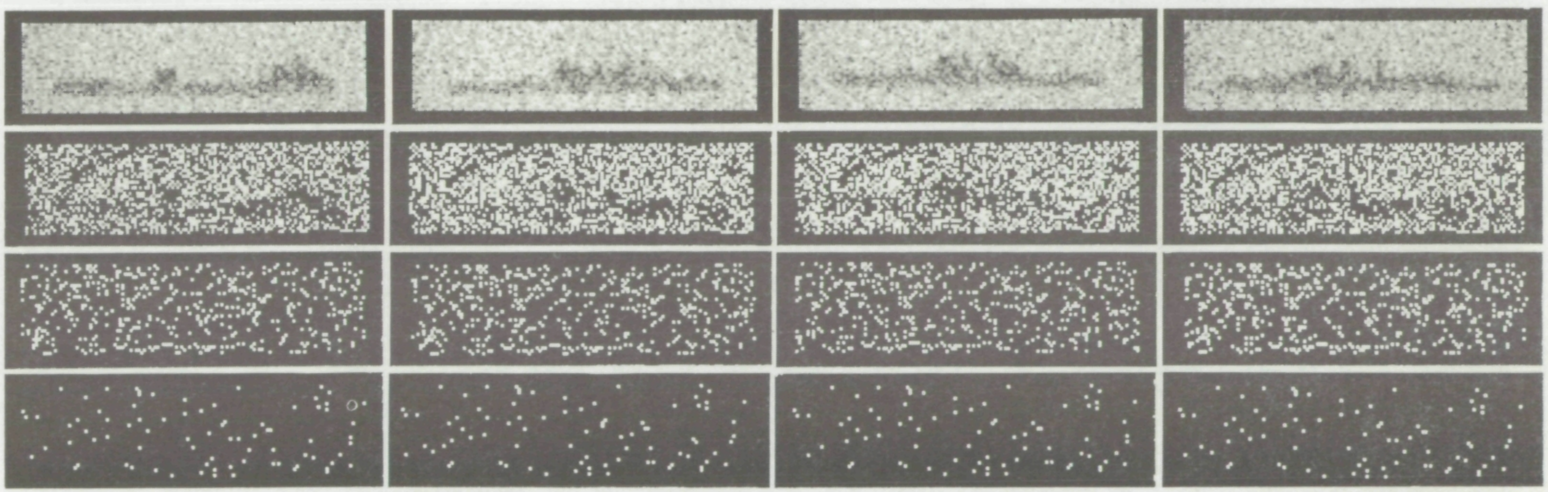


Fig. 3. Relative luminance maps – signal to noise ratios from 3.0 to .15.

2.3 PSYCHOPHYSICS TEST FACILITIES

Figure 4 is a sketch of the psychophysics test setup. These facilities are located in the Visibility Laboratory's Vision Research Branch. The screen of the viewing cube, except for the masked area reserved for target presentations has been adjusted to a luminance of 4×10^{-2} foot-lamberts. The rear screen projection system and the neutral density filters allow the target presentations to be added to the uniform background at the same luminance level.

All luminance levels were measured with both a MacBeth illuminometer and a Gamma Scientific model 721 photometer. Data recording was done with verbal responses into a magnetic tape recorder. All film runs were generated with title blocks and the observer verbally records both the film number and his responses.

The observer is located so that the rectangular target presentation in the center of the screen subtends 256 minutes of arc by 32 minutes of arc. The length of the ship within the rectangle subtends 208 minutes of arc. The total field of view of the screen of the viewing cube is 24° x 24°.

