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Three experiments were carried out to determine the quantitative relationships between FLIR image quality parameters and target recognition. Simulated FLIR imagery was used in each experiment to measure recognition performance as a function of specific image quality variables. The original target imagery was produced by photographing the displayed output of an infrared sensor. A variety of target types and examples were used. In each experiment the original target images were degraded by digital image processing techniques according to specific levels of the

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image quality variables. Experimentation was then carried out in a laboratory situation to measure recognition performance. Data from a total of 43,764 experimental trials were collected and analyzed. The implications of the results of the three experiments to system design is discussed.

The image quality variables investigated in Experiment ~~I~~ 1 were: number of scan lines, modulation transfer function, noise, and magnification. Increasing the number of scan lines improved resolution and therefore resulted in improved recognition performance. Raster sampling was found to dominate performance to such a degree that noise and modulation transfer function had minor roles. Target characteristics, such as size and contrast, were also highly correlated with recognition.

Experiment ~~II~~ 2 investigated the following image quality variables: number of scan lines, scan aperture size, noise, and magnification. Methods of measuring resolution and the effects of target size and contrast were also studied. The optimum scan aperture was found to depend on the scene noise level, with overscanning improving performance in a noisy environment. Magnifying the target image had little effect on performance, unless the image was noiseless or of high resolution. The best predictor of recognition performance was found to be the displayed maximum dimension divided by the system resolution.

In Experiment ~~III~~ 3, the effects of dynamic noise on the recognition of degraded FLIR targets were investigated. The targets were degraded according to the image quality variables of Experiment II. Dynamic noise was simulated by producing and then projecting film strips of the degraded targets. The noise on each 35 mm frame was independent of the noise on the preceding frame. The effects of the image quality variables were found to be highly consistent with those found in Experiment II. Overall, there was an average of 8 percent improvement in recognition at each noise level when the noise was dynamic. Data from this experiment suggest experimental results using static imagery may be extended to dynamic imagery.

PREFACE

This final report was prepared by Honeywell, Inc., Systems and Research Center for the Air Force Avionics Laboratory under contract F33615-72-C-1303, monitored by Burnett Rayner. It describes work performed during the period 13 March 1972 to 10 April 1975. The authors thank C. P. Graf for his useful suggestions and his involvement in obtaining the original imagery and design of the experimental apparatus, K. Graffunder for his contribution to the stimulus preparation and data collection phases of the experiment on dynamic noise, and D. Wesley for his effort in producing the stimuli. The authors also thank J. M. Lloyd for his comments on Experiment I included in this report.

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SECTION I

INTRODUCTION

OBJECTIVE

The overall objective of the Forward-Looking Infrared (FLIR) Requirements Study was to determine how target recognition in FLIR systems depends on variables affecting image quality. The optimum design of an airborne reconnaissance sensor system depends in part on the characteristics of the user of the displayed information, in part on the specific information to be displayed, and most importantly, on the characteristics of the display which presents the information to the observer. Three experimental studies were performed to relate FLIR hardware parameters to operator recognition performance.

Rational system design and cost-tradeoff decisions require that relevant operator performance data be available in terms readily understood by persons responsible for systems analysis, definition, or design. The present experiments were designed, therefore, to have direct relevance for people who specify and evaluate reconnaissance system characteristics. The variables under investigation have been related to display characteristics, and the experimental task closely simulated the recognition conditions of the FLIR mission.

In many operational situations, the operator's main task is to recognize a target which has already been detected. The designer of a system must attempt to specify those characteristics which relate to recognition and to make quantitative predictions about the accuracy of recognition. For a given set of conditions relating to the quality of the display, the main question becomes: What is the probability of recognizing the target? And, as a corollary question: How will the probability change as specific system changes are made?

Our approach to answering these questions was to obtain appropriate data in the laboratory by having subjects respond to stimuli which faithfully simulate imagery in realistic displays. Figure 1 shows the steps involved in this approach. The method used to obtain the original infrared imagery is described in Appendix A. The image processing techniques used to change the image quality of the original imagery are described in the sections discussing each experiment, with more detailed information provided in Appendix B.

Figure 1. General approach.

Each of the three experimental sections begins with a summary which includes the objective of the experiment, the independent variables, and the main results. The method portion of each section contains a description of the experimental design, the apparatus, the procedure, and in Experiments I and II, resolution and target size measurement. The results of each experiment are presented in the respective sections, with discussion of these results combined in the final section.

BACKGROUND

What is target recognition? When we recognize something, we are classifying it in a particular way--i.e., we are attaching a label to it. Thus, we say that an object is a jeep or a tank or whatever. This classification is based on features of the displayed object, such as its size, shape, contrast, prominent parts, internal details, texture, and orientation. For a given sensor, those features used to classify the target constitute the target signature. Assuming that the target signature is known, recognition will depend on the observer's ability to see the relevant features in the display, especially those which help to distinguish between it and other objects. Often, when the target is hard to see, the context provides the main basis for recognition. Small blurs on the road, for example, might appropriately be classified as vehicles. Photo interpreters and others become extremely skillful at recognizing objects using other information in the scene.

A key point about recognition is that the difficulty of the task depends on the available or specified set of responses. For example, when we know that there are only men, jeeps, and tanks in the scene, it is easier to recognize a tank than in another case where there are men, jeeps, tanks, and trucks. In the second case, tanks and trucks may be confused with one another, and the observer will make the correct response less often. Also, we would expect that a man will be recognized more easily than the other targets because he is relatively unique in size and shape. In an aerial view, the man is relatively round and small; the vehicles are rectilinear and large.

The difficulty of the recognition task depends on the precision required of the observer. If he has to decide which type of tank it is or whether or not the truck is a military vehicle, the task is more difficult. This is often referred to as identification rather than recognition. Typically, it is harder to choose between a larger set of available responses because the distinguishing features are less discernible.

The difficulty of recognizing a target also depends on the similarity of the different examples of a given target type. If all jeeps look alike and all tanks look alike, it may be relatively easy to distinguish between the two vehicles. However, when the displayed target images vary because of such factors as sensor aspect angle, orientation, or temperature (in an infrared system), it becomes far more difficult to differentiate between targets (Figure 2).

It is extremely important to realize that the categories and the membership of the categories determine which information the observer needs to make the recognition response. The information needed to make a classification is going to have a very strong impact on the effects of image degradation. If very gross information is needed, then a great amount of degradation can be tolerated. This imposes certain requirements on any experimental study of recognition. If an experiment uses only a small number of target categories or a few examples within each category, the experiment runs the risk of requiring very different information for response than would be the case in the real world. To respond correctly in these experiments might require paying attention to target signatures which are irrelevant to real-world problems. Such experimental results are likely to be specific to the unique requirements of those recognition tasks. If the realistic military situation is different in those respects from that of the experiment, then the results may have no predictive validity.

<u>What affects target recognition</u>? How well an observer can recognize a target depends on four main factors: image quality, target size, contextual cues, and training. Image quality means how well the displayed scene represents the radiation in the original scene as collected by the specific sensor. Image quality depends on such factors as display noise (Figure 3), system modulation transfer (Figure 4), scan line spacing, scan aperture size, magnification, luminance, geometric distortion (tearing, stretching), writing spot size, and vibration. The quality of the image will determine

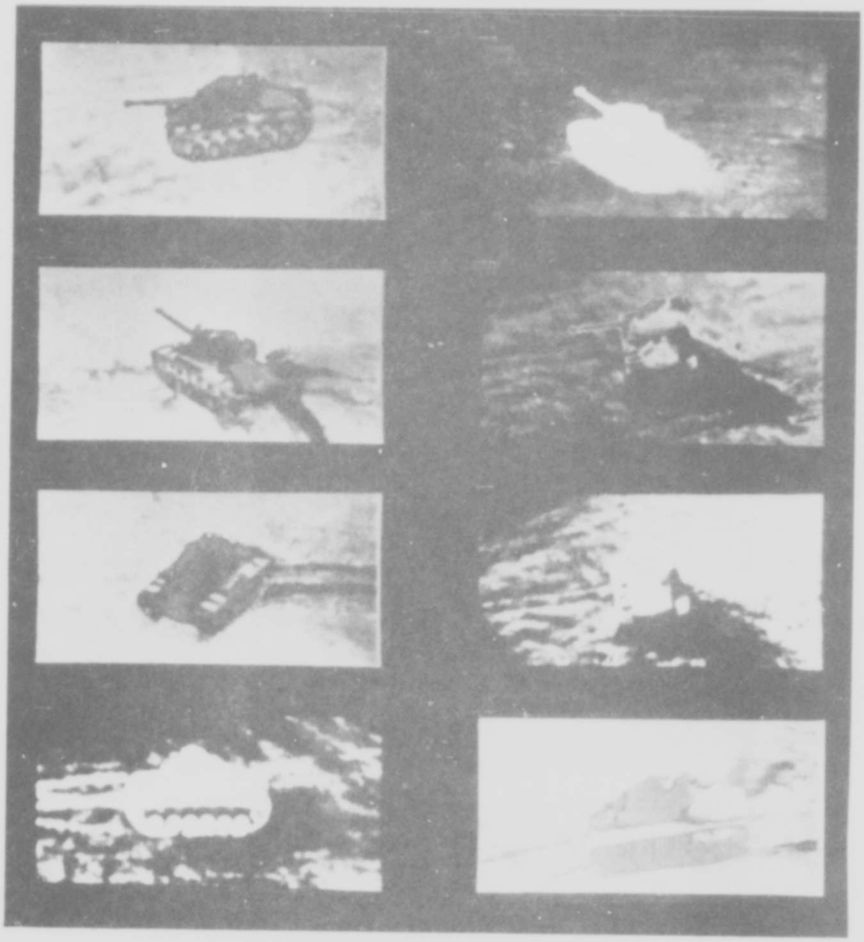

Figure 2. Eight views of a tank.

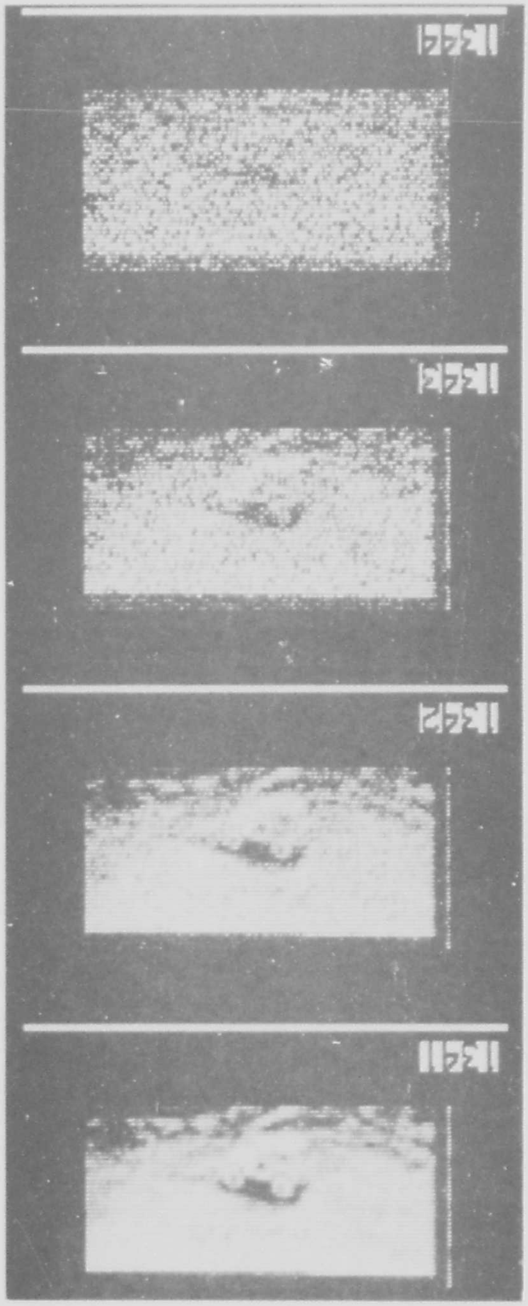

Figure 3. Four levels of static noise.

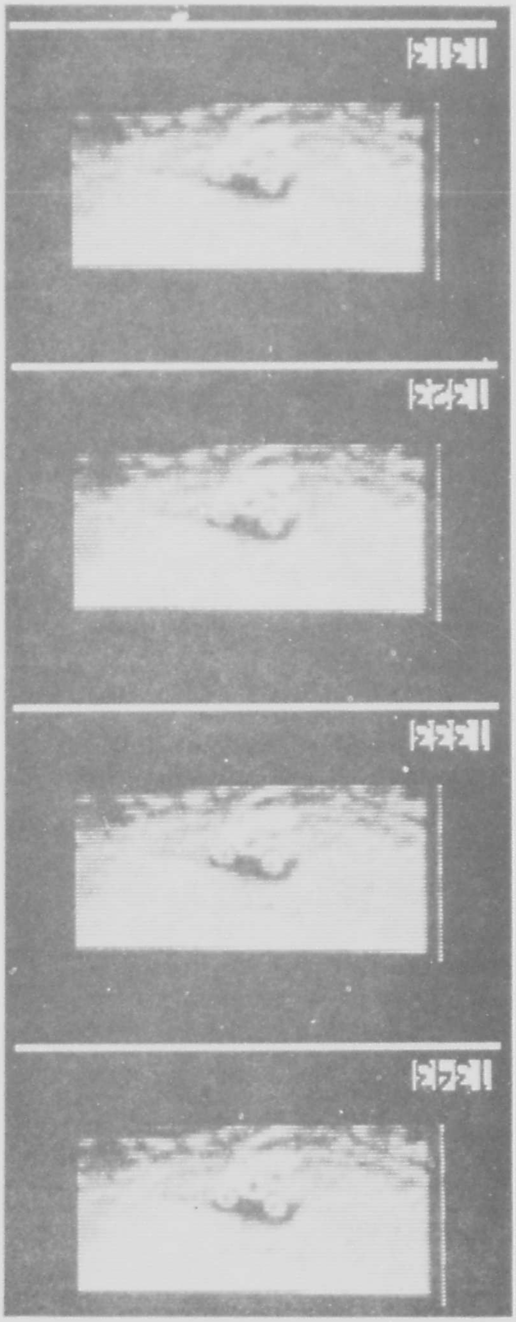

Figure 4. Four levels of modulation transfer function.

which features of the target and background the observer can see. The amount of degradation will, therefore, profoundly influence recognition performance. Over a broad range, improvement in image quality produces improvement in recognition.[1,2,3,4,5,6,7]

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[1] J. Johnson, Analysis of image forming systems. In Proceedings of the Image Intensifier Symposium of October 1958. 249-273, A. D. No. 220160.

[2] M. F. Elias, A. M. Snadowsky, and Rizzy. Identification of televised symbols as a function of symbol resolution. Perceptual and Motor Skills, 1965, 21, 91-99.

[3] M. Marsetta and D. Shurtloff, Studies in display symbol legibility. Part XIV. The legibility of military map symbols on television. Mitre Corp. Doc. MTR-264, 1966.

[4] C. A. Baker and R. M. Nicholson, Raster scan parameters and target identification. In Proceedings of the 19th Annual National Aerospace Electronics Conference (NAECON), 1967, 285-290.

[5] A. Bennett, H. Winterstein, and E. Kent, Image quality and target recognition. Human Factors, 1967, 9, 5-32.

[6] F. Scott and P. A. Hollanda, The informative value of sampled images as a function of number of scans per scene object. Photographic Sci. and Eng., 1970, 14, 21-27.

[7] P. A. Hollanda and F. Scott, The informative value of samples images as a function of number of scan lines per scene object and the signal-to-noise ratio. Photographic Sci. and Eng., 1970, 14, 407-412.

Target size (Figure 5) affects recognition mainly because the lower limit to the size of targets which can be recognized is about 5 arc minutes. How does recognition performance improve for increases in target size? If increased size results from simple magnification only, there will be improvement up to a point where further increases in size will result in poorer, rather than better, recognition.[1] However, if increase in size is accompanied by increased resolution, then more target details will be visible, and performance will continue to improve.

Contextual information can help in several ways. When the overall image quality is poor, the larger background features, such as roads, airfields, rivers, and buildings, may be recognizable even when the smaller targets are not. These larger features then may provide size information which can help an observer recognize the target which otherwise appears as a blur. The context can also provide information as to which way the target is facing. For example, if a road is going laterally across the display, then an observer will know that he is viewing a vehicle from its side. This may help him to decide what it is.

Recognition may also be improved by perceptual training. For example, Krumm and Farina[8] were able to achieve a 50 percent reduction in target identification time with no loss in accuracy or completeness by training photo interpreters to look only for critical target characteristics. Martinek and Sadacca[9] trained photo interpreters to avoid common misidentifications by directing their attention to the subtle distinctions while increasing accuracy. It may be that, with advanced reconnaissance systems such as FLIRs and radars, the training problem is more significant because less of the observer's previous natural visual experience is relevant, i.e., target signatures are different. Comparing the performance of trained FLIR operators with that of relatively naive subjects will provide some information regarding this problem.

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[8] R. L. Krumm and A. J. Farina, Jr., Rapid identification and interpretation techniques. RADC-TDR-63-421, November 1963.

[9] H. Martinek and R. Sadacca, Error keys as reference aids in image interpretation. U.S. Army Personnel Research Office, Support Systems Research Laboratory. Technical Research Note 153, June 1965.

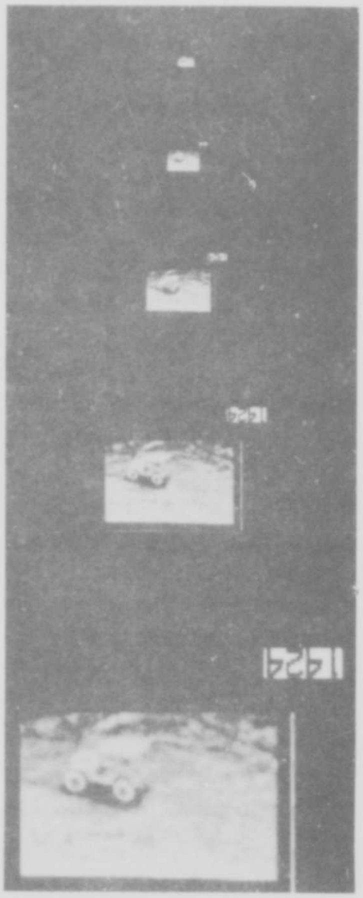

Figure 5. A target at five heights ranging from 5 to 80 arc minutes.

SECTION II

EXPERIMENT I: The Effects of Number of Scan Lines, Modulation Transfer Function, Noise, and Magnification on FLIR Target Recognition

SUMMARY

Objective: to determine the effects on FLIR target recognition of number of scan lines, modulation transfer function, noise, and magnification.

Independent variables:

1. Number of scan lines (L)--the number of horizontal scan lines within the stimulus frame viewed by the subjects.
2. Modulation transfer function (MTF)--the frequency response of the system across a horizontal scan line.
3. Noise--the random variation in luminance at each point in the display.
4. Magnification--the angular size of the display. In the present study, the display height was either 0.5, 1, 2, or 4 degrees.
5. Target category--jeep, gun, van, tank, truck, tractor, horses, men, barrels, landscapes.

Results: Recognition time and accuracy data from 15,108 trials (18 subjects) were analyzed by linear regression techniques.

1. Of the main variables, recognition was most affected by number of scan lines (L) and noise. MTF had a negligible effect.
2. System resolution, measured by the horizontal 3-bar test pattern, was the best single predictor of performance.
3. System resolution was affected mainly by L and magnification.
4. There was a wide variation in recognition of different types of targets and of different examples of a given type.

5. For the individual targets, recognition was best predicted by a combination of the four variables: system resolution, noise, target size, and target contrast.

6. RMS noise was a better predictor than sever. other signal-to-noise measures using RMS noise in conjunction with target signal intensity. Target perimeter was the most useful measure of size, while mean edge contrast was the best measure of contrast.

METHOD

Design

There were 224 degradation conditions in the main experiment (Table 1). A pilot study was initially carried out to determine the appropriate combinations of the image quality variables. For the 83 L condition, the quality of the original transparencies was insufficient to achieve MTF levels of 0.33 or 0.47. For each of the 56 cells defined by number of scan lines, MTF, and noise, there were twenty degraded targets (two examples of ten types), or 1120 pictures in all. The independent variables investigated in this experiment are described below:

Number of scan lines (L) and average lines per target (L/T)--This experiment directly simulated the effects on performance of varying raster line subtense within a fixed 12.5 x 25 degree field of view for the original IR sensor. The number of scan lines (L) and the corresponding subtenses are given below:

Number of Scan Lines (L)	Line Subtense (mrad)
10	20.9
21	10.5
42	5.2
83	2.6

This experiment indirectly simulated the effects of varying line subtense within a field of view, or piece of a field of view, with dimensions 12.5/M by 25/M degrees, where M is a field of view scale factor or magnification. In that case, this experiment showed the effects of the following line subtenses:

Table 1. THE 224 DEGRADATION CONDITIONS FOR THE MAIN EXPERIMENT. (RMS noise levels are shown in each cell. Each degraded image was presented at all four magnifications.)