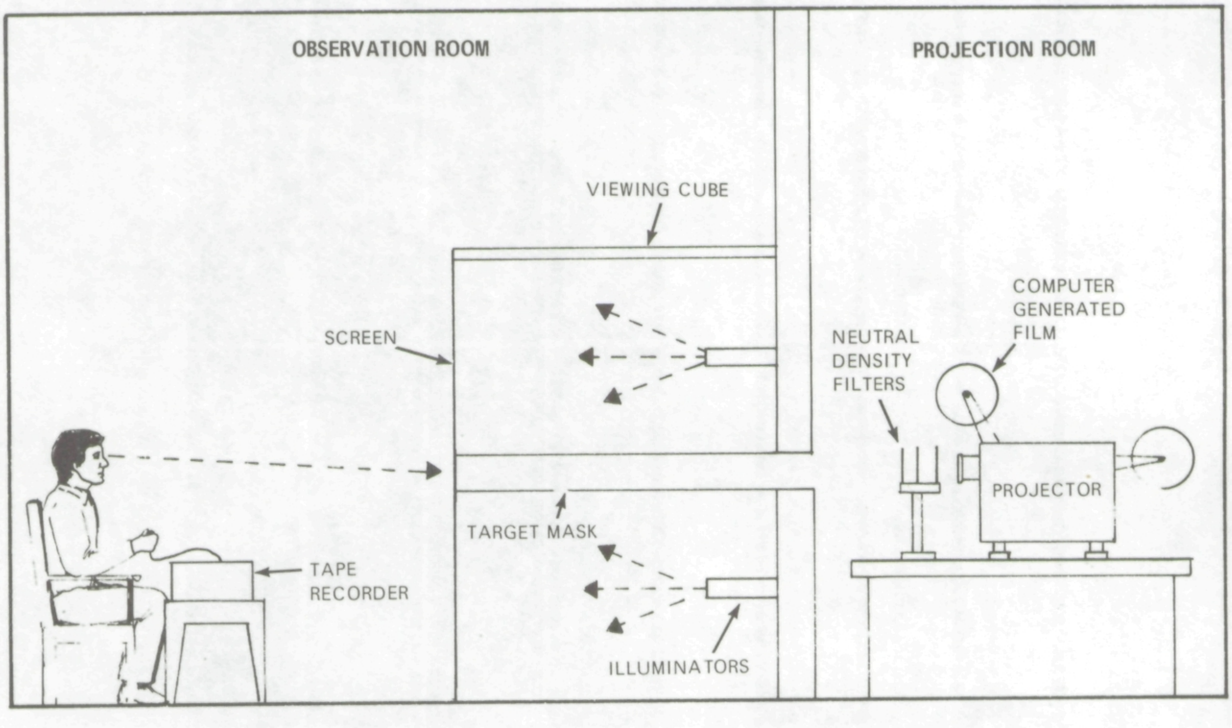


Fig. 4. Facilities Psychophysics Recognition Experiment.

3. RESULTS

The results of this experiment are shown graphically in Fig. 5 to 8. Each figure is the probability of correct recognition versus the signal-to-noise ratio for a particular ship. Each figure gives the results of the observer's visual performance and the results of a decision made by the "Ideal Processor." Each plotted data point is the percent of correct recognition decisions for the 50 trials that were made.

In an effort to determine if the observer had bias for one target over another, Fig. 9 has been given. Figure 9 gives the percentage of times that the observer chose each ship out of the 200 presentations that were done at each signal-to-noise ratio (50 for each ship, 4 ships).

4. CONCLUSIONS AND DISCUSSION

The curves of Fig. 5 to 8 show that the observer is operating near the chance level for a signal-to-noise ratio of 0.15. The ideal observer, on the other hand, made no errors in distinguishing between the four ships under those same conditions. It should be noted that the signal-to-noise ratio of 0.15 was the lowest used in the experiment so that we cannot determine, from this data, the signal-to-noise ratio at which the ideal observer would fail.

There is, then, substantial difference between the performance of the human observer and the ideal observer. This means that for the type of decision used in this experiment, the human observer has a low efficiency of information extraction. This fact, in quantitative form, is the essential finding of this study.

It has long been recognized that the statistics of the number of photoelectrons emitted from an element of an image during the time period of observation determines the detectability of that element of image. It has, likewise, long been recognized that this statistical limitation can be favorably altered by increasing the number of photoelectrons by increasing the size of the collection optics or by increasing the quantum efficiency of the photoemmissive surface.

This report places emphasis on the fact that, even if we are unable to increase the size of the collection optics or make further improvements in quantum efficiency, there is still a potential for achieving improved performance by introducing changes which will increase the efficiency of extraction by the observer of that information which is collected by the image intensifier system.

The author offers the following as possible avenues of exploration relative to achieving this improved efficiency:

(1) The ideal observer performs an integration of the fluctuating photoelectron stream for the full period of time available for the observation. It is well known that the human has only limited capability for performing temporal integration. One possibility then would be to incorporate temporal filtering into the system with the observer able to control the duration of the integration as indicated by his needs relative to his specific viewing problem.

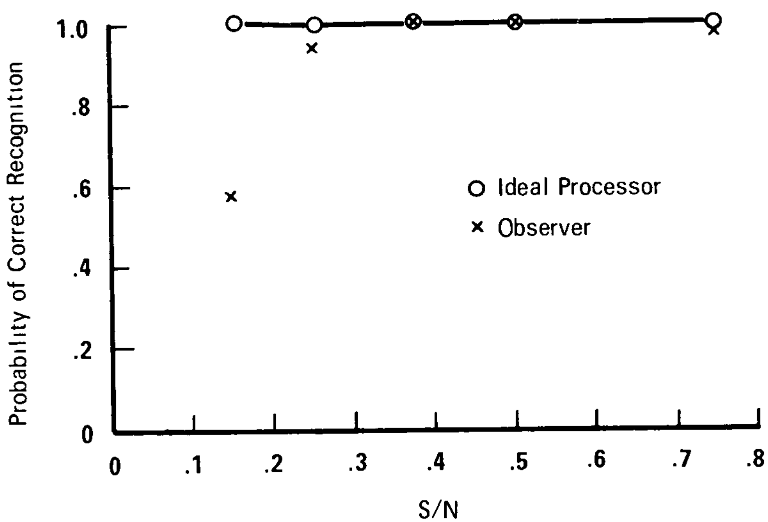


Fig. 5. Ship No. 1, Probability of Correct Recognition vs S/N Ratio.

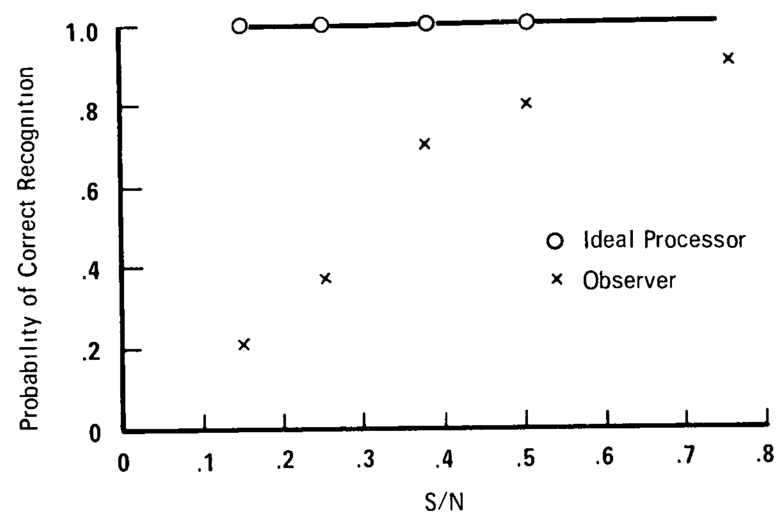


Fig. 6 Ship No 2, Probability of Correct Recognition vs S/N Ratio.