MTF No. of Scan Lines(L)	0.08	0.11	0.16	0.23	0.33	0.47
10					0.5 1 2 4	0.5 1 2 4
21			0.5 1 2 4	0.5 1 2 4	0.5 1 2 4	1 2 4 8
42			1 2 4 8	1 2 4 8	2 4 8 16	2 4 8 16
83	1 2 4 8	1 2 4 8	2 4 8 16	2 4 8 16		

Number of Scan Lines (L)	Line Subtense (mrad)
10	21.0/M
21	10.5/M
42	5.3/M
83	2.6/M

For example, if one desired to ascertain the effects of variations from 0.25 mrad to 2 mrad, an M of 10 with a field of view or FOV segment of 1.25 by 2.5 degrees will show these effects. Since the targets were located at a mean slant range of 140 feet from the sensor, they appear in approximately the same scale in the imagery. Therefore, L, as a measure of the resolution in object space, should be valid for all targets. L was used as an image quality parameter in the initial analysis. As L increases, the number of lines crossing the target increases. For the present, the target size is defined in terms of its minimum dimension (see page 41). The average number of lines per target, minimum dimension (L/T), is shown below:

Number of Scan Lines (L)	Approximate L/T
10	3
21	6
42	12
83	24

Modulation transfer function (MTF)--The present study modeled the MTF produced by a circularly-symmetric two-dimensional point spread function of the form

$$r(x, y) = e^{-(x^2 + y^2)/2\sigma^2}$$

The standard deviation, σ, of the point spread function, $r(x, y)$ was defined as a fraction of the vertical line spacing, β. The corresponding MTF in the x-direction is

$$\tilde{r}(f_x) = e^{-2\pi^2 f_x^2 \sigma^2}$$

The σ values used in this experiment and the MTF values at a spatial frequency of $f_x = 1/2\beta$ are shown below:

σ	MTF ($\frac{1}{2\beta}$)
$.72\ \beta$	.08
$.67\ \beta$	.11
$.61\ \beta$	.16
$.55\ \beta$	.23
$.48\ \beta$	.33
$.38\ \beta$	.47

Noise--The source of the noise distribution was a gaussian distribution with zero mean and variance, s^2. For each point in the picture, a value was sampled from the distribution and added to the density of the sample point. The noise levels in the present study were defined in terms of the standard deviation, s, of the distribution. The six values of s, defined in terms of the command value in the image processing system, were 0.5, 1, 2, 4, 8, and 16. The corresponding film densities are shown below. There are a variety of procedures for defining a signal-to-noise ration (SNR) for this situation. However, each such procedure results in a different specification of SNR. For the present the standard deviation of the noise distribution seems to be the best descriptor of the noise level. Keep in mind that the range of the density command values is 0-63, and the film density range is 0.2-2.5 (i.e., the transmittance ranged from 0.3 to 63). Many of the individual targets spanned a good part of this range. Later, when the data were analyzed, some types of SNR were related to performance.

Command Value	Film Density
0.5	.018
1	.026
2	.073
4	.146
8	.292
16	.584

Magnification--The processed imagery was projected at four different magnifications to simulate the effects of varying FLIR display size and viewing distance. The projected picture heights were 0.5, 1, 2, and 4 degrees. The mean target heights and the picture heights for the four cases are tabulated below:

Mean Target Size (Minimum Dimension)			Picture Height		
Arc Minutes	Degrees	Milliradians	Arc Minutes	Degrees	Milliradians
10	0.16	2.91	30	0.5	8.73
20	0.33	5.82	60	1	17.45
40	0.66	11.64	120	2	34.91
80	1.33	23.27	240	4	69.81

<u>Target category</u>--The ten target types are listed below:

- Jeep
- Truck
- Gun
- Van
- Tank
- Tractor
- Men
- Horses
- Barrels
- Landscape (no target)

There were two groups of subjects: 12 students at secondary school and college level and 6 men with considerable experience with FLIR systems or imagery. Two of the latter were Air Force officers. All 18 subjects saw 1120 slides, 280 during training and the remaining 840 during the main experiment. To balance the slides used in the main experiment, different subjects were trained on different slides. Also counterbalanced in the experiment were the order of the magnification conditions and the order of the four levels of number of scan lines. The experimental data consisted of the time and accuracy scores from the 18 x 840 trials.

Stimuli

Two examples of each of the ten target types were degraded by digital image processing techniques for each of the 56 combinations of MTF, L, and noise. The steps involved in the digital image processing are shown in Figure 6. Each original negative was scanned using the Optronics digital scanner (see Appendix A for steps involved in obtaining

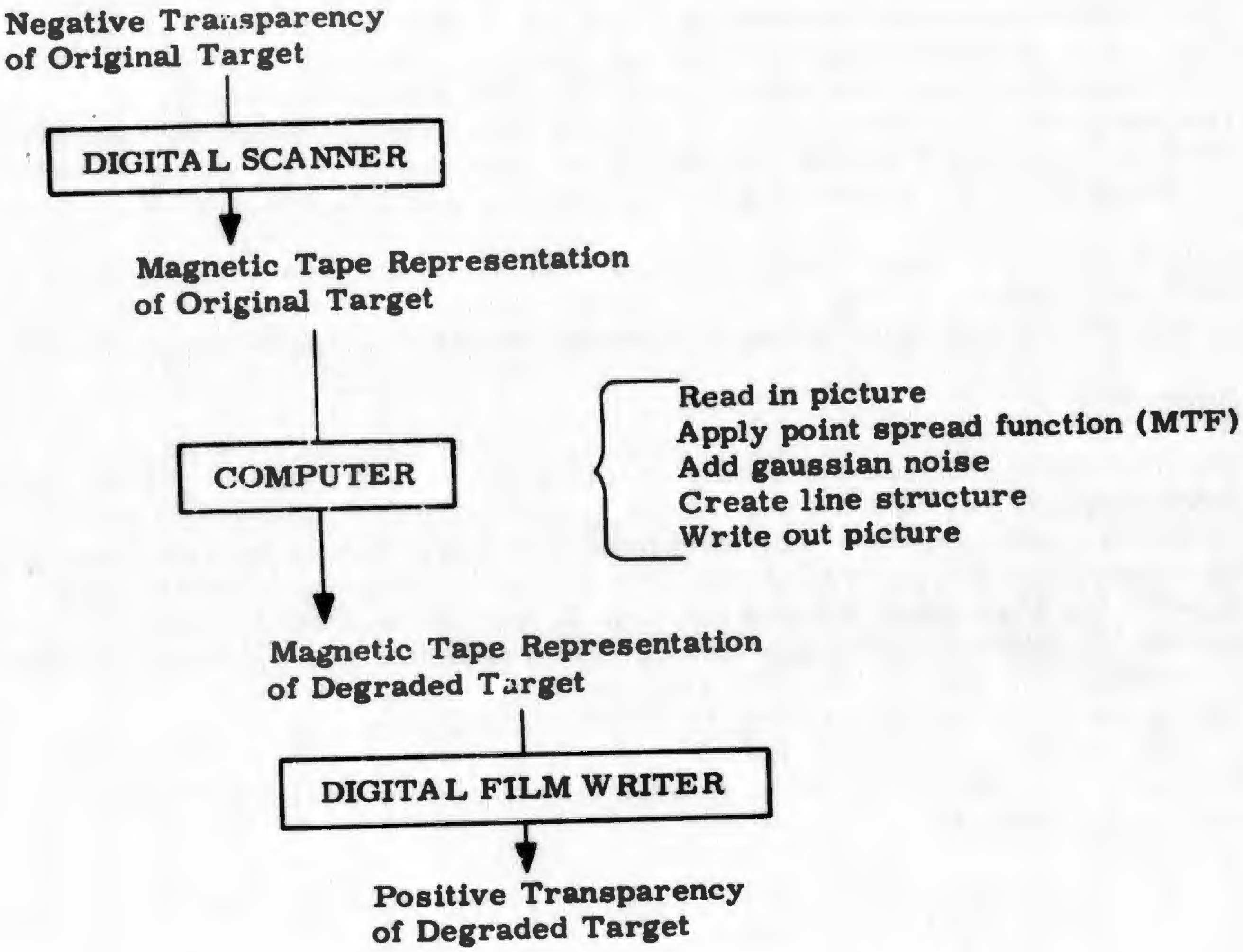

Figure 6. Image processing steps of Experiment I.

the target imagery and Appendix B for a description of digital image processing). The resultant picture was represented on magnetic tape by an array of 280 x 540 picture elements (which included the outside frame). The picture was then degraded by computer processing in three steps. First, a point spread function was applied to create a given level of MTF. Then gaussian noise was added to each picture element. Finally, the line scan structure was created. The magnetic tape so produced was then used as input to the digital film writer to make the positive transparency. An example of this processing is described in detail in Appendix B.

Figure 7 shows a truck degraded at all levels of number of scan lines, MTF, and noise. A total of 1120 transparencies of degraded targets mounted in 35 mm slide holders produced the stimuli for the experiment.

Apparatus

Figure 8 shows the subject's view of the experimental display. The degraded transparency, 12.7 x 25.4 mm (0.5 x 1.0 inch), was projected on a rear projection screen at four magnifications corresponding to the four display size conditions. The small frame containing the target was surrounded by a 17.8 x 17.8 cm (7 x 7 inches) field of neutral content in order to reduce the glare of the target frame. The projection screen was a HELIO rear projection screen made by DeOude Delft, a Dutch company. It is a high quality, practically grainless screen having a gain of 2.0.

The main components of the experimental apparatus, shown in Figure 9, were as follows:

- Logic control unit--to control the presentation of slides, the timer, and the printer.
- Timer and printer--a digital clock and printer for measuring and recording the subject's response time.
- Target slide projector--Kodak 35 mm slide projector.
- Background projector--Kodak 35 mm slide projector.

Figure 7. A truck degraded at all levels of number of scan lines, MTF, and noise.

Figure 7. A truck degraded at all levels of number of scan lines, MTF, and noise. (concluded)

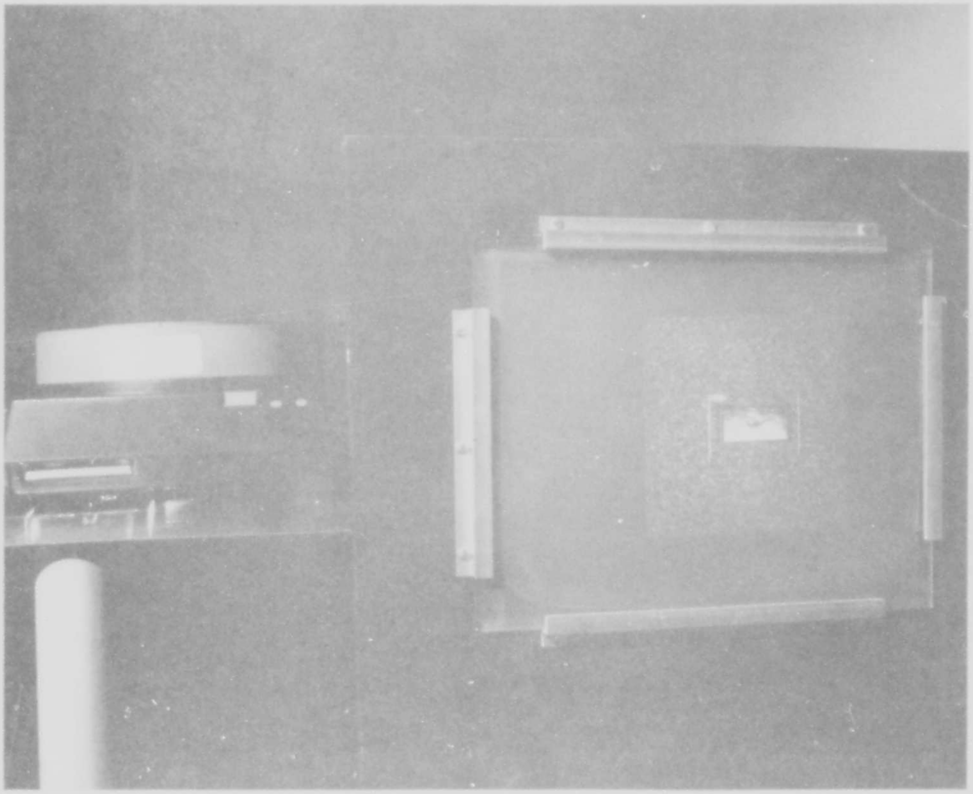

Figure 8. Subject's view of the display.

Figure 9. Main components of the apparatus: Logic control unit; printer; timer; target slide projector; background projector; and rear projection screen.

Each target slide was presented for a maximum of 5.25 seconds. For each trial, the time from stimulus onset to the subject's response was printed out. The subject's responses as to target type were recorded by the experimenter. Variation in size of the target was achieved by separate positioning of the projector carriage and lens in relation to the projection screen. Compensation was made for the resultant change in luminance by placing appropriate neutral density filters in the light path. The main target luminance was 90 cd/m^2 (26 fL).

Procedure

Each subject was given a vision test using a Titmus Optical T/O Vision Tester. If his vision was acceptable (at least 20/20 corrected), he was read instructions regarding the experimental task (Appendix C).

The training session lasted about three hours. The subject was seated in front of the projection screen so that his eyes were 38.1 cm (15 inches) from the screen. The subject responded to the first set of 70 training slides, with the experimenter giving feedback as to the type of target displayed in each slide. Each of the 70 slides in the second set was presented for 5.25 seconds. Feedback was again given on each of the subject's responses. Each of the 70 training slides in the third set was also presented for a maximum of 5.25 seconds. However, this time no feedback was given to the subject. If the subject met the criterion level of correct responses, he was asked to return the following morning for the testing sessions. If he did not meet the criterion, he was given another set of 70 trials. If he failed again, he was given a third and last chance.

During the main experiment, all slides not used in training were presented to the subject. The instructions were to respond quickly and accurately with a response required on almost all trials, no matter how uncertain the subject might feel. The subject received no feedback during the main experiment. The four target sizes were presented in four main blocks of trials, each containing 210 slides. The orders in which the four sizes were experienced and the slides used for training were counterbalanced over all subjects.

During training, two subjects went through the first two sets of slides together but were run separately on the third set. During experimentation, the two subjects were run in sequence with each hour session followed by an hour break. At least five minutes were also allowed between each tray of slides.

Resolution Measurement

The resolution of a sensor display system is a measure of how well the system, including the observer, can transmit fine grain information. System resolution was measured in the present experiment by projecting high contrast Air Force charts that had been degraded at the 244 degradation levels used in the main experiment. Figure 10 shows some of the degraded test patterns. Eight observers viewed the test patterns two times at all 224 levels to determine the minimum visible bar spacing at each level. For the levels of greatest degradation, the separate bars of even the largest 3-bar pattern were not visible. Therefore, larger patterns were created by digital image processing techniques to assess those levels.

Resolution was found to depend almost entirely on the number of scan lines and magnification (Figure 11); that is, for the range of the variables studied here, noise and MTF had little effect on resolution. Moreover, resolution was not influenced by magnification for the coarse scan line spacing. In fact, for only the finest scan line spacing did magnification have a large effect.

Target Measurement

We were also concerned with measures of target size, such as height, width, and area, as ways of describing the target. Precise measurements were made on each of the 144 target objects. These measures were obtained for two reasons: 1) to define the values of degradation parameters, such as number of scan lines, signal-to-noise ratio, and magnification; and 2) to determine which other target characteristics were related to recognition. The following measurements were made:

1) Height (mm on original negative)

2) Width

3) Minimum dimension

4) Maximum dimension

5) Area (mm^2)

6) Perimeter

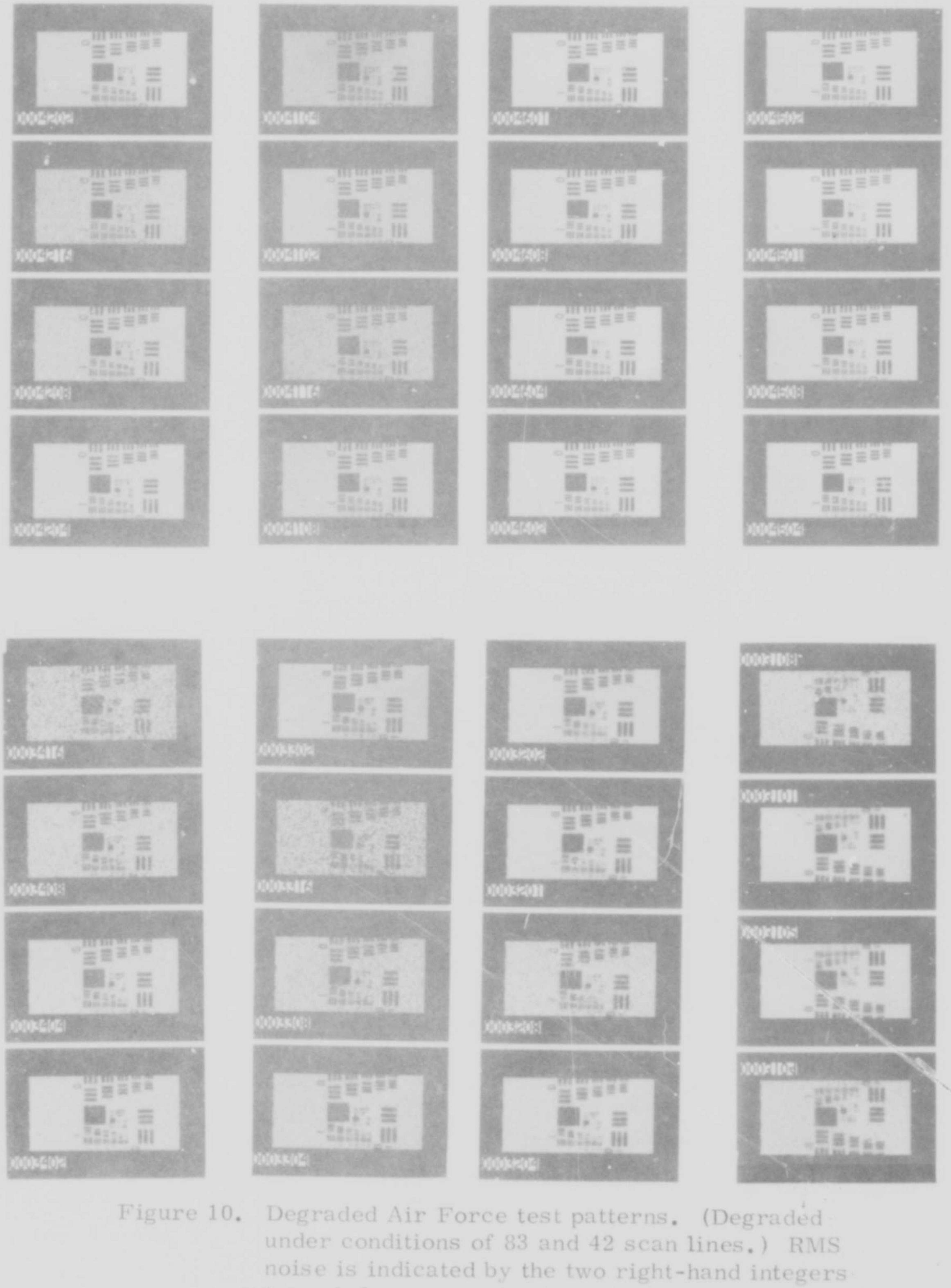

Figure 10. Degraded Air Force test patterns. (Degraded under conditions of 83 and 42 scan lines.) RMS noise is indicated by the two right-hand integers in each frame.