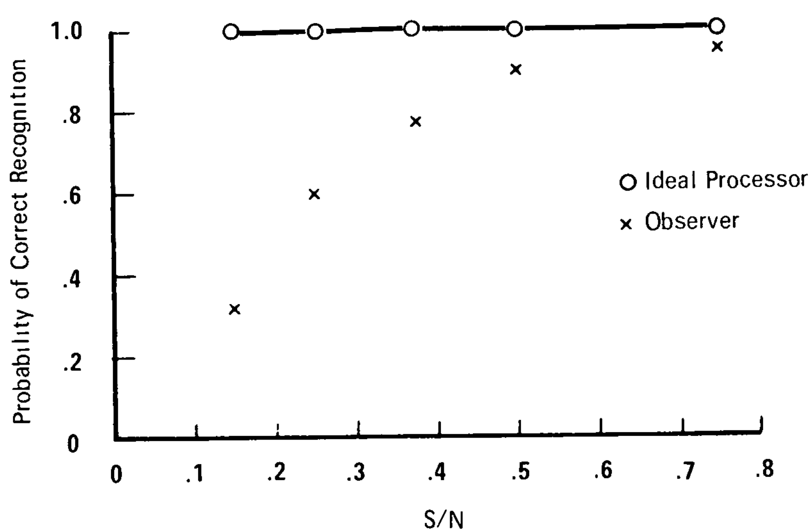


Fig. 7. Ship No. 3, Probability of Correct Recognition vs S/N Ratio

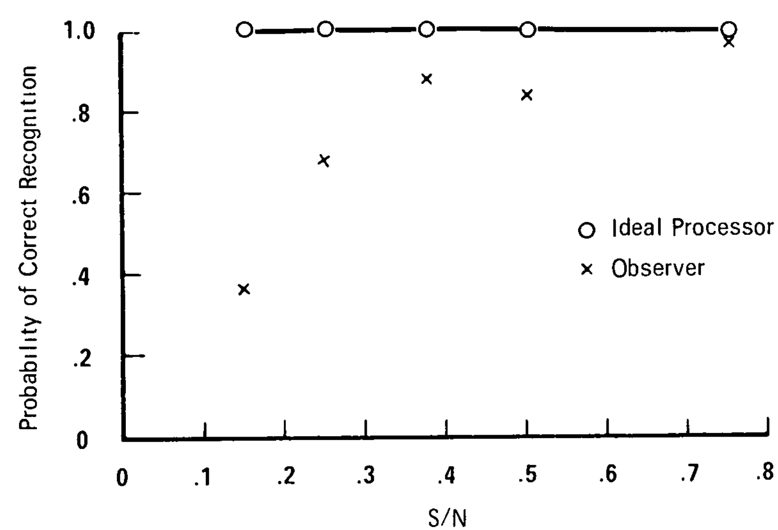


Fig 8 Ship No 4, Probability of Correct Recognition vs S/N Ratio

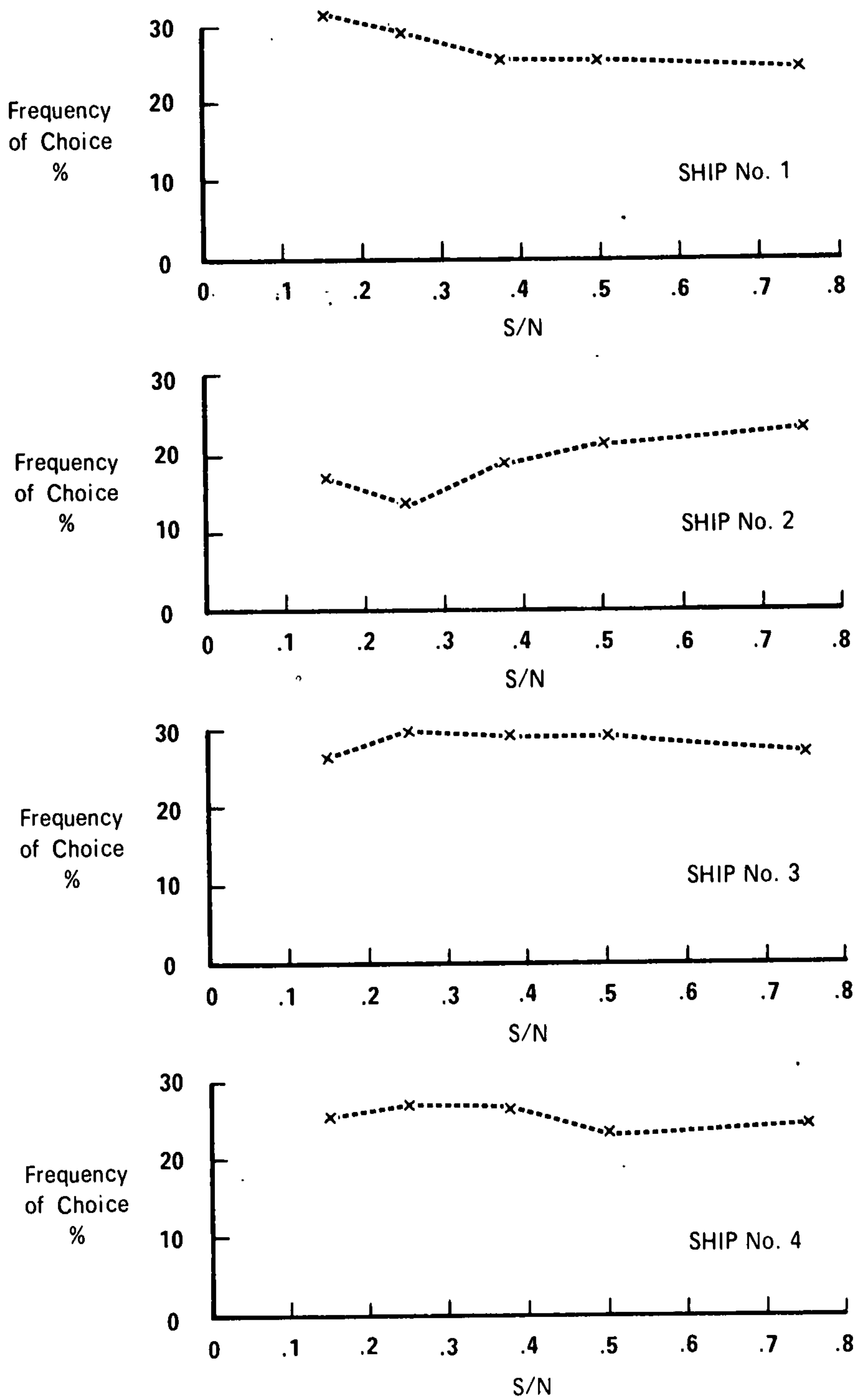


Fig. 9. Frequency of Choice vs S/N Ratio.