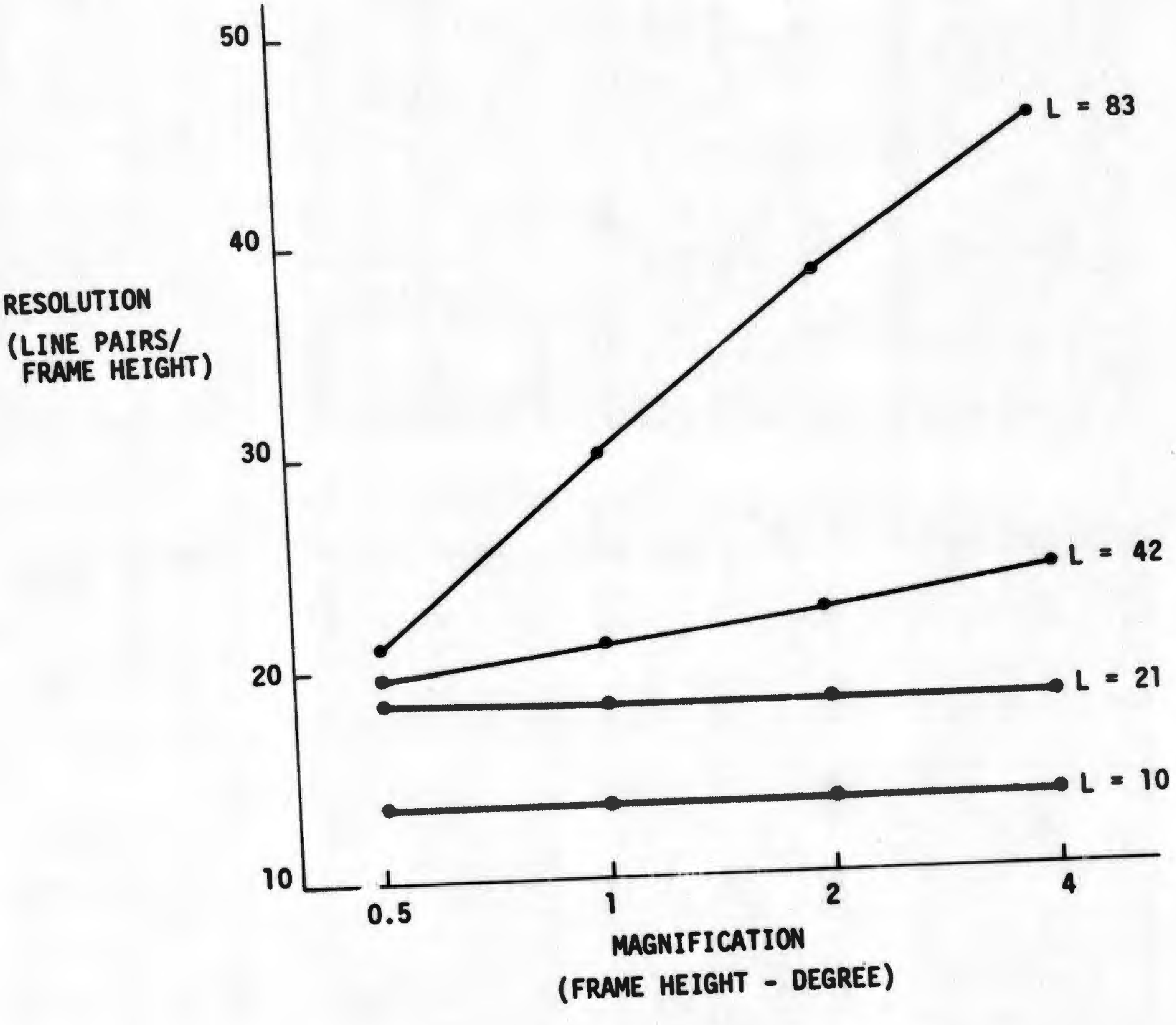

Figure 11. Resolution as a function of number of scan lines and magnification.

7) Mean edge contrast (the mean of the absolute differences in density between 10 representative boundary points on the target and corresponding areas in the background)

8) Target density (the mean of the 10 representative boundary points)

9) Background density (the mean of the 10 corresponding areas in the background)

10) Maximum picture density (the cell that had the greatest density when the picture was divided into 1 mm cells)

11) Minimum picture density

The meanings of the measures 1 through 4 are shown in Figure 12.

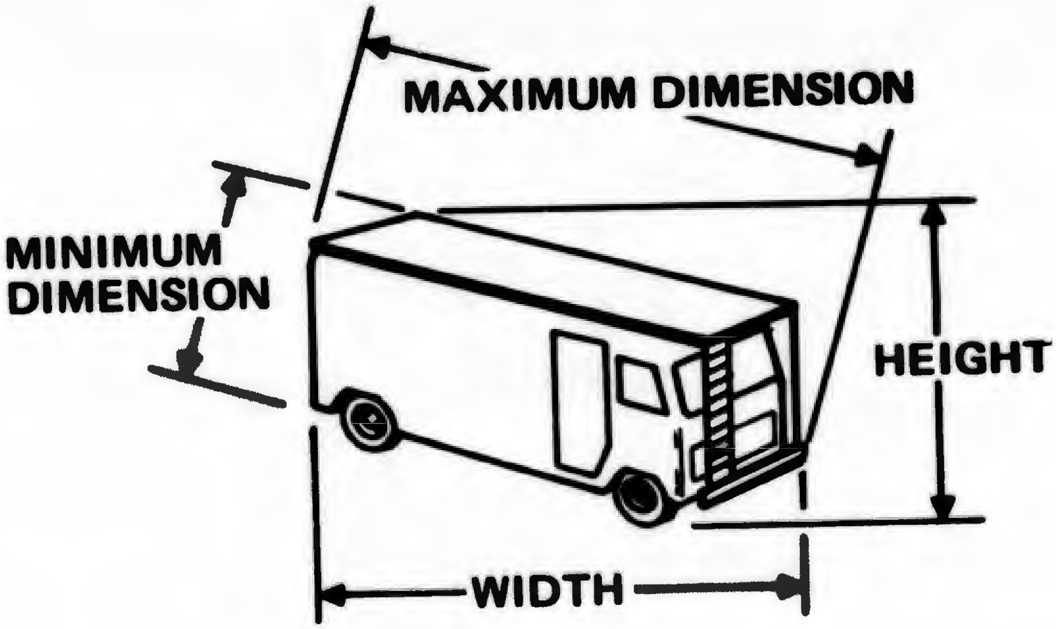

Figure 12. Four measures of target size.

Two aids were used for determining the values of the above measures: a grid super-imposed over a reproduction of each of the original transparencies (Figure 13) and a computer printout of the densities in each cell (Figure 14). The gridded transparency of each target was then used to determine those cells corresponding to the target and the surrounding regions.

The target measures were combined with the measures of image quality to create a variety of combined measures. Magnification was combined with the above target dimensions in mm to provide a measure of size in terms of visual angle. Also, the nominal number of scan lines was combined with the target dimensions to provide the actual number of scan lines. Finally, the resolution of the system was combined with the target dimensions to measure size in terms of resolution.

Similarly, the measures described previously were used with the noise level to give three signal-to-noise ratios:

1) Target-background/RMS noise
2) Mean absolute edge contrast/RMS noise
3) Density range/RMS noise

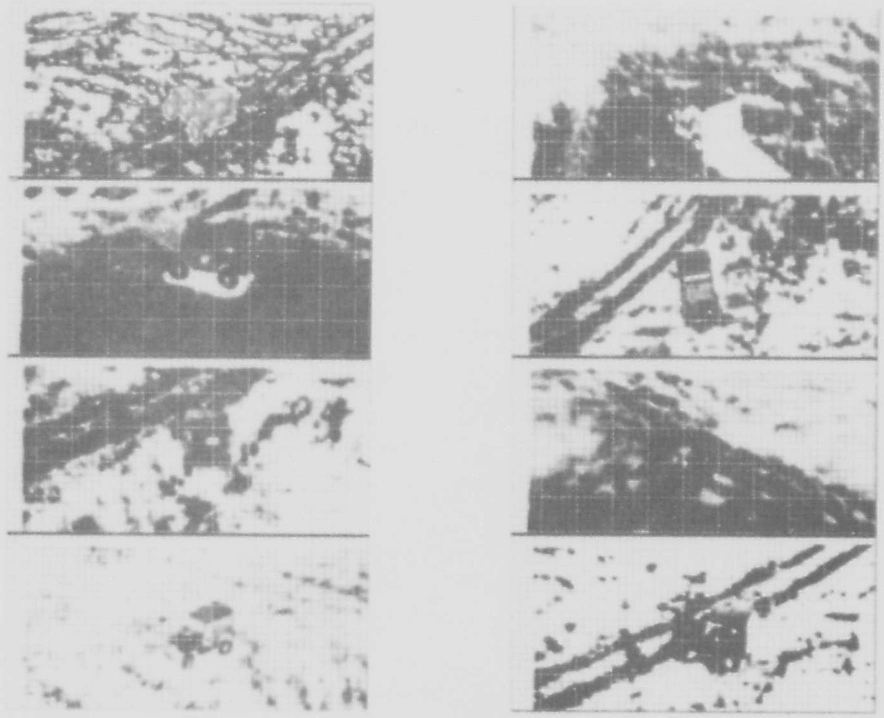

Figure 13. Grid superimposed over original jeep examples.

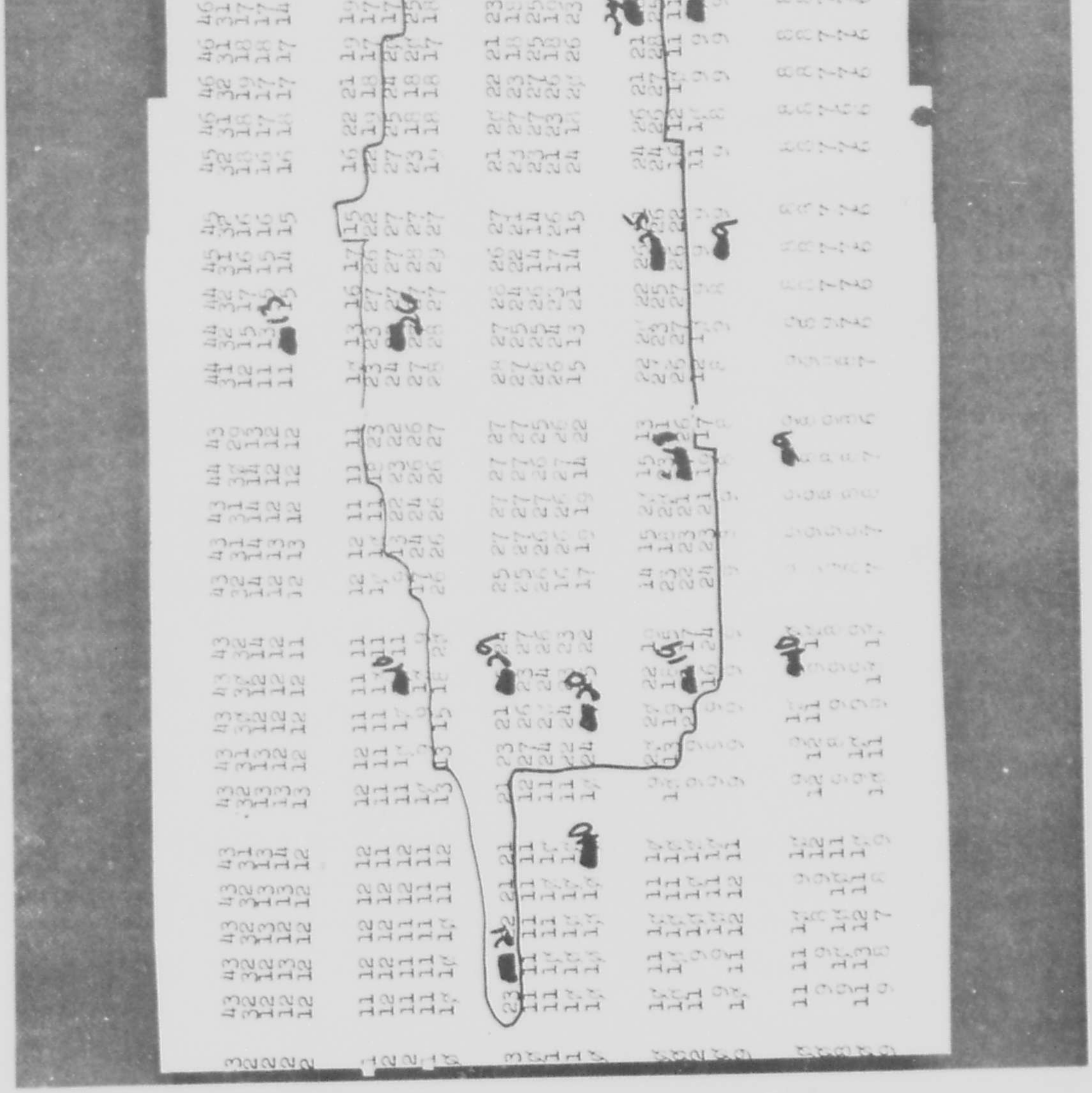

Figure 14. Computer printout of the densities for each cell of a tank.

RESULTS

Our primary objective in analyzing the data was to answer the following questions:

- How much did each of the main degradation parameters contribute to target recognition?
- What other measures of the target and the situation affected recognition?

Stepwise regression analysis[10] was used as the primary tool for treating the data because it permits detailed examination of the effects of any set of selected variables.

The main output of the analysis was to show how a given set of parameters was related to the criterion measure (accuracy or time). The output included an equation showing the linear relationship between the parameters and the criterion. In addition, a measure of how much of the variability in the criterion was attributable to the effects of the parameters was provided. For example, 66 percent of the variance in recognition accuracy over the 224 degradation conditions in the experiment was due to differences in resolution. One can then ask how much improvement in the relationship can be obtained by adding one or more variables to the prediction equation. If another variable does little to improve the relationship, the model of the relationship need not include that latter variable. Different sets of variables can also be compared. For example, assume that 70 percent of the variance in recognition can be attributed to three specific parameters. A user might prefer to use a different set of parameters which are significantly easier to measure. If it were found that the latter set accounted for almost as much of the variance in accuracy as the former set, one might decide to adopt the latter set for practical application.

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[10] N. R. Draper and H. Smith, <u>Applied Regression Analysis</u>, New York: Wiley, 1967.

Summary Data

The data from 15,108 trials were analyzed. The overall recognition accuracy was 58 percent. The mean response time was 2.75 seconds. When recognition time and accuracy were compared over the 224 degradation conditions, a correlation of -0.93 was found.

Figure 15 is a plot of recognition time and accuracy for each of the 18 subjects. The experienced subjects recognized about as many targets as the students, but the students responded considerably faster. Perhaps the experienced subjects wanted to have greater certainty before responding. Nevertheless, no increase in accuracy was obtained for the additional response time.

Figure 16 is a plot of recognition time and accuracy for the 10 target categories. Except for the no-target category, there was a strong relationship between time and accuracy. This is to be expected--the easier it is to recognize a target, the faster is the response to it. It is likely that the relatively long time for the no-target response was a result of subjects spending time in an attempt to obtain information which could lead to a more positive response (viz., one of the targets).

Figures 17 and 18 indicate that it was much easier to recognize some targets, such as the tank or the truck, than others. The figures also show the large differences between the 16 examples within each target category. A given target example may be highly recognizable over a broad range of degradation, while another may be very difficult to recognize over the same range. This sets an upper limit to the gains obtainable from system improvements. The data supported our premise that to predict absolute levels of recognition, it is necessary to use a variety of target types and a range of examples for each type. Otherwise, the results will depend highly on sampling variation. A further conclusion is that a high overall recognition level (for example, 85 percent) places very strong demands on any sensor display system.

Table 2 shows the percentage of responses in which target types were confused. This table indicates (in percentages) the type of responses made to each target type. Subjects were more likely to make the no-target response when incorrect, and presumably uncertain, than any other target category response. There were some other minor confusions. Jeeps frequently were called tractors and vice versa. Barrels and men were also confused with one another.

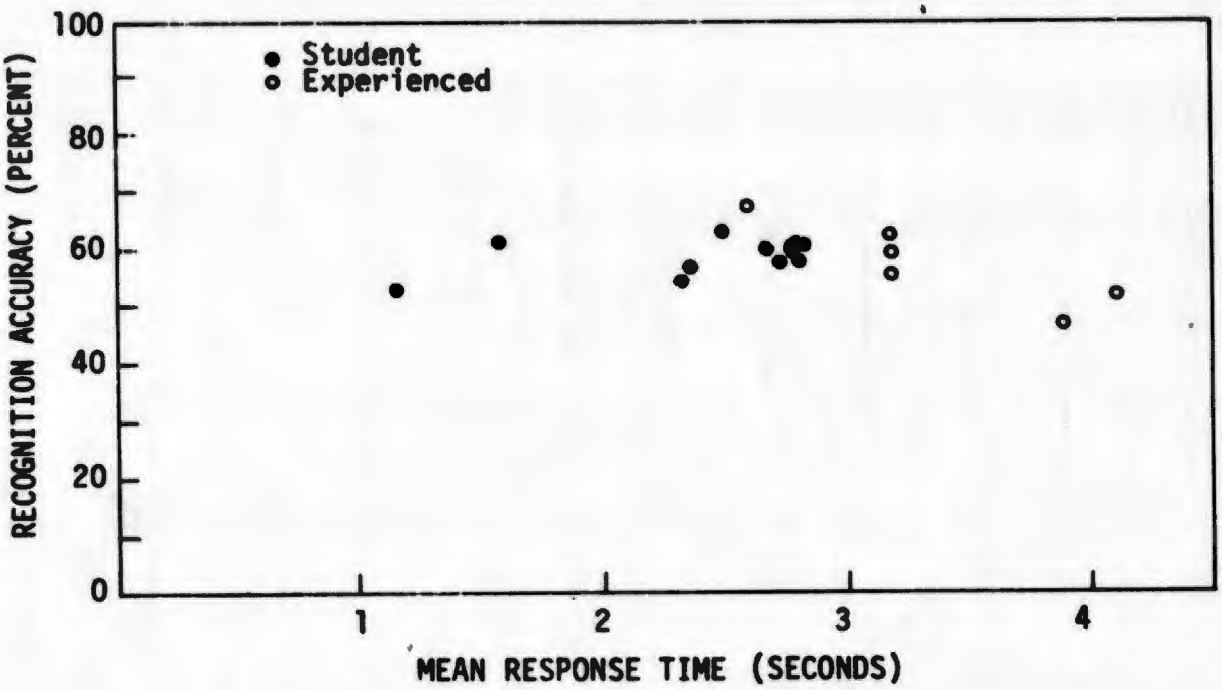


Figure 15. Mean response time and accuracy for each subject.

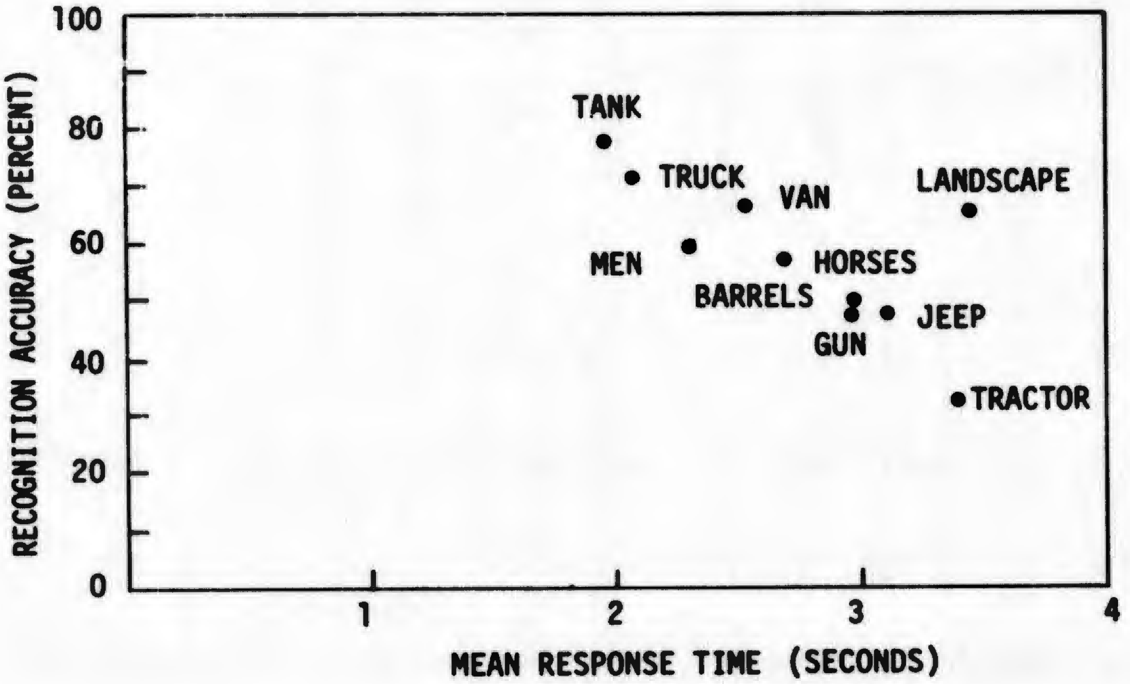


Figure 16. Mean response time and accuracy for each target type.

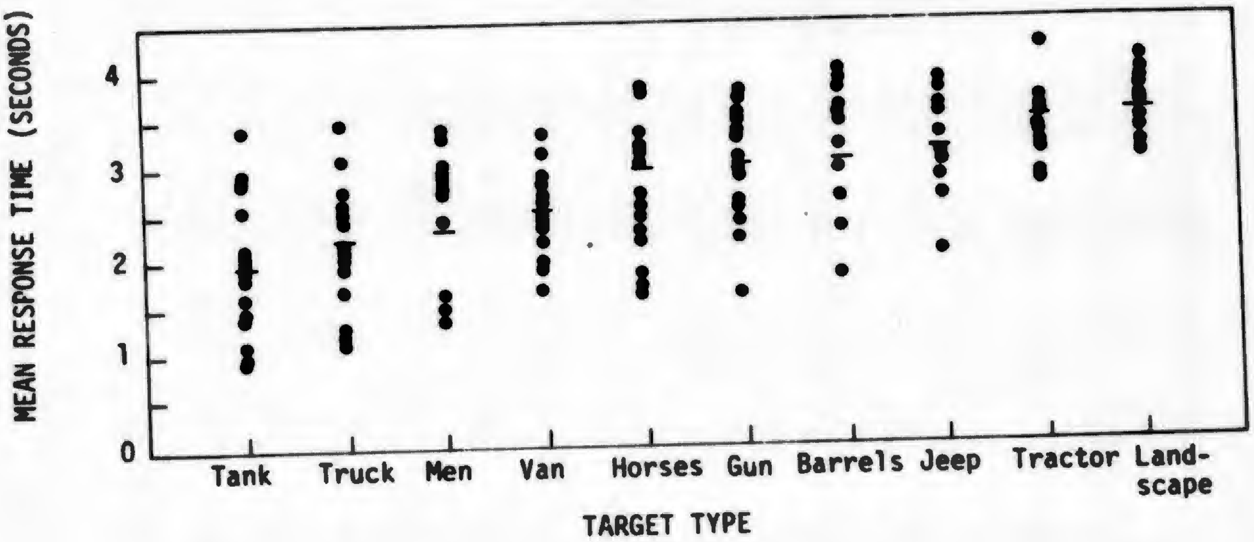


Figure 17. Mean response time for each target example.

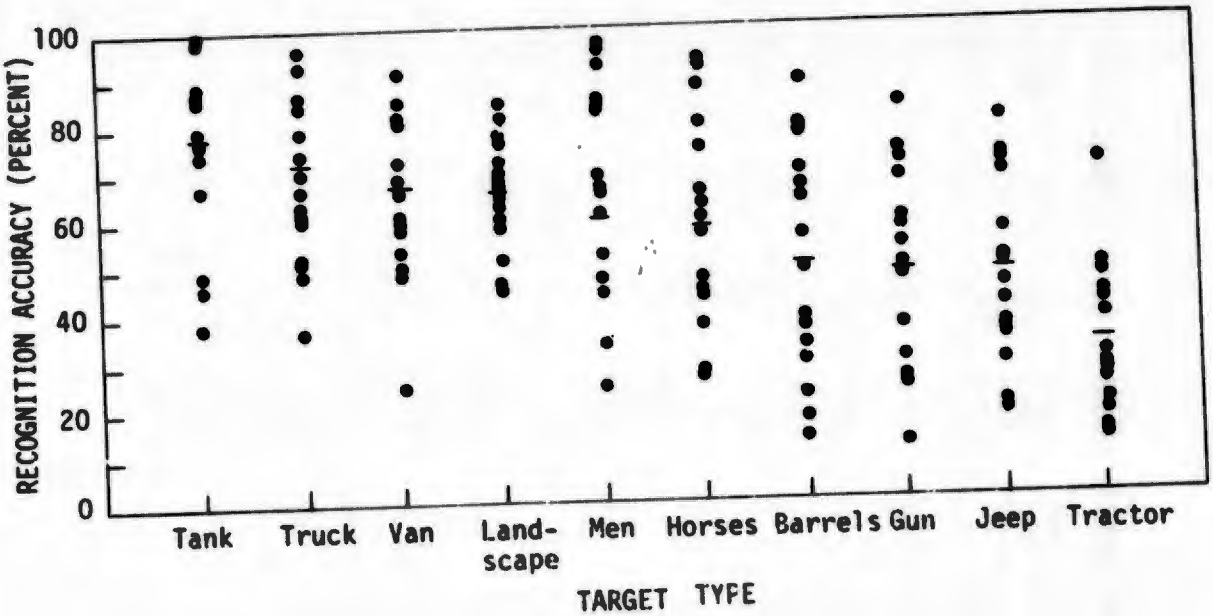


Figure 18. Recognition accuracy for each target example.*

*There are 16 examples of each target type. Not all 16 are visible here because the response levels were equal for two or more of the examples.

Table 2. THE TYPE OF RESPONSES MADE TO EACH TARGET CATEGORY (The percentage of responses for each type are shown.)

		Response											
		Jeep	Truck	Gun	Men	Horses	Tractor	Van	Tank	Barrels	Landscape	No Response	No. of Responses
Target	Jeep	48	4	3	2	2	11	8	5	2	12	1	1530
	Truck	2	72	2	2	2	3	7	5	1	5	1	1522
	Gun	6	4	48	1	3	9	2	6	3	16	1	1503
	Men	2	2	1	60	7	3	1	3	12	8	1	1499
	Horses	8	1	2	7	58	3	3	3	3	11	1	1504
	Tractor	13	7	5	2	4	34	5	9	2	17	2	1534
	Van	4	7	3	2	1	5	67	4	1	5	1	1479
	Tank	3	1	3	0	0	6	3	79	0	3	1	1527
	Barrels	3	6	2	8	6	6	1	3	51	14	1	1498
	Landscape	4	4	5	2	3	4	1	4	4	66	1	1512

Regression Analysis

Image quality variables--The dependence of recognition on the four main image quality variables was examined by a regression analysis applied to all target trials (excluding the no-target trials) for all eighteen subjects.

The main result was that L, the number of scan lines, was by far the most significant variable. Treating recognition accuracy first, L accounted for

52 percent of the variance between the 224 conditions, with a correlation of 0.72. The relationship between recognition accuracy and L was:

$$\text{Accuracy} = .46\ L + 36.8$$

The relationship was improved to account for 65 percent of the variance by including noise (N) (RMS values ranging from 0.5 to 16). Then the relationship became:

$$\text{Accuracy} = .55\ L - 1.69\ N + 40.1$$

The prediction was not improved measurably by including magnification or MTF.

A similar result held for recognition time. L and noise accounted for 62 percent of the variance. Response time (in seconds) was predicted by:

$$\text{Time} = -.017\ L + 0.038\ N + 3.24$$

Target recognition was related even more to vertical resolution, measured by visible line pairs per frame height. The correlation between recognition accuracy and resolution (R) was 0.81. The linear relationship is expressed as:

$$\text{Accuracy} = 1.23\ R + 35.2$$

Once again the prediction was improved by including noise. The following equation accounted for 78 percent of the variance:

$$\text{Accuracy} = 1.3'\ R - 1.6\ N + 38.9$$

Similarly, recognition time was best predicted from a single variable by using resolution, which accounted for 71 percent of the variance. Then, by including noise, the equation accounted for 78 percent of the variance in time:

$$\text{Time} = -.04\ R + 0.036\ N + 3.29$$

This represents the major outcome of the study. Image quality was best expressed in terms of vertical resolution, with noise aiding the prediction and with MTF having virtually no effect on recognition. The relationship between resolution and recognition is shown in Figures 19 and 20. The effect of noise is shown in Figures 21 and 22.

The effects of the four main experimental variables are best understood by plotting L together with each of the remaining three variables. The combined effects of L and noise are shown in Figures 23 and 24. One sees that

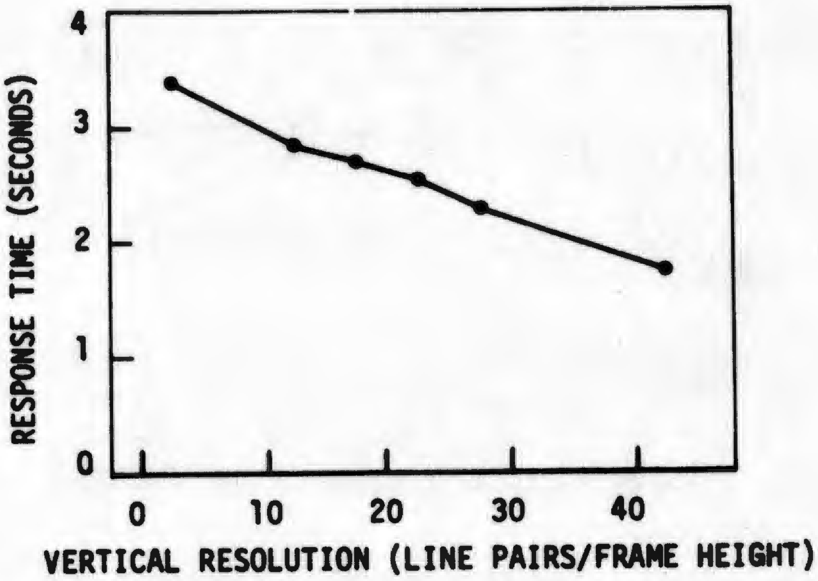


Figure 19. Response time as a function of vertical resolution.

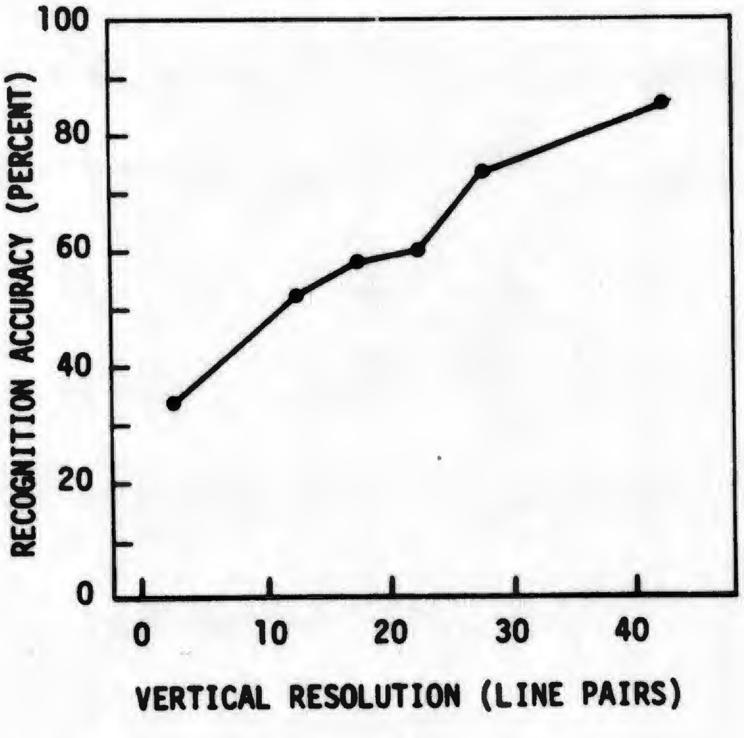


Figure 20. Recognition accuracy as a function of vertical resolution.

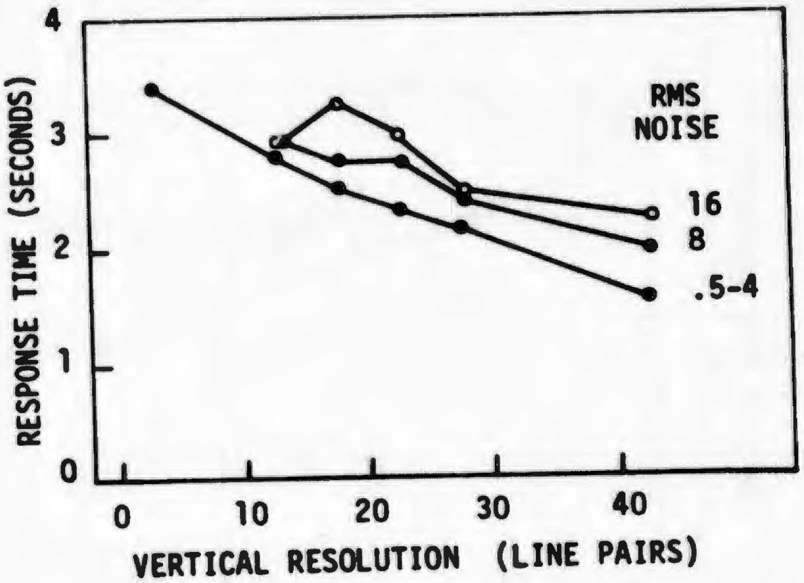


Figure 21. Response time as a function of vertical resolution and noise.

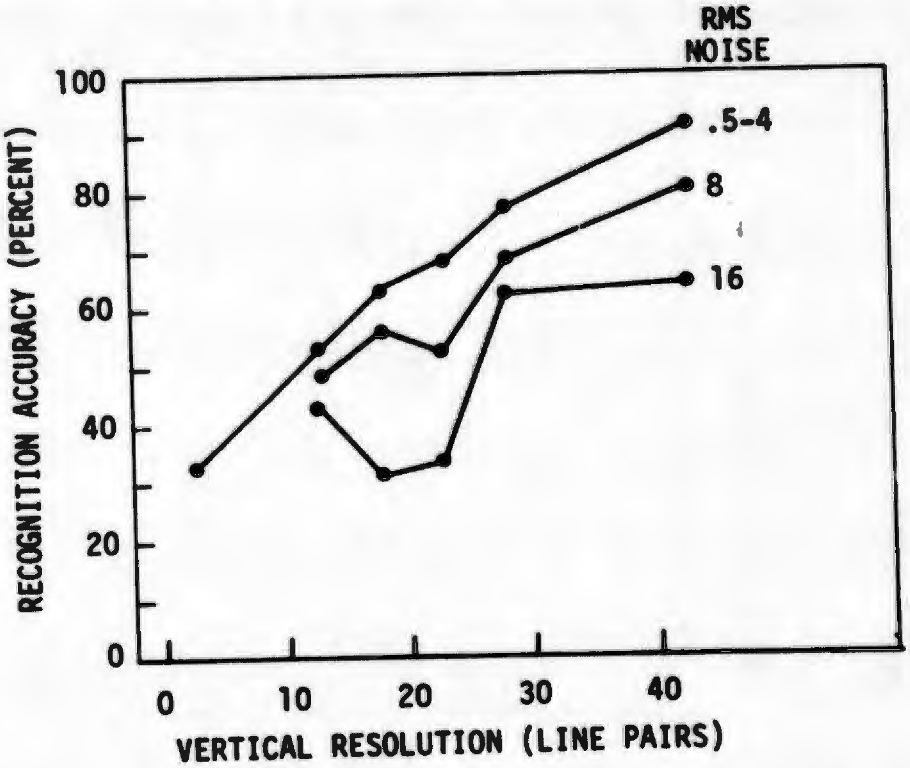


Figure 22. Recognition accuracy as a function of vertical resolution and noise.

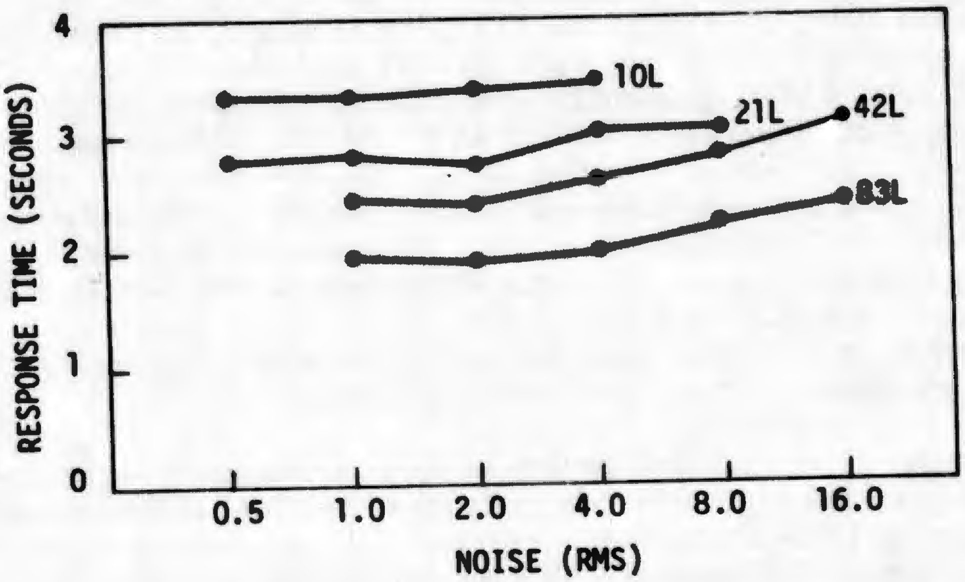


Figure 23. Response time as a function of number of scan lines and noise.

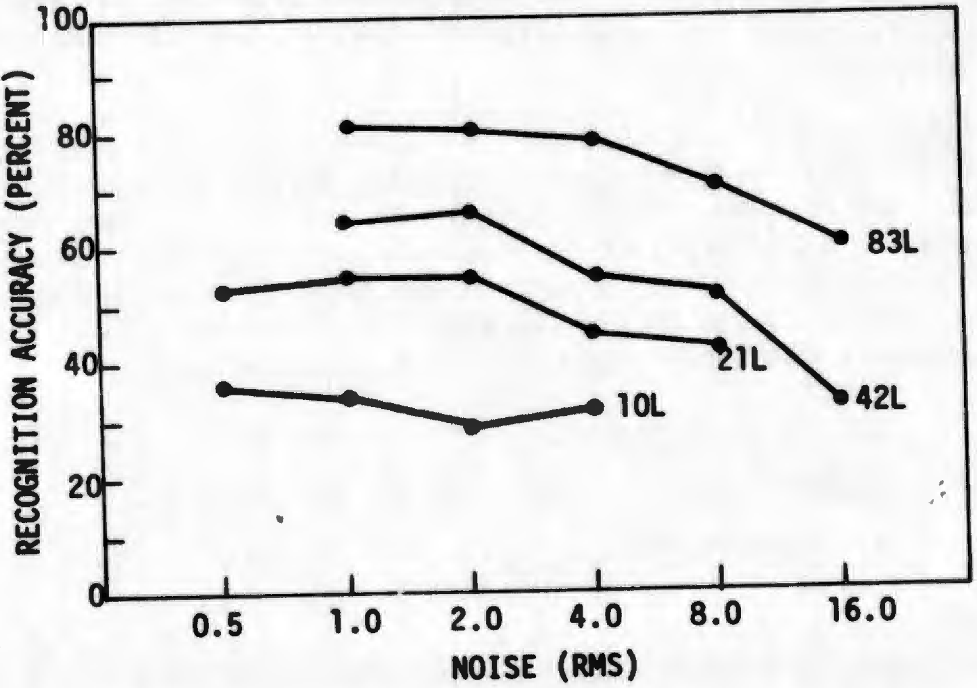


Figure 24. Recognition accuracy as a function of number of scan lines and noise.

the effects of noise were most apparent at higher levels. This may have been due to the smaller noise increments at the lower noise levels. The combined effects of L and magnification are shown in Figures 25 and 26. An increase in magnification had no effect at 10 or 21L. There was some effect at 42L and a much larger effect at 83L. The dependency of recognition on L and magnification appears to be a direct reflection on the relationship between resolution and L and magnification. This can be observed by comparing Figure 25 with Figure 14. The difference is that recognition with the 4 degree display may be somewhat inferior to that at 2 degrees. However, resolution did not decrease at the largest size. The effects of MTF are shown in Figures 27 and 28 to be negligible.

Incremental effects--The separate effects of each of the main variables can be shown by determining how changes in each variable affect recognition when everything else is held constant. For example, assume we wish to determine the effects of increasing MTF from 0.33 to 0.47. This can be done by averaging the increments over each of the separate combinations of L, noise, and magnification, where MTF was equal to 0.33 and 0.47. That is, for each fixed level of L, noise, and magnification, the increase of MTF from 0.33 to 0.47 results in a given change in recognition. Averaged over all the actual combinations of the other three variables, the gain in accuracy comes out to be 1 percent. Figure 29 shows the effects for the four main variables.