(2) It is also well known that the human observer has only limited capability for performing spatial integration in a noisy image. The eye tends to act more like a spatial differentiator rather than an integrator. Spatial differentiation is particularly harmful in a high noise level image. This gives rise to the possibility that the output display should have the capability for spatial integration, the amount of which should be set by the observer depending upon his particular viewing problem. This could be as simple as controlled defocus of the final election image delivered to the output phosphor although more sophisticated spatial filtering could probably be expected to yield better improvement of observer performance.

(3) Another possibility is that the observer fails to see subtle contrast variations in the scene because of continuity breakup associated with the fibre optics coupling plates. Solutions in this case might include techniques of orbiting the image over the fibers both at the input phosphor image and at the output electron image on either side of the fibre.

The suggestions listed above are based upon intuitive and unsubstantiated hypotheses. Experiments could be conducted to evaluate these possibilities. It might be expected that in the course of performing such experiments, further understanding would result and might lead to the development of new techniques above and beyond the simple suggestions offered by the author of this report.

APPENDIX A

Computer Generation of Degraded Noisy Images

COMPUTER FACILITY

The Visibility Laboratory computer installation, shown in Fig. 10 and 11, is an IBM System 360/44. The physical characteristics of the IBM 360/44 are listed below.

UNIT	DESCRIPTION
2044	Central Processing Unit with 1 microsecond, 32K 32-bit word core and disk storage of 1×10^6 bytes.
1442	Card Read-Punch, 400 cards/minute.
1443	Line Printer, 240 lines/minute.
2415	Magnetic Tape Unit, two drives, nine track, 15 000 bytes/second.
2841	Disk Storage Control.
2311	Disk Drive with 1316 cartridge, 7×10^6 bytes.
2701	Data Adapter Unit.
2741	Communication Terminal: One 16-bit A/D converter Two 16-bit contact operate banks Three 16-bit digital input groups Two 13-bit D/A converters

Fig. 10. The IBM System 360/44 Computer.