Combining subject groups--Although the data from the student and experienced groups were clearly not identical, their overall accuracy levels were reasonably close (Figure 15). Their time scores were more disparate. The two groups were also compared by observing the regression analyses applied to each group separately. For both response time and accuracy, first resolution and then noise emerge as the significant variables. The prediction equations shown below indicate some correspondence.

ACC	=	$1.44R - 1.7N + 38.6$	Students
ACC	=	$1.30R - 1.4N + 39.5$	Experienced
TIME	=	$-0.04R + 0.03N + 2.95$	Students
TIME	=	$-0.05R + 0.04N + 3.97$	Experienced

The main difference is that the constant for the time prediction was 1.02 seconds longer for the experienced subjects. The relative weightings for noise and resolution were similar for the two groups. This is

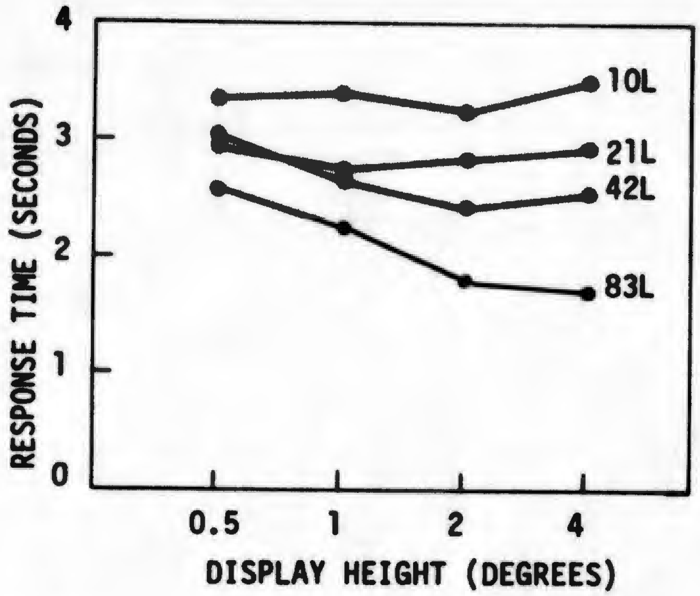


Figure 25. Response time as a function of number of scan lines and magnification.

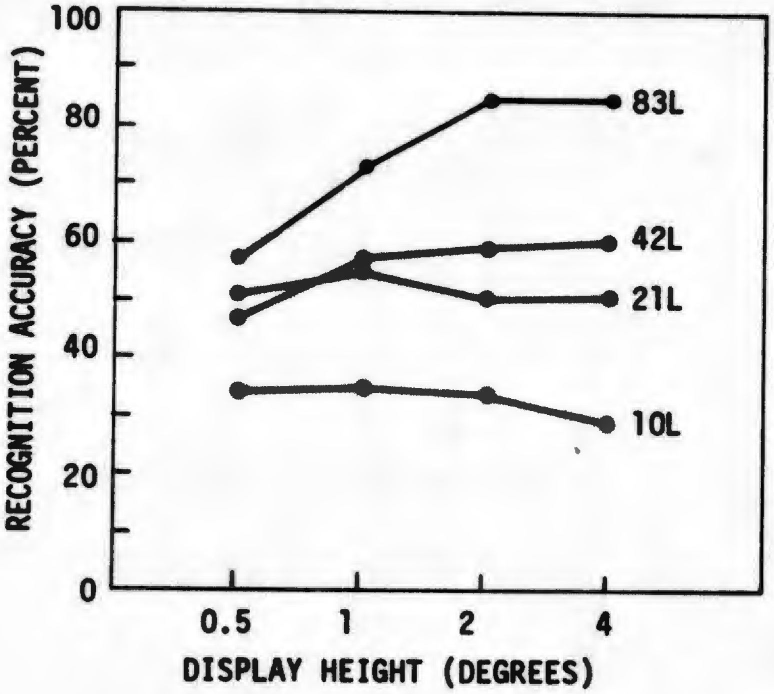


Figure 26. Recognition accuracy as a function of number of scan lines and magnification.

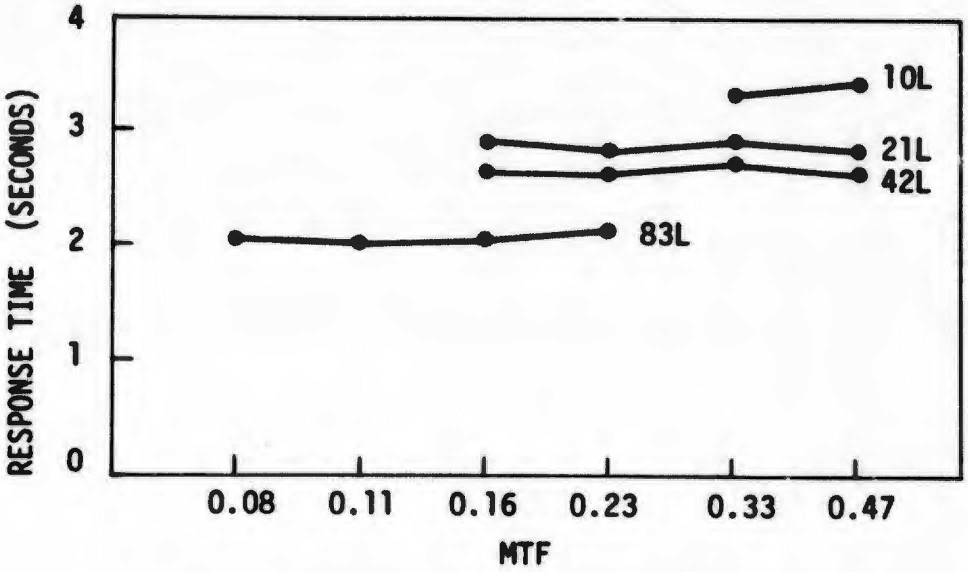


Figure 27. Response time as a function of number of scan lines and MTF.

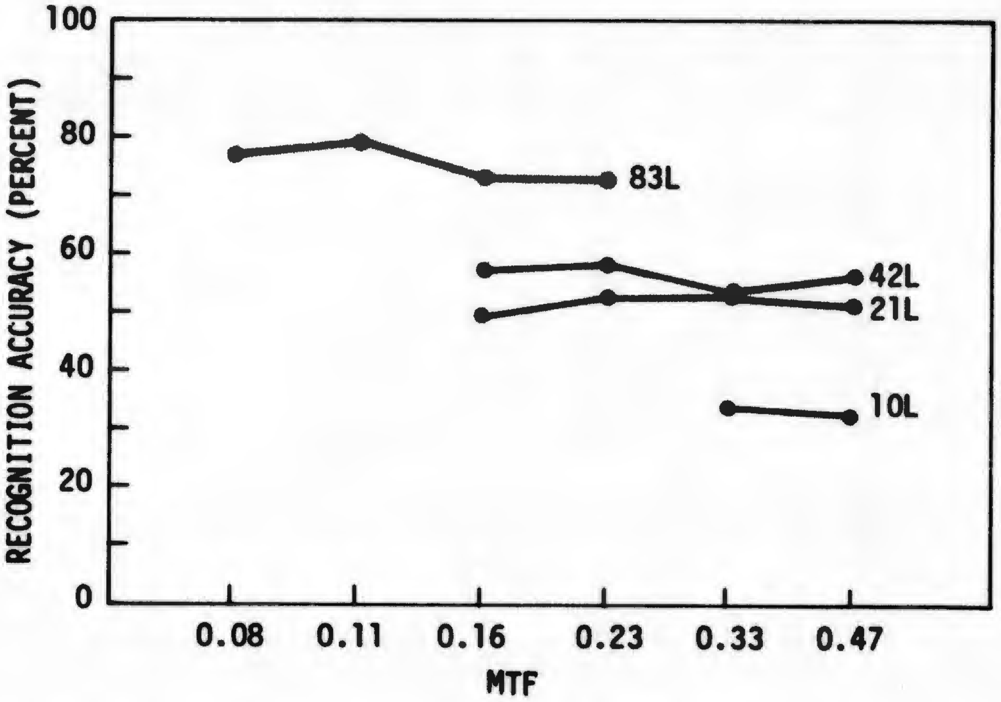


Figure 28. Recognition accuracy as a function of number of scan lines and MTF.

Number of Scan Lines			Noise (Rms)			Magnification (Display Height - Degrees)			MTF		
ΔA		ΔT	ΔA		ΔT	ΔA		ΔT	ΔA		ΔT
	83			.5			0.5			.47	
22	↑	-.66	-1	↑	0	0	↑	.10	2	↑	-.03
	42			1			1			.33	
9	↑	-.28	2	↑	0	2	↑	-.20	2	↑	.01
	21			2			2			.23	
20	↑	-.51	5	↑	-.14	9	↑	-.23	2	↑	0
	10			4			4			.16	
			6	↑	-.18				-1	↑	-.05
				8						.11	
			16	↑	-.34				2	↑	-.05
				16						.08	

Figure 29. Incremental effects of each of the main variables on delta-accuracy (ΔA) and delta-time (ΔT).

an indication that the main image quality parameters had similar effects on each group. The two groups were therefore treated as one.

Predicting to individual targets--In a previous section we specified the relative importance of the main image quality variables. However, the vast difference between targets and the smaller differences between subjects demonstrate that image quality is only part of the story. Although the present study was not designed to analyze why some targets are easier to recognize than others, much of the data is relevant to this inquiry.

We wish to address the following question: What properties make a target easy or hard to recognize? Why, for example, are tanks in this study easier to recognize than jeeps? And why are some views of the tank much easier to recognize than others? The data in the present study provide information about how size and contrast affect recognition. However, to the extent that contour and internal details are significant factors, the present analysis must be considered incomplete. For instance, if the shape of the tank is much more unique than the shapes of the other targets, then perhaps this one factor is much more important than other features such as size and contrast.

Three steps were taken to answer the above questions. We determined:

1. Which factors were most important
2. Which measures of those factors were most effective
3. How much is lost if these factors were measured more simply

The data to be presented came only from the trials for the military targets: tank, truck, van, jeep, and gun. The data from the horses, men, and barrels were eliminated at this time since these were usually multiple targets and the size measures were ambiguous. The data from the tractor were not used because it was so much more difficult to recognize than the other targets.

Table 3 shows the correlations between 38 variables of concern. To create this correlation table the elementary unit of analysis was a single transparency viewed at a given magnification. Since there were 560 transparencies for the five targets of interest viewed at four possible magnifications, there were 2240 elementary conditions. The data for each of these conditions usually came from the responses of four subjects, although sometimes there were three or five subjects. For each condition an accuracy score was expressed as a mean response time. The accuracy scores for each condition may take on a small number of possible values (e.g., 2/4, 3/4, 2/3, etc.), whereas the times may take on almost any value. This may be the reason that the correlations with time are slightly larger than those with accuracy.

First, note that the correlations of the main image quality variables with time and accuracy were considerably lower than those in the earlier correlation tables. This does not mean that the strengths of the relationships have changed, but that the correlation coefficient depends on the range of the variables involved. The large variability among the different targets produced a larger variation in time and accuracy between the 2240 elementary cells in this design than in the 224 cells in the main design. This, in turn, reduced the correlation coefficient.

Consider the variables themselves. In the present analysis there were three kinds of variables which relate to performance:

- Image quality
- Target size
- Target-background contrast

It was found earlier that image quality was best measured in terms of resolution and noise. Resolution was measured here using both horizontal and vertical 3-bar patterns. Vertical resolution (as measured by the horizontal bars) typically had correlations with time and accuracy of about 0.04 higher than horizontal resolution (as measured by the vertical bars). Therefore, vertical resolution was used as the appropriate measure.

There are two kinds of questions relating to the measurement of target size. First, what is the appropriate unit of measurement, and second, which is the best target dimension to measure? Addressing the first question, the correlations in Table 3 show that if recognition is to be predicted from size alone, then size is best measured in terms of resolution. More specifically, target perimeter measured in terms of vertical resolution was the best single predictor; it accounted for 26 and 19 percent of the overall variance in time and accuracy, respectively. This, in fact, is similar to the measure suggested by Johnson[1] as an effective predictor of various perceptual tasks such as detection and recognition. Johnson's measure, which is widely accepted, is target minimum dimension measured in terms of resolution. Table 3 shows that the latter measure correlated slightly less with time and accuracy than did perimeter. In fact, height, minimum target dimension, and maximum target dimension were approximately equally effective. However, the most significant result bears repeating. The best single predictor of system performance was target perimeter measured in terms of resolution.

When the data were examined further, it was found that a better prediction could be made from target site, measure in mm, combined in a linear equation with resolution than simply size in terms of resolution as discussed in the above paragraph. Size in terms of visual angle was a surprisingly poor predictor. For distinguishing among targets overall, it was found that target perimeter, as measured on the transparency, was the most effective measurement to be made on the target. However, since all the size measures were highly intercorrelated, it might in practice be better to use a simpler measure such as maximum dimension, which also correlated highly with performance.

The regression analysis shows that noise was best measured by the standard deviation of the noise distribution (i.e., RMS noise). The three signal-to-noise ratios had no predictive power. Contrast measured by the mean edge contrast was a better predictor of performance than the simple overall target-background contrast measure.

In summary, recognition of the five military targets can be best predicted by the following variables:

- Resolution (line pairs/frame height)
- Perimeter (mm)
- Edge contrast
- Noise (RMS)

Table 3. CORRELATION MATRIX (M

	L	MTF	Noise	Magnification	Resolution (Vertical)	Resolution (Horizontal)	Height (mm)	Width (mm)	Minimum Dimension (mm)	Maximum Dimension (mm)	Area (mm^2)	Perimeter (mm)	Height (Arc Min)	Width (Arc Min)	Minimum Dimension (Arc Min)	Maximum Dimension (Arc Min)	Area (Arc Min^2)	Height (Scan Lines [L])
1 L	1.00	-.63	.34	.00	.81	.70	.00	.00	.00	.01	.00	.00	.00	.00	.00	.00	.00	.88
2 MTF	-.63	1.00	.02	.00	-.47	-.34	-.11	.01	-.02	-.03	-.01	-.04	-.04	.01	-.01	-.01	-.01	-.59
3 Noise	.34	.02	1.00	.00	.26	.17	-.04	.00	.00	.01	.01	-.01	-.01	.00	.00	.00	.00	.28
4 Magnification	.00	.00	.00	1.00	.33	.40	.00	.00	.00	.00	.00	.00	.90	.77	.84	.84	.74	.00
5 Resolution (Vertical)	.81	-.47	.26	.33	1.00	.92	.00	.00	.00	.00	.00	.00	.29	.25	.27	.27	.21	.72
6 Resolution (Horizontal)	.70	-.34	.17	.40	.92	1.00	-.01	.00	.00	.00	.00	.00	.35	.31	.33	.33	.27	.62
7 Height (mm)	.00	-.11	-.04	.00	.00	-.01	1.00	.39	.70	.45	.60	.54	.36	.20	.31	.20	.26	.39
8 Width (mm)	.00	.01	.00	.00	.00	.00	.39	1.00	.66	.87	.87	.89	.14	.52	.29	.39	.37	.16
9 Minimum Dimension (mm)	.00	-.02	.00	.00	.00	.00	.70	.66	1.00	.57	.84	.66	.25	.34	.45	.25	.36	.27
10 Maximum Dimension (mm)	.01	-.03	.01	.00	.00	.00	.45	.87	.57	1.00	.89	.95	.16	.45	.25	.44	.38	.18
11 Area (mm^2)	.00	-.01	.01	.00	.00	.00	.60	.87	.84	.89	1.00	.90	.21	.45	.30	.40	.43	.24
12 Perimeter (mm)	.00	-.04	-.01	.00	.00	.00	.54	.89	.66	.95	.90	1.00	.19	.46	.29	.42	.38	.22
13 Height (Arc Min)	.00	-.04	-.01	.90	.29	.35	.36	.14	.25	.16	.21	.19	1.00	.80	.92	.86	.83	.14
14 Width (Arc Min)	.00	.01	.00	.77	.25	.31	.20	.52	.34	.45	.45	.46	.80	1.00	.87	.95	.92	.08
15 Minimum Dimension (Arc Min)	.00	-.01	.00	.84	.27	.33	.31	.29	.45	.25	.38	.29	.92	.87	1.00	.87	.91	.12
16 Maximum Dimension (Arc Min)	.00	-.01	.00	.84	.27	.33	.20	.39	.25	.44	.40	.42	.86	.95	.87	1.00	.93	.08
17 Area (Arc Min^2)	.00	-.01	.00	.74	.21	.27	.26	.37	.36	.38	.43	.38	.83	.92	.91	.93	1.00	.10
18 Height (Scan Lines [L])	.88	-.59	.28	.00	.72	.62	.39	.16	.27	.18	.24	.22	.14	.03	.12	.08	.10	1.00
19 Width (L)	.75	-.46	.25	.00	.61	.53	.22	.56	.37	.50	.49	.50	.08	.29	.16	.22	.21	.78
20 Minimum Dimension (L)	.82	-.52	.28	.00	.66	.57	.34	.33	.49	.28	.41	.33	.12	.17	.22	.13	.18	.91
21 Maximum Dimension (L)	.82	-.52	.28	.00	.66	.57	.21	.43	.27	.49	.43	.46	.08	.22	.12	.22	.18	.84
22 Area (Scan Lines^2)	.72	-.46	.22	.00	.57	.50	.28	.41	.39	.42	.47	.42	.10	.21	.17	.19	.20	.82
23 Height (Resolution [R])	.72	-.45	.21	.29	.89	.82	.38	.15	.26	.17	.23	.21	.41	.31	.38	.33	.31	.84
24 Width (R)	.55	-.26	.13	.31	.72	.78	.19	.51	.33	.45	.44	.45	.36	.56	.44	.50	.46	.59
25 Minimum Dimension (R)	.63	-.34	.18	.31	.81	.82	.32	.31	.46	.26	.39	.31	.41	.43	.50	.40	.42	.73
26 Maximum Dimension (R)	.64	-.35	.18	.31	.81	.82	.20	.40	.26	.46	.41	.44	.36	.49	.39	.50	.43	.67
27 Area (R)	.51	-.28	.11	.30	.70	.75	.22	.32	.31	.33	.36	.33	.38	.46	.44	.46	.46	.59
28 Perimeter (R)	.69	-.41	.21	.28	.85	.79	.23	.39	.29	.42	.40	.44	.34	.45	.38	.45	.39	.74
29 Mean Edge Contrast	.01	.08	-.01	.00	.01	.01	.01	.13	-.03	.10	.02	.16	.01	.07	-.01	.04	.01	.01
30 Mean Target Density	.00	-.07	.01	.00	.00	-.02	-.04	.04	.10	.12	.16	.09	-.01	.02	.04	.05	.07	-.02
31 Mean Background Density	.01	.04	.03	.00	.00	.00	-.04	.11	.02	.12	.10	.11	-.01	.06	.01	.05	.04	-.01
32 Overall Density Range	.00	.17	.00	.00	.01	.02	-.04	.18	-.01	.18	.09	.14	-.01	.09	.00	.08	.04	-.01
33 Target-Background Contrast	.00	.08	.01	.00	.00	.01	.04	.08	.02	.02	-.01	.11	.01	.04	.01	.01	.00	.02
34 T-B Contrast/Noise	-.25	.10	-.38	.00	-.20	-.16	.04	.03	.01	.01	.00	.05	.01	.01	.00	.00	.00	-.21
35 Edge Contrast/Noise	-.30	.09	-.48	.00	-.25	-.20	.03	.04	-.01	.04	.02	.07	.01	.02	.00	.02	.01	-.25
36 Density Range/Noise	-.35	.09	-.58	.00	-.29	-.23	.03	.04	.01	.06	.05	.05	.01	.02	.00	.03	.02	-.30
37 Recognition Accuracy	.34	-.23	-.03	.07	.38	.35	.25	.28	.30	.27	.30	.33	.15	.19	.19	.17	.16	.30
38 Recognition Time	-.40	.26	-.04	-.09	-.44	-.40	-.22	-.31	-.30	-.30	-.31	-.36	-.16	-.22	-.20	-.21	-.18	-.43

LATION MATRIX (MILITARY TARGETS).

Minimum Dimension (Arc Min)	Maximum Dimension (Arc Min)	Area (Arc Min^2)	Height (Scan Lines [L])	Width (L)	Minimum Dimension (L)	Maximum Dimension (L)	Area (Scan Lines^2)	Height (Resolution [R])	Width (R)	Minimum Dimension (R)	Maximum Dimension (R)	Area (R)	Perimeter (R)	Mean Edge Contrast	Mean Target Density	Mean Background Density	Overall Density Range	Target-Background Contrast	T-B Contrast/Noise	Edge Contrast Noise	Density Range/Noise	Recognition Accuracy	Recognition Time
.00	.00	.00	.88	.75	.82	.32	.72	.72	.55	.63	.64	.51	.69	.01	.00	.01	.00	.00	-.25	-.30	-.35	.34	-.40
-.01	-.01	-.01	-.59	-.46	-.52	-.52	-.46	-.45	-.26	-.34	-.35	-.28	-.41	.08	-.07	.04	.17	.08	.10	.09	.09	-.23	.26
.00	.00	.00	.28	.25	.28	.28	.22	.21	.13	.18	.18	.11	21	-.01	.01	.03	.00	.01	-.38	-.48	-.58	-.03	-.04
.84	.84	.74	.00	.00	.00	.00	.00	.29	.31	.31	.31	.30	.28	.00	.00	.00	.00	.00	.00	.00	.00	.07	-.09
.27	.27	.21	.72	.61	.66	.66	.57	.89	.72	.81	.81	.70	.85	.01	.00	.00	.01	.00	-.20	-.25	-.29	.38	-.44
.33	.33	.27	.62	.53	.57	.57	.50	.82	.78	.82	.82	.75	.79	.01	-.02	.00	.02	.01	-.16	-.20	-.23	.35	- 40
.31	.20	.26	.39	.22	.34	.21	.28	.38	.19	.32	.20	.22	.23	.01	-.04	-.04	-.04	.04	.04	.03	.03	.25	-.22
.29	.39	.37	.16	.56	.33	.43	.41	.15	.51	.31	.40	.32	.39	.13	.04	.11	.18	.06	.03	.04	.04	.28	-.31
.45	.25	.36	.27	.37	.48	.27	.39	.26	.33	.46	.26	.31	.29	-.03	.10	.02	-.01	.02	.01	-.01	.01	.30	-.30
.25	.44	.38	.18	.50	.28	.49	.42	.17	.45	.26	.46	.33	.42	.10	.12	.12	.18	.02	.01	.04	.06	.27	-.30
.30	.40	.43	.24	.49	.41	.43	.47	.23	.44	.39	.41	.36	.40	.02	.16	.10	.09	-.01	.00	.02	.05	.30	-.31
.29	.42	.38	.22	.50	.33	.46	.42	.21	.45	.31	.44	.33	.44	.16	.09	.11	.14	.11	.05	.07	.05	.33	-.36
.92	.86	.83	.14	.08	.12	.08	.10	.41	.36	.41	.36	.38	.34	.01	-.01	-.01	-.01	.01	.01	.01	.01	.15	- 16
.87	.95	.92	.08	.29	.17	.22	.21	.31	.56	.43	.49	.46	.45	.07	.02	.06	.09	.04	.01	.02	.02	.19	-.22
1.00	.87	.91	.12	.16	.22	.12	.17	.38	.44	.50	.39	.44	.38	-.01	.04	.01	.00	.01	.00	.00	.00	.19	-.20
.87	1.00	.93	.08	.22	.13	.22	19	.33	.50	.40	.50	.46	.45	.04	.05	.05	.08	.01	.00	.02	.03	.17	-.21
.91	.93	1.00	.10	.21	.18	.18	.20	.31	.46	.42	.43	.46	.39	.01	.07	.04	.04	.00	.00	.01	.02	.16	-.18
.12	.08	.10	1.00	.78	.91	.84	.82	.84	.59	.73	.67	.59	.74	.01	-.02	-.01	-.01	.02	-.21	-.25	-.30	.38	-.43
.16	.22	.21	.78	1.00	.86	.94	.92	.65	.79	.70	.78	.67	.81	.08	.03	.07	.10	.05	-.16	-.20	-.24	.40	-.48
.22	.13	.18	.91	.06	1.00	.86	.91	.76	.66	.82	.69	.66	.75	-.01	.05	.02	.01	.01	-.20	-.25	-.29	.40	-.47
.12	.22	.18	.84	.94	.86	1.00	.93	.70	.73	.69	.82	.67	.83	.05	.06	.07	.09	.02	-.19	-.22	-.26	.89	-.48
.17	.19	.20	.82	.92	.91	.93	1.00	.67	.71	.73	.75	.72	.78	.02	.07	.05	.05	.00	-.16	-.18	-.21	.34	-.43
.38	.33	.31	.84	.65	.76	.70	.67	1.00	.75	.89	.83	.78	.88	.01	-.02	-.01	-.01	.02	-.17	-.21	-.25	.42	-.48
.44	.50	.46	.59	.79	.66	.73	.71	.75	1.00	.87	.94	.91	.90	.08	.01	.06	.11	.05	-.11	-.13	-.16	.39	-.48
.50	.40	.42	.73	.70	.82	.69	.73	.89	.87	1.00	.86	.89	.88	-.01	.04	.01	.01	.01	-.15	-.19	-.22	.42	-.49
.39	.50	.43	.67	.78	.69	.82	.75	.83	.94	.86	1.00	.91	.96	.06	.05	.06	.10	.02	-.14	-.16	-.19	.41	-.51
.44	.46	.46	.59	.67	.67	.67	.72	.78	.91	.89	.91	1.00	.86	.01	.05	.03	.04	.00	-.11	-.12	-.14	.32	-.41
.38	.45	.39	.74	.81	.75	.83	.78	.88	.90	.88	.96	.86	1.00	.08	.04	.05	.07	.05	-.15	-.18	-.22	.44	-.54
-.01	.04	.01	.01	.08	-.01	.05	.02	.01	.08	-.01	.06	.01	.08	1.00	-.33	.56	.61	.89	.55	.51	.26	.20	-.25
.04	.05	.07	-.02	.03	.05	.06	.07	-.02	.01	.04	.05	.05	.04	-.33	1.00	.34	-.32	-.34	-.18	-.13	-.05	.01	.03
.01	.05	.04	-.01	07	.02	.07	.05	-.01	.06	.01	.06	.03	.05	.56	.34	1.00	.36	.48	.33	.33	.20	.06	-.09
.00	.08	.04	-.01	.10	-.01	.09	.05	-.01	.11	.01	.10	.04	.07	.61	-.32	.36	1.00	.45	.27	.28	.28	.11	-.12
.01	.01	.00	.02	.05	.01	.02	.00	.02	.05	.01	.02	.00	.05	.89	-.34	.48	.45	1.00	.60	.47	.21	.18	-.23
.00	.00	.00	-.21	-.16	-.70	-.19	-.16	-.17	-.11	-.15	-.14	-.11	-.15	.55	-.18	.33	.27	.60	1.00	.95	.77	.06	-.06
.00	.02	.01	-.25	-.20	-.25	-.22	-.18	-.21	-.13	-.19	-.16	-.12	-.18	.51	-.13	.33	.28	.47	.95	1.00	.88	.04	-.02
.00	.03	.02	-.30	-.24	-.29	-.26	-.21	-.25	-.16	-.22	-.19	-.14	-.22	.24	-.05	.20	.28	.21	.77	.88	1.00	-.03	.07
.19	.17	.16	.30	.40	.40	.39	.34	.42	.39	.42	.41	.32	.44	.20	-.01	.06	.11	.18	.06	.04	-.03	1.00	-.71
-.20	-.21	-.18	-.43	-.48	-.47	-.48	-.43	-.48	-.48	-.49	-.51	-.41	-.54	-.25	.03	-.09	-.12	-.23	-.06	-.02	.07	-.71	1.00

The following equation accounted for 37 percent of the total variance in time:

$$\text{TIME} = -0.05\ R - 0.016\ \text{PER} - 0.034\ \text{EDGE CONT} + 0.023\ \text{NOISE} + 4.84$$

If noise is left out of the equation, the three remaining variables will still account for 36 percent of the variance:

$$\text{TIME} = -0.04R - 0.016\ \text{PER} - 0.034\ \text{EDGE CONT} + 4.90$$

If L and noise are used instead of resolution, the explained variance is reduced to 33 percent. Similarly, if a simpler measure of target size such as target width is substituted for perimeter, the explained variance is reduced to 34 percent.

Recognition accuracy is predicted from the following equation:

$$\text{ACCURACY} = 1.32R + 0.5\ \text{PER} + 0.8\ \text{EDGE CONT} - 1.3\ \text{NOISE} + 0.7$$

The equation accounts for 29 percent of the variance. If L were used in the equation in place of resolution, the explained variance is reduced to 27 percent. If target width were substituted for perimeter, the variance would also be reduced to 27 percent. If L and target width were both substituted for the more complex measures, then the explained variance would be reduced even further--namely, to 25 percent.

What affects recognition of individual targets? What makes a tank or a jeep easy or hard to recognize? Although recognition for the individual target types generally depended on image quality, size, and contrast, there was much variability. First, it was found that the best measures of size and contrast varied over the nine targets. Tables 4 and 5 show how the several measures of image quality, size, and contrast relate to response time and accuracy. Beyond the general effectiveness of resolution, there was little additional consistency. It was even found that MTF had predictive power for some targets.

The individual targets can be examined in a second way. We can determine the relationship of the four most useful parameters--resolution, perimeter, edge contrast, and noise--to time and accuracy and the proportion of the variance explained thereby. This information is contained in Tables 6

Table 4. THE CORRELATION OF EACH SIMPLE TARGET MEASUREMENT WITH RESPONSE TIME CALCULATED SEPARATELY FOR EACH TARGET TYPE. (Example: For jeeps, the correlation of perimeter and response time was -0.22.)

	Jeep	Truck	Gun	Van	Tank	Tractor	Men	Horses	Barrels
L	-0.39	-0.45	-0.47	-0.49	-0.32	-0.25	-0.24	-0.36	-0.31
MTF	0.22	0.27	0.32	0.39	0.20	0.05	0.30	0.24	0.34
Noise	0.02	-0.16	0	-0.01	-0.06	0.03	0.06	0.14	-0.01
Magnification	-0.08	-0.15	-0.12	-0.07	-0.05	-0.19	-0.04	-0.14	-0.10
Resolution	-0.46	-0.51	-0.52	-0.55	-0.35	-0.40	-0.26	-0.45	-0.34
Height (mm)	-0.16	0.17	-0.05	-0.01	0.21	0.08	0.13	0.11	-0.22
Width (mm)	-0.25	-0.23	0.30	-0.04	-0.29	0.02	0.19	0.01	-0.16
Min Dim (mm)	-0.21	-0.06	-0.02	0.02	-0.05	0.17	0.25	-0.07	-0.34
Max Dim (mm)	-0.18	-0.20	-0.12	-0.10	-0.28	0.11	0.14	-0.07	-0.30
Area (mm^2)	-0.22	-0.13	-0.11	0.01	-0.20	0.16	0.28	-0.08	-0.37
Perimeter (mm)	-0.22	-0.24	-0.19	-0.08	-0.31	0.04	0.16	0.05	-0.24
Mean Edge Contrast	-0.18	-0.34	-0.08	-0.09	-0.29	-0.26	-0.13	-0.10	0.10
Target Density	0.15	-0.04	-0.19	-0.08	0.13	0.15	0.25	0.04	-0.05
Background Density	0.14	-0.24	-0.16	0	-0.12	-0.12	-0.04	0.27	0.15
Density Range	-0.27	-0.22	0.04	0.01	-0.03	-0.14	0	0.15	0.35
Tar-Back Contrast	0.01	-0.30	-0.01	-0.04	-0.36	-0.25	-0.12	-0.11	0.11

Table 5. THE CORRELATION OF EACH SIMPLE TARGET MEASUREMENT WITH RECOGNITION ACCURACY CALCULATED SEPARATELY FOR EACH TARGET TYPE.

	Jeep	Truck	Gun	Van	Tank	Tractor	Men	Horses	Barrels
L	0.40	0.26	0.47	0.43	0.23	0.45	0.32	0.39	0.28
MTF	-0.21	-0.15	-0.32	-0.37	-0.18	-0.25	-0.27	-0.24	-0.35
Noise	-0.09	0	-0.04	-0.01	-0.02	0.05	0	-0.12	-0.03
Magnification	0.07	0.09	0.07	0.04	0.08	0.15	0.01	0.08	0.19
Resolution	0.45	0.32	0.52	0.44	0.27	0.54	0.33	0.44	0.40
Height (mm)	0.12	-0.06	0.11	0.04	-0.13	0.07	0	-0.07	0.18
Width (mm)	0.30	0.13	-0.22	0.09	0.33	-0.01	-0.12	-0.11	0.22
Min Dim (mm)	0.18	0.09	-0.02	0.02	0.10	-0.07	-0.30	0	0.31
Max Dim (mm)	0.13	0.12	0.15	0.15	0.33	0.03	0	0.04	0.26
Area (mm^2)	0.17	0.11	0.09	0.04	0.27	-0.06	-0.35	0.01	0.33
Perimeter (mm)	0.20	0.16	0.20	0.12	0.34	0.08	-0.28	-0.12	0.27
Mean Edge Contrast	0.17	0.33	0.18	-0.02	0.17	0.31	0.13	0.16	-0.15
Target Density	-0.20	0.04	0.16	0.10	-0.04	-0.17	-0.35	0.04	0.04
Background Density	-0.12	0.24	0.25	-0.10	0.05	0.16	-0.08	-0.19	-0.05
Density Range	0.26	0.25	0.02	-0.04	-0.07	0.15	0.13	-0.20	-0.39
Tar-Back Contrast	-0.02	0.28	0.10	-0.06	0.25	0.32	0.11	0.18	-0.19

and 7, which show the coefficients for each of the variables and the total proportion of the criterion variable which is explained. No coefficient is shown in cases where the variable had little predictive relevance. The main variation between target types is found in differences in the relevance of target perimeter as a predictor. There is also considerable variability in the amount of variance attributable to these four variables. The main conclusion here is that, aside from resolution, those features which relate to recognition may differ greatly from one target type to another.

We assume that we have barely grazed the issue of what affects the recognition of individual targets. As an example of this point, consider that target aspect has considerable relevancy (Table 8). Further, how much more important are such characteristics as contour and internal structure?

Table 6. COEFFICIENTS IN REGRESSION EQUATION FOR RESPONSE TIME. (No entry is shown when the measure had little predictive relevance.)

	Resolution	Perimeter	Edge Contrast	Noise	Constant	Proportion of Variance
Jeep	-0.04	-0.026	---	0.034	4.88	27
Truck	-0.05	-0.008	-0.048	---	4.54	39
Gun	-0.06	-0.028	---	0.044	5.37	33
Men	-0.03	-0.004	---	0.038	2.48	11
Horses	-0.05	---	---	0.078	3.25	28
Tractor	-0.04	-0.036	---	0.035	4.37	24
Van	-0.05	---	---	0.039	3.32	31
Tank	-0.03	-0.020	-0.036	---	4.65	32
Barrels	-0.03	-0.130	-0.029	---	---	19

Table 7. COEFFICIENTS IN REGRESSION EQUATION FOR RECOGNITION ACCURACY.

	Resolution	Perimeter	Edge Contrast	Noise	Constant	Proportion of Variance
Jeep	1.6	0.9	---	-1.9	-11	28
Truck	0.9	---	1.7	---	34	21
Gun	1.9	1.0	1.1	-1.6	-51	37
Men	1.1	-0.3	---	---	49	18
Horses	1.6	---	1.7	-2.5	18	28
Tractor	1.7	---	1.5	-1.8	-12	43
Van	1.4	---	---	-1.2	46	21
Tank	0.7	0.6	0.6	---	---	23
Barrels	1.3	5.2	-1.4	---	---	27

Table 8. TIME AND ACCURACY AS A FUNCTION OF TARGET ASPECT.

		ACCURACY	TIME
ASPECT	Front	46	3.02
	Front Quarter	56	2.73
	Side	61	2.54
	Rear Quarter	61	2.63
	Rear	45	3.10
	Not Applicable	56	2.65

SECTION III

EXPERIMENT II: The Effects of Number of Scan Lines, Scan Aperture Size, Noise, and Magnification on FLIR Target Recognition

SUMMARY

<u>Objective</u>: To determine the accuracy of FLIR target recognition as a function of number of scan lines, scan aperture size, noise, and magnification; to compare methods of system resolution measurement; and to determine the effects of target size and contrast on target recognition.

<u>Independent Variables</u>:

1. Number of scan lines-- the number of horizontal scan lines within the stimulus frame viewed by the subjects.
2. Scan aperture size --the scanning aperture is assumed to be square. In the present study it was either 1, 2, 4, or 8 times as large as the scan line spacing.
3. Noise --the random variation in luminance at each point in the display.
4. Magnification--the angular size of the display. In the present study the display height was either 0.5, 1, or 2 degrees.
5. Target category - jeep, truck, gun, van, tank.

<u>Results</u>: Recognition accuracy data from 14,400 trials (24 subjects) were analyzed by linear regression techniques.

1. Magnifying the target image so that its maximum dimension was greater than about one degree of visual angle had little effect on performance, unless the image was noiseless or of high resolution.
2. The optimum scan aperture depended on the scene noise level; overscanning improved performance in a noisy environment.
3. System resolution measured with a new checkerboard pattern correlated better with recognition performance than when measured with the standard 3-bar pattern.

4. The best predictor of recognition performance was the displayed target maximum dimension divided by the system resolution.

METHOD

Design

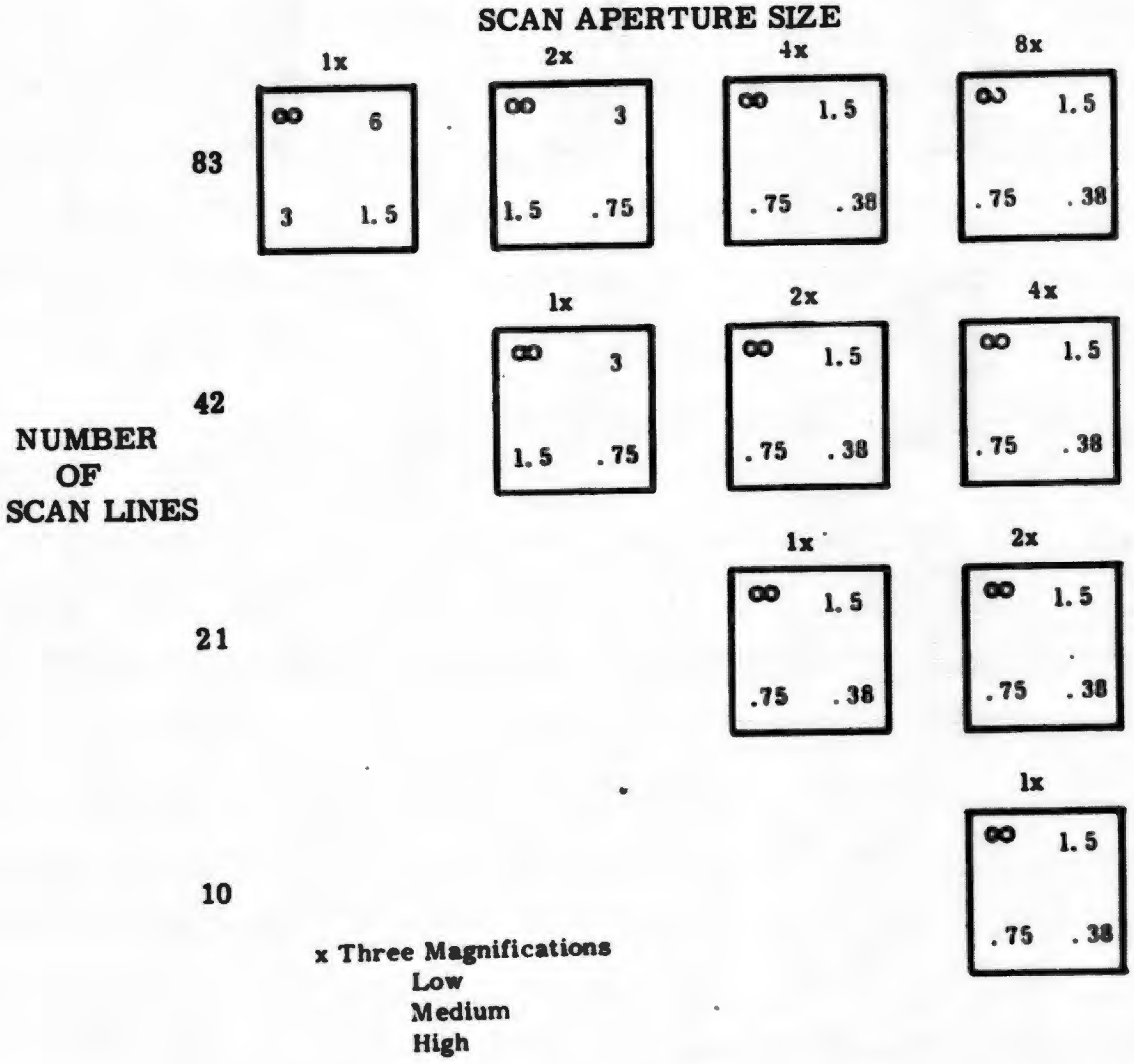
There were 192 degradation conditions in the experiment (Figure 30). For each of the 64 cells defined by scan aperture size, number of scan lines, and noise, fifteen target examples were degraded to create a total of 600 slides. The slides were presented at three magnifications during experimentation. The independent variables investigated in this experiment are described below:

Number of scan lines--It was assumed that a scanning aperture sweeps the frame horizontally. There were either 83, 42, 21 or 10 scan lines for the frame.