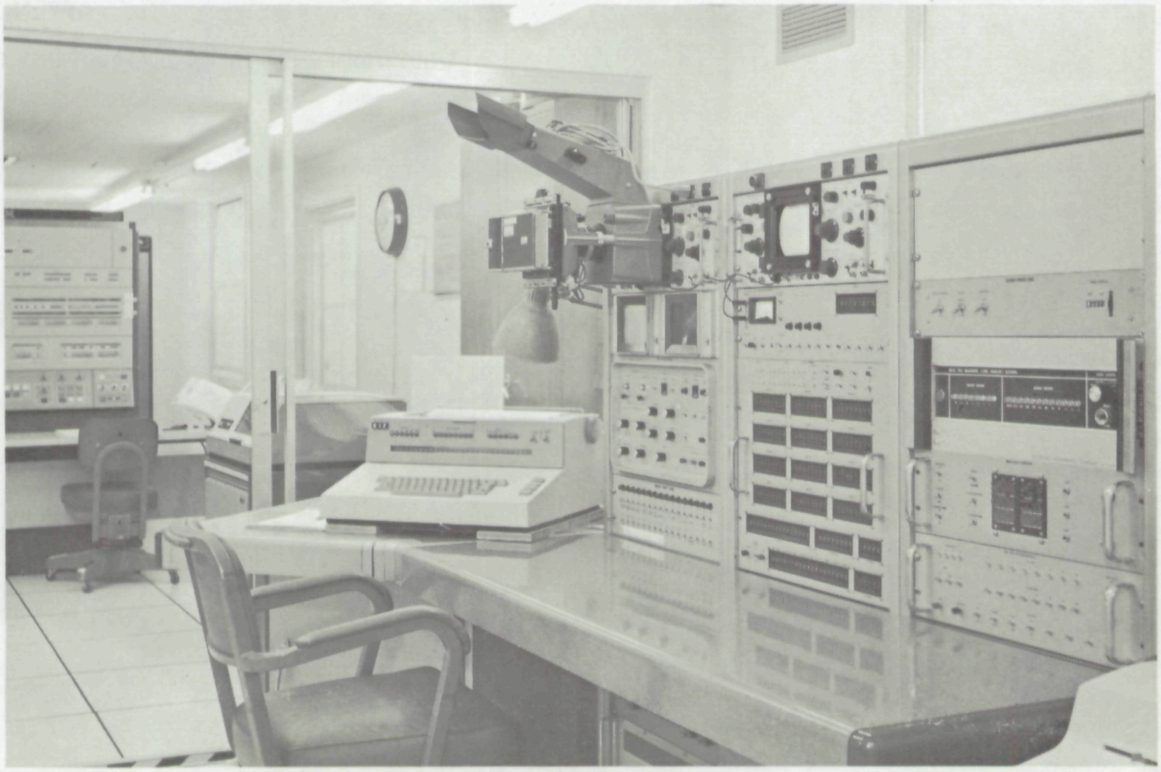


Fig. 11. The IBM System 360/44 Computer and the Refresh Display Console.

COMPUTER PROCESSING

Figure 12 shows a modified block diagram of the software scheme used to generate the films used in the psychophysics experiment. The original relative luminance maps were obtained by making electro-optic scans of photographic negatives of the ship models.

MODULATION TRANSFER FUNCTION (MTF) OF A TYPICAL IMAGE INTENSIFIER SYSTEM

Since a previous detection experiment had been completed at the Visibility Laboratory using the United States Army's Starlight Scope, it was natural to do the computer simulation of that particular low-light-level device. The form of the MTF as plotted from the manufacturer's data was found to closely fit a Gaussian function representable by e^{-ks^2}, where s is the normalized spatial frequency and $k = 10.1$. The effect of this MTF upon the original images has been shown in Fig. 2.

POISSON NOISE

The degraded images $D_i(j)$ were subjected to the Poisson noise process so that each point in the image $D_i(j)$ was considered to be the mean value of a Poisson noise distribution. A sample was taken from each of those Poisson noise distributions and used to establish the noisy degraded image, $R(j)$. The noise level was established by a constant of multiplication on the original image, since the mean-to-variance ratio of the Poisson distribution is equal to the mean.

APPENDIX B

Decision Function for an Ideal Processor

We are given a set of N noise free degraded images which are the relative luminance maps of the target ships after being subjected to the MTF of the image intensifier. We define these N images as:

$$D_1(x,y),\ D_2(x,y),\ \ldots\ D_N(x,y)\ .$$

If we randomly choose an image from this set, we can call it $D_i(x,y)$. The image $D_i(x,y)$ when subjected to Poisson noise results in an image defined as $R(x,y)$.

The task of the ideal processor is to compute the N probabilities that $R(x,y)$ is due to each of the possible N images; $D_1(x,y) \ldots D_N(x,y)$.

The Poisson probability law gives the probability P of M events occurring in a process having a Poisson distribution with a mean of μ.