Scan aperture size--The square scan aperture had either the same dimension as the spacing between lines (nominal case), or was 2, 4, or 8 times as large (overscanning). Figure 31 shows a jeep degraded under the ten combinations of number of scan lines and scan aperture size.

Noise--Noise was defined as a modification of the luminance (brightness) of each elementary unit of area in the scene. If the noiseless luminance was B_i then the luminance with noise was $B + N_i$, where N_i was a random variable having a gaussian distribution with zero mean and a variance which depended on the selected noise level. The elementary unit area corresponded to the smallest scanning aperture size. Four noise levels were used for each combination of number of scan lines and scan aperture size. Since much more noise can be tolerated with coarser resolution (fewer scan lines or larger aperture), higher noise levels were used for those conditions. For each resolution condition, the levels of noise were selected so the highest level would usually obliterate the target. The range of noise levels was greater in the experiment then in Experiment 1.

Magnification--Three magnifications were produced by the experimental apparatus - low, medium, and high. These produced picture heights of 0.5, 1, and 2 degrees, as viewed by the observer. The 4 degree condition was not included in this experiment since recognition performance under that condition in Experiment I was similar to that under the 2 degree condition.



x Three Magnifications
Low
Medium
High

The four S/N ratios for each combination of number of scan lines and scan aperture size are shown in each cell.

Figure 30. Experimental design. (Scan aperture size is defined in terms of the line spacing. For example, 2x means that the scan aperture is 2 times the line spacing. Within each column, all scan apertures are the same size.)

Figure 31. A jeep degraded under the ten combinations of number of scan lines and scan aperture size.

Target Category--Since data from Experiment I indicated large differences between the military and non-military targets, only the military targets (jeep, truck, gun, van, tank) were used in this experiment. Examples of the five target types that were either too easy or too difficult to recognize in the previous experiment were excluded from the present imagery set. Twelve examples of each target type were divided into four sets so that the difficulty range of the fifteen examples in each set was equivalent. Figure 32 shows the sixty original target examples which served as input for subsequent image processing.

Twenty-four college students, fifteen males and nine females, were paid for their participation in this experiment. For training, each subject viewed 140 target slides that were not presented during the experiment. During experimentation each subject viewed the entire set of 600 target slides. The slides were divided into ten sets, defined by the ten combinations of scan aperture size and number of scan lines. The slides within each set were randomized in a slide tray. The order in which these trays were presented was balanced across the twelve pairs of subjects. Each pair of subjects saw 240 slides at one magnification and 180 slides at each of the other magnifications. The order of the magnification conditions as well as the trays presented at those magnifications were balanced across pairs of subjects. The experimental data consisted of accuracy scores from 14,400 trials. Since response time and accuracy were found to be very highly correlated in Experiment I, only recognition accuracy was measured in this experiment.

Stimuli

Six hundred degraded targets were produced by digital image processing techniques. The steps involved in this image processing are shown in Figure 33.

Negative transparencies of the sixty original targets (see Appendix A for steps involved in obtaining the original target imagery) were scanned by the Optronics digital scanner and written on magnetic tape. (See Appendix B for the details of the digital image processing.) Twenty other original targets were processed as training stimuli.

Computer processing techniques were then used to degrade the targets according to specific levels of numbers of scan lines, scan aperture size, and noise. The details of the computer processing simulated the model of an infrared system as shown in Figure 34. The starting point of a

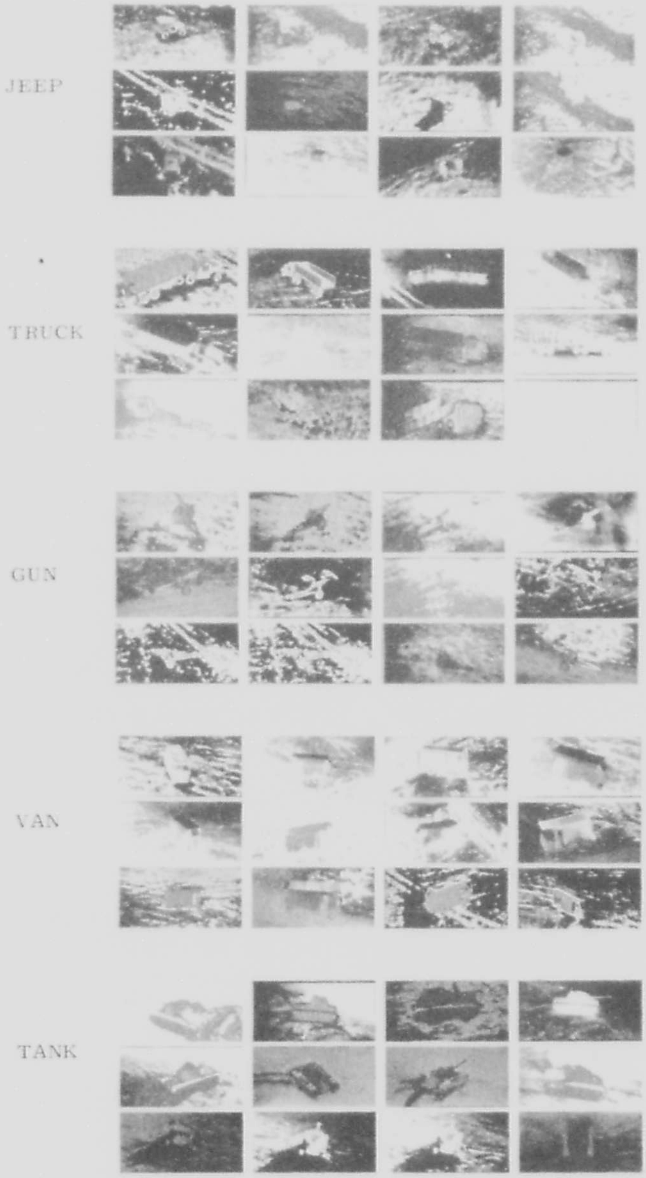


Figure 32. The sixty original target examples.

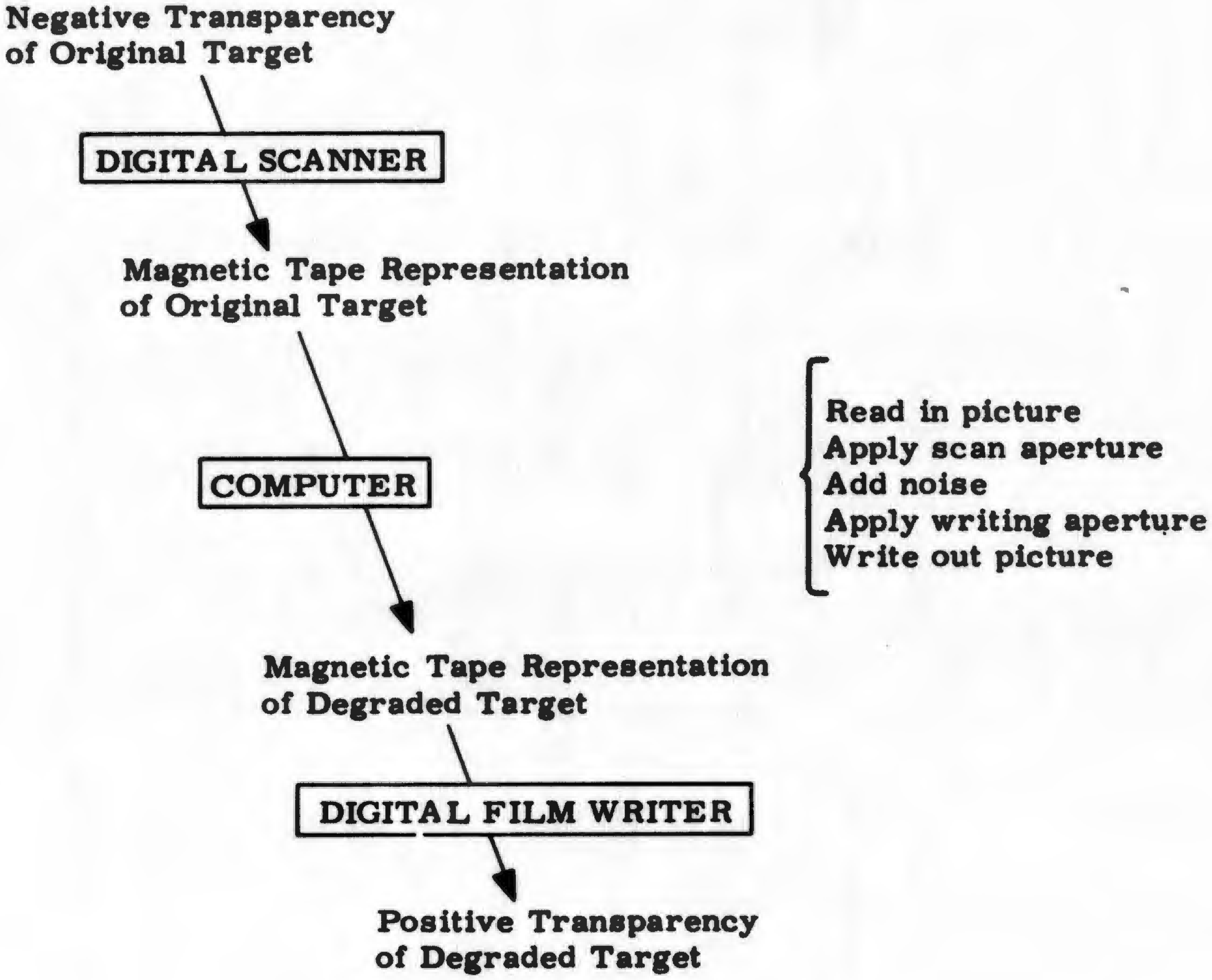


Figure 33. Image processing steps of Experiment II.

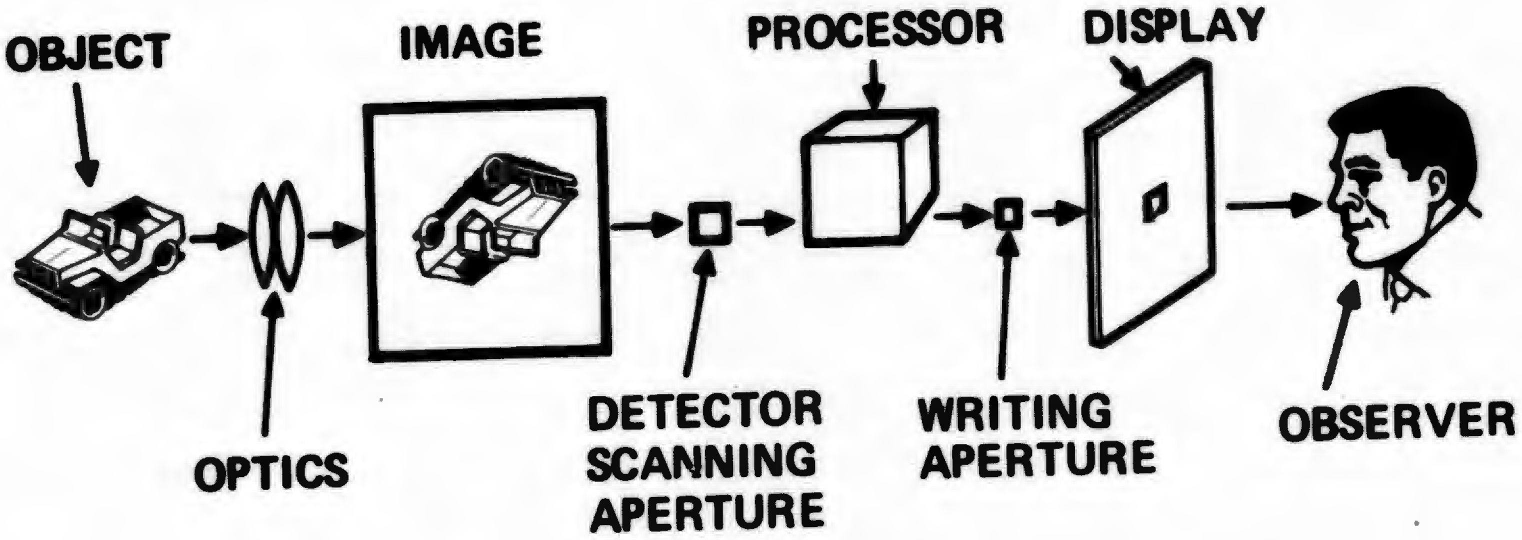


Figure 34. Simulation model of an infrared system.

sensor-display system is an object space--a distribution of infrared energies. Optics are first used to form an image of the radiation. That image, which is assumed to contain some noise, is then scanned by a detector or aperture, whose output can be represented by a time-varying voltage. This voltage is processed (amplified, formatted) and then written on a display surface by a writing aperture. The ultimate image characteristics and quality depend on the energy transfer at each processing step. By making a series of test pictures, we established the appropriate levels of each of the system parameters under control of the simulation software (i. e., size, shape, spacing, sampling of the scanning and writing apertures, variance of the noise distribution). The computer processing used to create the number of scan lines, scan aperture size, and noise is described in detail in Appendix B.

Figure 35 shows a jeep that was processed under all forty degradation conditions. The degraded targets were then made into positive transparencies using the Optronics film writer (Appendix B).

Apparatus

Figure 36 shows the experimental apparatus. The degraded transparency, 12.7 x 25.4 mm (0.5 x 1 inch), was projected on a rear projection screen at three magnifications corresponding to the three nominal target size conditions. The height of the small frame containing the target was 0.5, 1, or 2 degrees for the respective conditions. The frame was surrounded by a 17.8 x 17.8 mm (7 x 7 inches) field of neutral content to reduce the glare of the target frame.

The main components of the apparatus were as follows:

- Logic control unit--to control the presentation of slides and to display each of the subject's responses.
- Target slide projector--to project each slide at a magnification of 2:1, 1:1, or 1:2.
- Background projector--to project a neutral content area surrounding the target frame.
- Rear projection screen--a high quality practically grainless HELIO screen having a gain of 2.0 and made by DeOude Delft, a Dutch company.

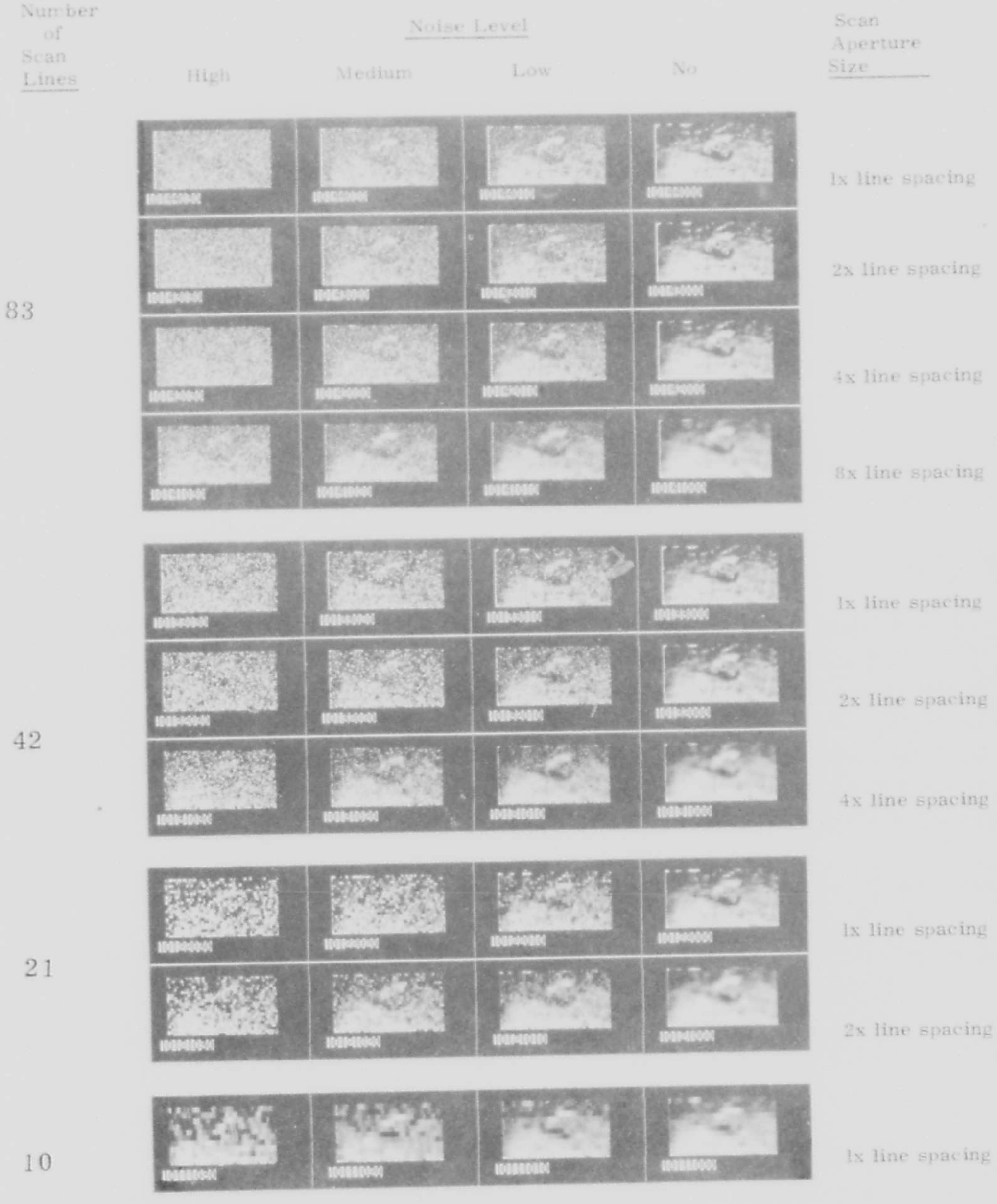


Figure 35. A jeep degraded under all combinations of number of scan lines, scan aperture size, and noise.

Figure 36. The main components of the experimental apparatus: Logic control unit; target slide projector; background projector; and rear projection screen.

Each slide was presented for five seconds, with a two second interval between slides. The three magnifications were achieved by separate positioning of the lens and the projector. Neutral density filters were placed in the light path to compensate for the resultant changes in luminance. Two subjects were seated 76.2 cm (30 inches) from the rear projection screen. During experimentation a divider was placed between the subjects to prevent communication. Each subject held a response unit which contained five buttons corresponding to the five target categories. When a button was pushed, a number corresponding to that target category was displayed to the experimenter. This display was visible only to the experimenter and was cleared as soon as the next slide was presented.

Procedure

The near acuity of each subject was first tested using a Titmus Optical T/O Vision Tester. Subjects were required to have 20/20 near acuity with refractive correction. Instructions regarding the experimental task (Appendix C) were then read to the subjects.

Three subjects were trained at a time. The 140 training slides contained degraded targets that would not be seen during experimentation and were divided into three sets of graduated difficulty. All three sets were presented at the one degree magnification condition at a viewing distance of 76.2 cm (30 inches). The subject' s task was to determine the type of target that was displayed each time. The presentation of the first set of forty slides, which contained no noise, was untimed. The experimenter gave feedback as to the type of target displayed in each instance. The second set of forty slides contained a higher level of noise, and each slide was displayed for five seconds, with a two second interval between presentations. Feedback was again given for each of these target slides. The presentation of the third set of sixty training slides, which contained an even higher level of noise, was also automatically timed. The two subjects to be selected for experimentation were required to meet a minimum performance criterion on this set. Therefore, no feedback was given, and the three subject' s responses were recorded and scored.

After a short break, the two subjects that were selected were again seated 76.2 cm (30 inches) from the display. A screen was placed between them to discourage any communication. The subjects viewed 240 slides at one magnification and 180 slides at each of the two other magnifications. The presentation of the slides was automatically timed so that each slide was displayed for five seconds with a two second interval between slides. Subjects were instructed to respond to each slide within seven seconds, no matter how uncertain they might feel about the response. A response was made by pushing a button that corresponded to one of the five categories. Numbers representing their responses were then displayed to the experimenter to be recorded on code sheets.