$$P(m) = \frac{e^{-\mu}\,\mu^M}{M!} \tag{1}$$

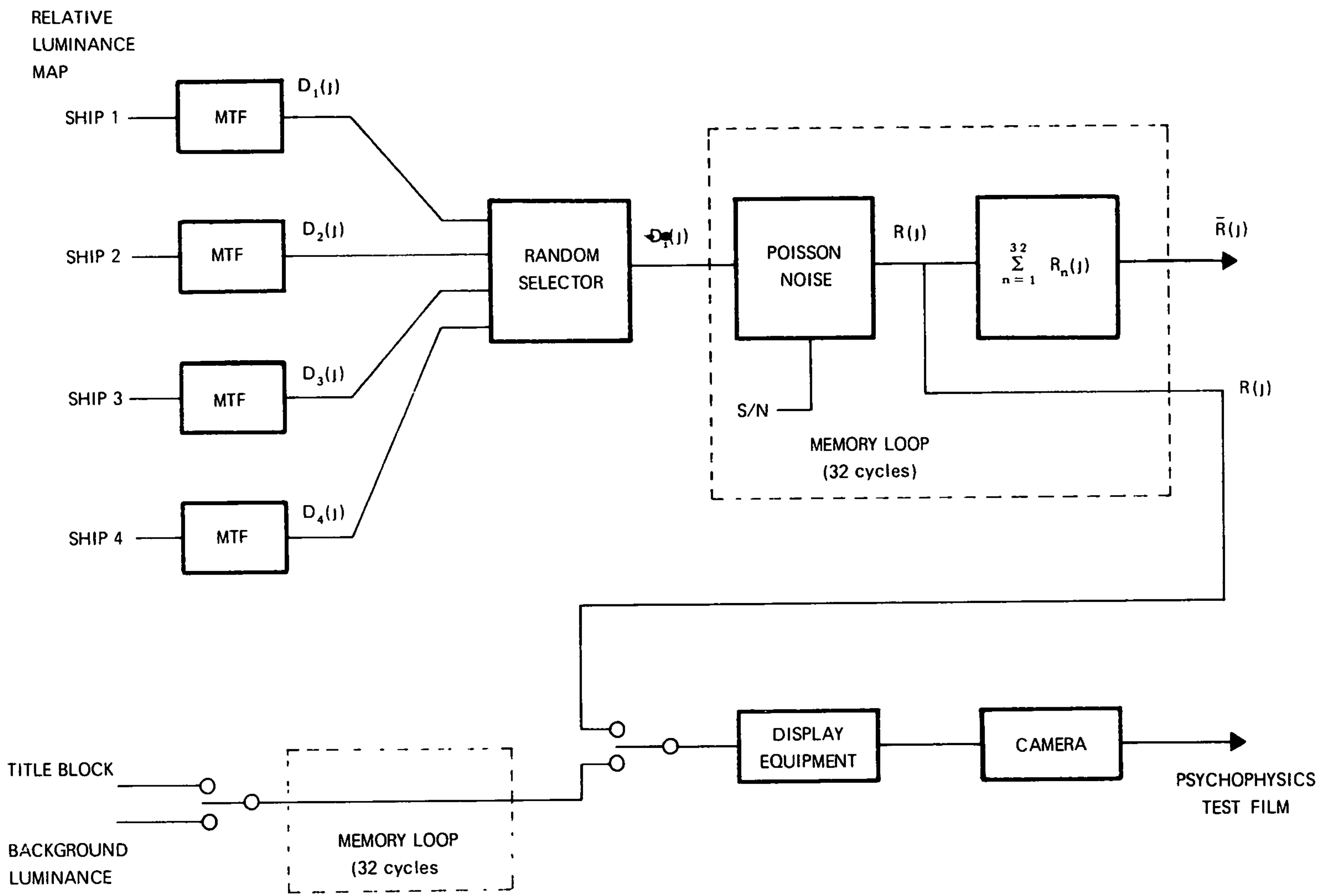


Fig. 12. Block Diagram: Computer Generation of Psychophysics Test Film.

At any one value of (x,y), $D_i(x,y)$ is the mean value of the Poisson noise distribution for that point. The probability of getting the reading $R(x,y)$ at that point is then:

$$P_i\,[R(x,y)] = \frac{e^{-D_i(x,y)}\,[D_i(x,y)]^{R(x,y)}}{R(x,y)\;!} . \tag{2}$$

The probability that all points in $R(x,y)$ were due to $D_i(x,y)$ is, assuming independent noise between points and letting all the picture elements be numbered in some sequential manner so that (x,y) can be replaced by a single index (j):

$$P_i(R) = \prod_{j=1}^{m} P_i[R(j)] = \prod_{j=1}^{m} \frac{e^{-D_i(j)}\,[D_i(j)]^{R(j)}}{R(j)\;!} . \tag{3}$$

Since we are seeking the identity of i, that is, which of the N degraded images is the source of the noisy image $R(j)$, we will compute the probability $P_i(r)$ for all N values of i. Once we have computed the N probabilities, i.e., $P_1(R)$, $P_2(R)$ ... $P_N(R)$, then the one having the largest probability would indicate the most probable source of the degraded noisy images.

A more convenient decision function can be derived from the probability function just described.

$$\alpha_i = \ln\,[P_i(R)] = \ln \prod_{j=1}^{m} \frac{e^{-D_i(j)}\,[D_i(j)]^{R_j}}{R(j)\;!} \tag{4}$$

$$\alpha_i = \sum_{j=1}^{m} \left\{ -D_i(j) + R(j)\ln D_i(j) - \ln\,[R(j)!] \right\} . \tag{5}$$

The term $\sum_{j=1}^{m} - \ln\ [R(j)!]$ is the same for all values of i and so a modified decision function is defined as

$$\alpha_i' = \sum_{j=1}^{m} R(j)\ln D_i(j) - D_i(j) \quad , \tag{6}$$

and if $\sum_{j=1}^{m} D_1(j)$ is the same for all the possible N images then

$$\alpha_i'' = \sum_{j=1}^{m} R(j)\ln D_i(j) . \tag{7}$$

In order to simplify the calculation and still utilize all the information available in the 32 frames that are presented to the observer, the ideal processor will integrate the 32 images on a point-to-point basis. The four decision functions required for each two-second presentation will then be calculated using

$$\overline{R(j)} = \frac{1}{32} \sum_{n=1}^{32} R_n(j) \tag{8}$$

in place of $R(j)$ in Eq. (7). Fig. 13 shows a modified block diagram for the ideal processor.

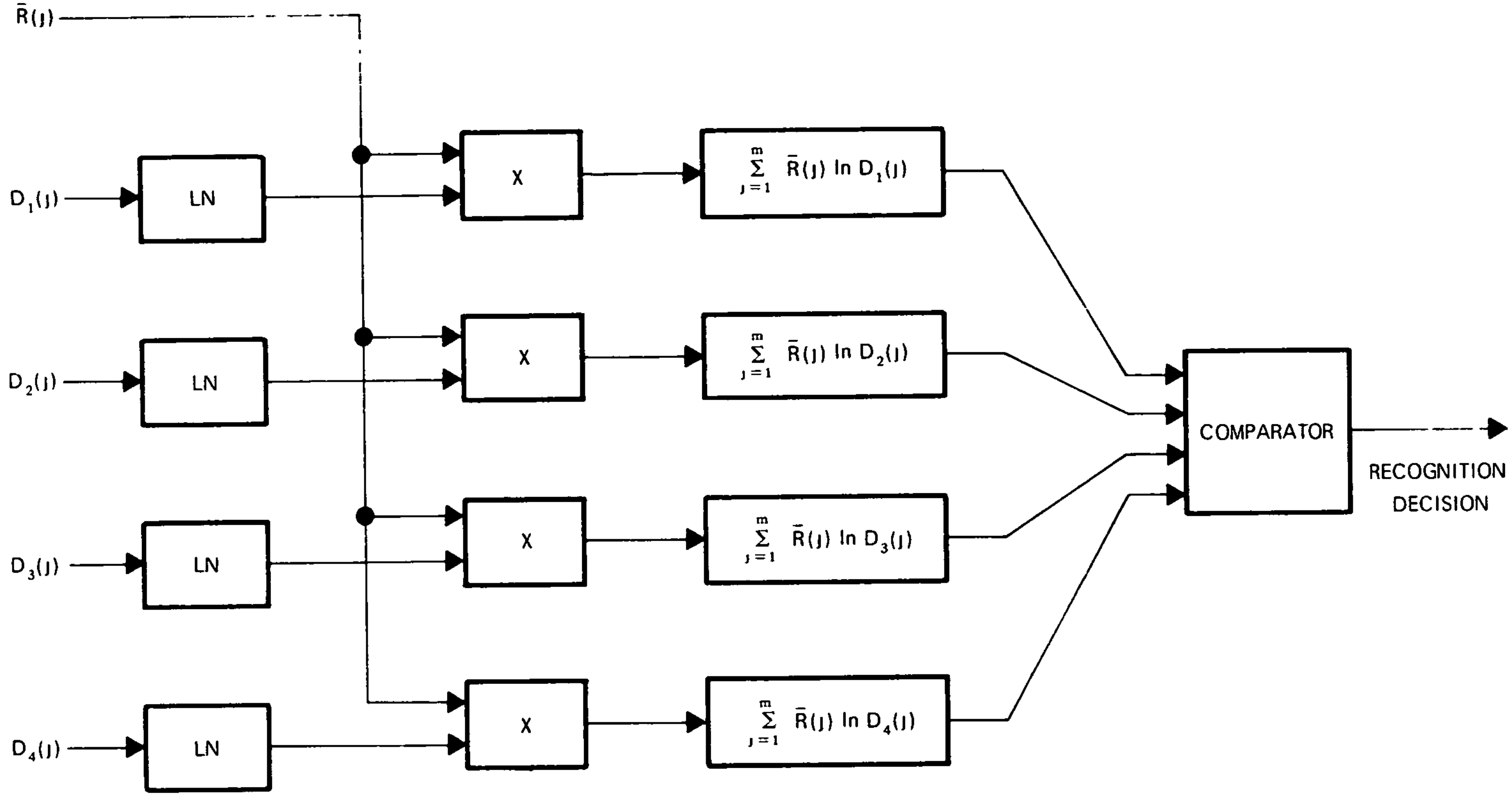


Fig. 13. Block Diagram: Decision Function for an Ideal Processor.

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Image Intensifier						
Visual Recognition						
Optical S/N Ratios						