Resolution Measurement

Previous studies of this type have indicated a high correlation between system resolution and target recognition performance. Since problems have been experienced in attempting to obtain precise measurements of resolution, a secondary objective of this study was to obtain these measures by alternative methods. Two types of test patterns were degraded at all levels of the experimental variables and used to measure display resolution.

One test pattern was a high-contrast Air Force 3-bar chart. This chart was degraded by digital image processing at all 120 combinations of the experimental variables. Six subjects responded to each of the 120 conditions. The psychophysical procedure associated with this chart was found to be very imprecise, an undesirable feature being the large subjective element. The subject's response as to when he could resolve the three bars depended on his confidence level, which varied both within and between subjects. A forced choice between whether the bars were horizontal or vertical was not valid, since horizontal resolution is often superior due to the horizontal orientation of the raster scan. Therefore, even though a large number of responses were taken and the methodology improved somewhat, the precision of the measurements made with this pattern is questionable. As an afterthought, a lower contrast 3-bar chart was also degraded at each of the main degradation conditions. The contrast of this chart (0.75) corresponded to the average contrast of the targets used in the experiment. Two responses were taken for each condition.

New ideas for measuring resolution were implemented by using a checkerboard pattern, consisting of light and dark squares on a neutral background. This test chart, which contained nine patterns of decreasing size, was also degraded at all combinations of the experimental variables (Figure 37). Three subjects responded to each of the 120 conditions. The checkerboard

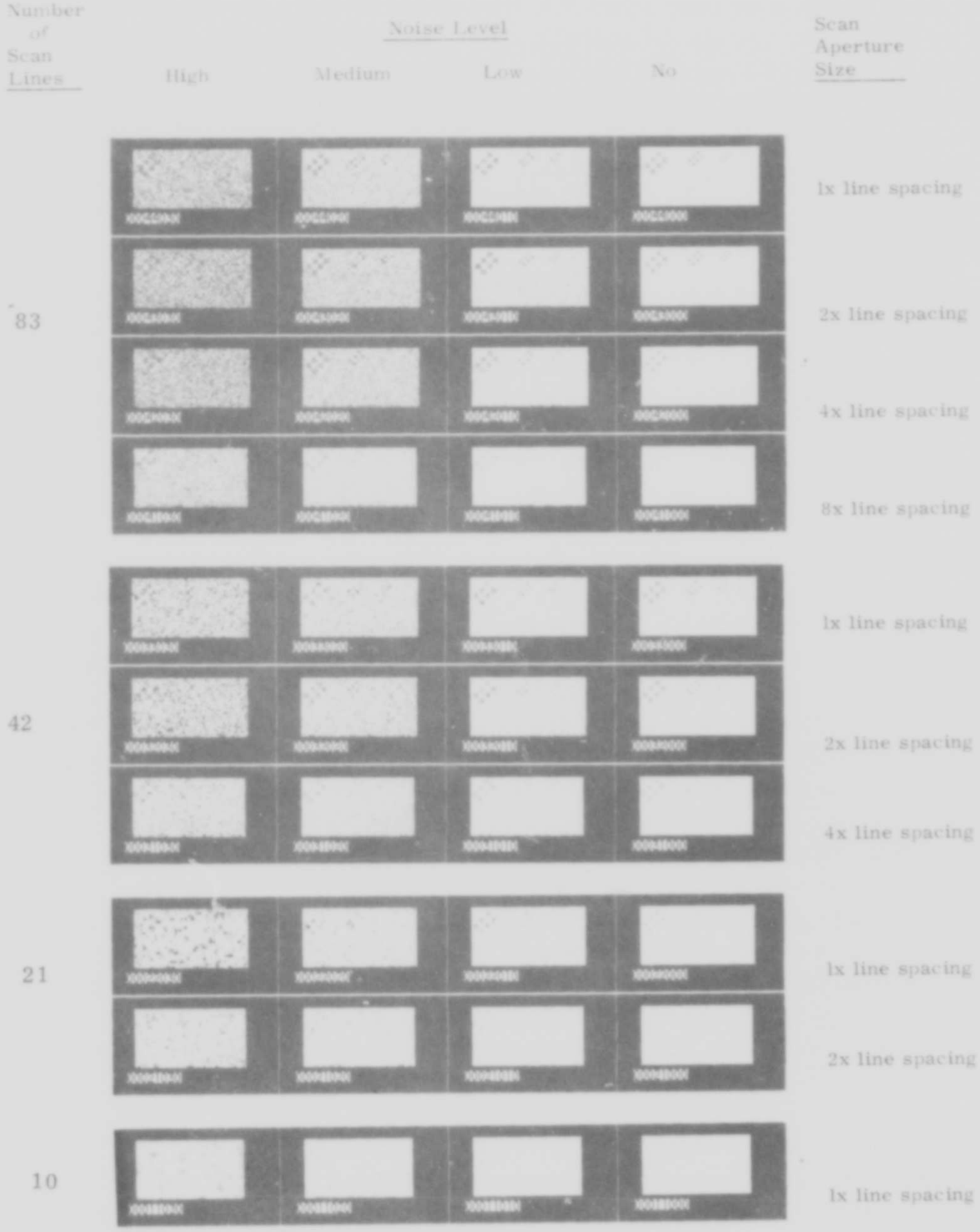


Figure 37. Checkerboard test chart degraded under all combinations of number of scan lines, scan aperture size, and noise.

pattern offers several advantages over the 3-bar test chart. It can be constructed so that the black squares are on a diagonal either to the left or to the right. This allows a forced-choice technique to be used in measuring resolution by asking the subject the orientation of the black squares. Another anticipated advantage of the checkerboard pattern is that the values of the squares and background can be chosen so that the pattern disappears into the background when it cannot be resolved. Even if the 3-bar pattern is greatly degraded, something is usually visible against the background.

The quantification of resolution is somewhat arbitrary, since all such measures are proportional to one another. It is necessary to determine how narrow the bars in the 3-bar pattern can be and still be resolved. This dimension can be measured in terms of: sensor viewing angle, display angular subtense, display size, size in the real world (ground resolution), etc. For present purposes, resolution was most conveniently defined in terms of the frame height. Thus, for a given condition we may find that 30 line pairs (bar pairs) are resolvable over the total height of the display viewed by the observer. We say then, that there are 30 resolvable cycles per frame height, or one resolvable cycle is one-thirtieth of the frame height. Of course, resolution becomes more meaningful when it is related to the sizes of targets. Thus, the target dimension is measured in terms of the number of resolvable cycles as defined above. However, since the target dimension and resolution are defined with the same units, the size of the target in terms of the number of resolvable cycles will be unaffected by the unit for measuring resolution.

Target Measurement

An additional objective of this study was to determine the effect of certain target characteristics on recognition performance. To do this, the following target measurements of the original undegraded pictures were made: minimum dimension, maximum dimension, height, width, area, perimeter, and contrast. The procedure used to make these measurements in Experiment I was also used in this experiment (see Figures 12, 13 and 14). A grid was superimposed over a reproduction of each of the undegraded target originals. A computer printout of the density values making up a target corresponded to the gridded targets. Since each cell of the grid was represented by a printout density value, the gridded transparency could be used to determine those cells corresponding to the target and the surrounding regions. Target contrast was measured by outlining the edge of each target on its corresponding computer printout.

Representative transmittance values were then selected from the target and the background and the difference between these values was used to define the contrast of that target.

RESULTS

Recognition accuracy data from 14, 400 trials were summarized and analyzed by linear regression techniques to indicate the effects of the main variables.

Target Difficulty--There were large differences in difficulty between the target examples (Figure 38). The two target examples which were too easy (recognition > 88 percent) and the nine target examples which were too difficult (recognition < 25 percent) were excluded from subsequent analysis since it was expected their inclusion would add error to the results.

Magnification--The effect of magnification depended on scan aperture size, number of scan lines, and noise. In the case of highest resolution and no noise (Figure 39), target recognition was better at high magnification than at the lower magnifications. In the typical case, that of all but the lowest resolution plus noise (Figure 40), a target was recognized about as well at high and medium magnifications. This implies that there existed no information in the image which could be brought out by the higher magnification. In the case of very coarse resolution (Figure 41), targets were better recognized at the low magnification that at the higher magnifications. Presumably in the latter case, the target structure was disrupted by the more visible noise and raster information. It is interesting to note that this effect is never reflected by measures of system resolution using standard test patterns, since increased magnification results in improved visibility of the standard test pattern.

Number of scan lines, scan aperture size, and noise--The effects of number of scan lines, scan aperture size, and noise are shown in Figure 42, where the data for the three magnifications are combined. With no noise, optimum performance was provided by fine line spacing and small aperture. In this noiseless case, a larger aperture caused a performance decrement. At higher noise levels, very fine resolution no longer offered a gain. The optimum scan aperture size depended on the noise level. For more noise, a larger aperture was required for filtering. For a given aperture, some amount of overscanning (i. e., more scan lines per frame) improved performance.

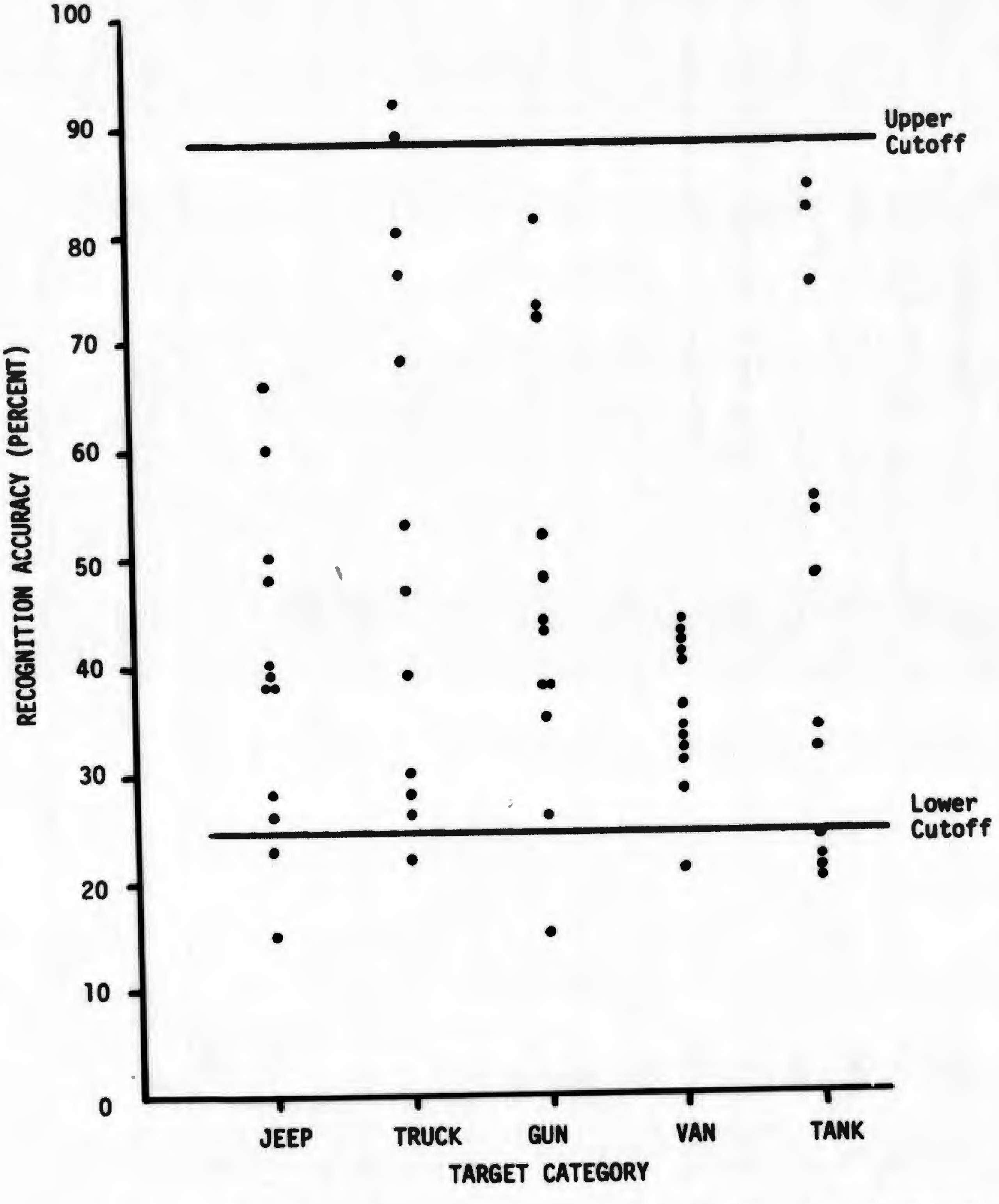


Figure 38. Recognition accuracy for the five target categories. Each dot represents one of the sixty target examples.

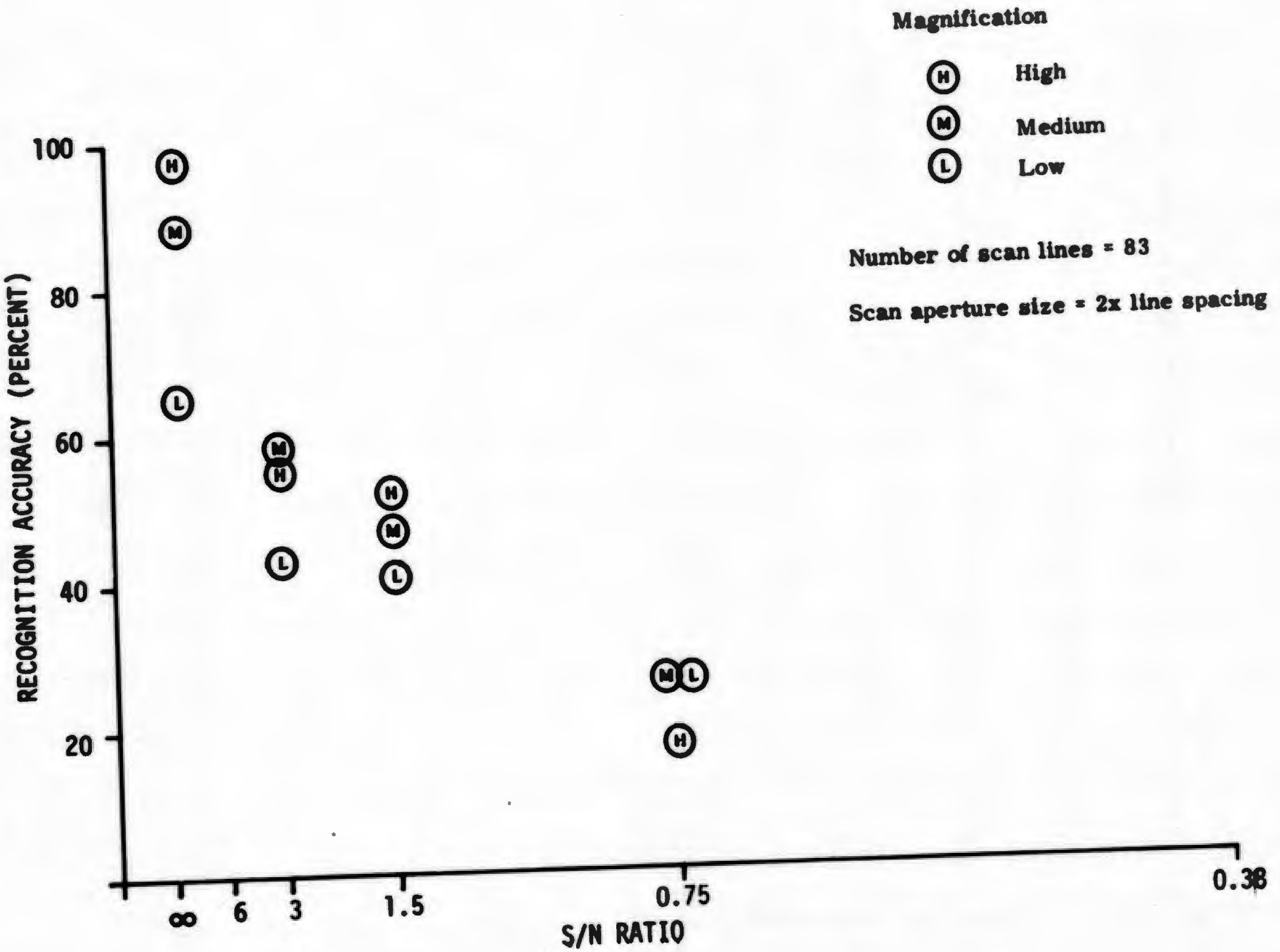


Figure 39. Magnification improved recognition under conditions of high resolution and no noise (S/N = ∞).

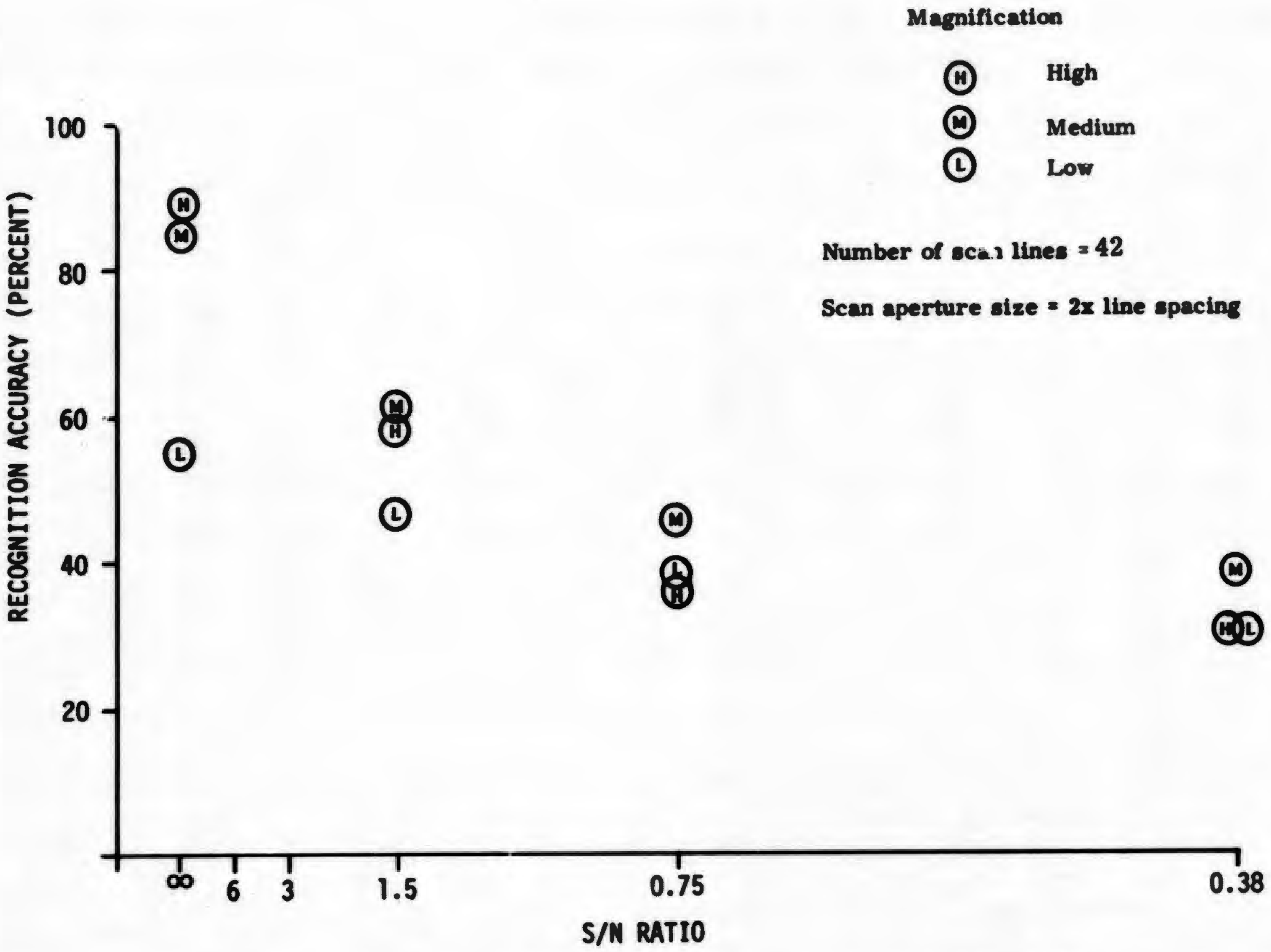


Figure 40. High magnification did not improve recognition in the typical case, where either the resolution was not high or there was some amount of noise.

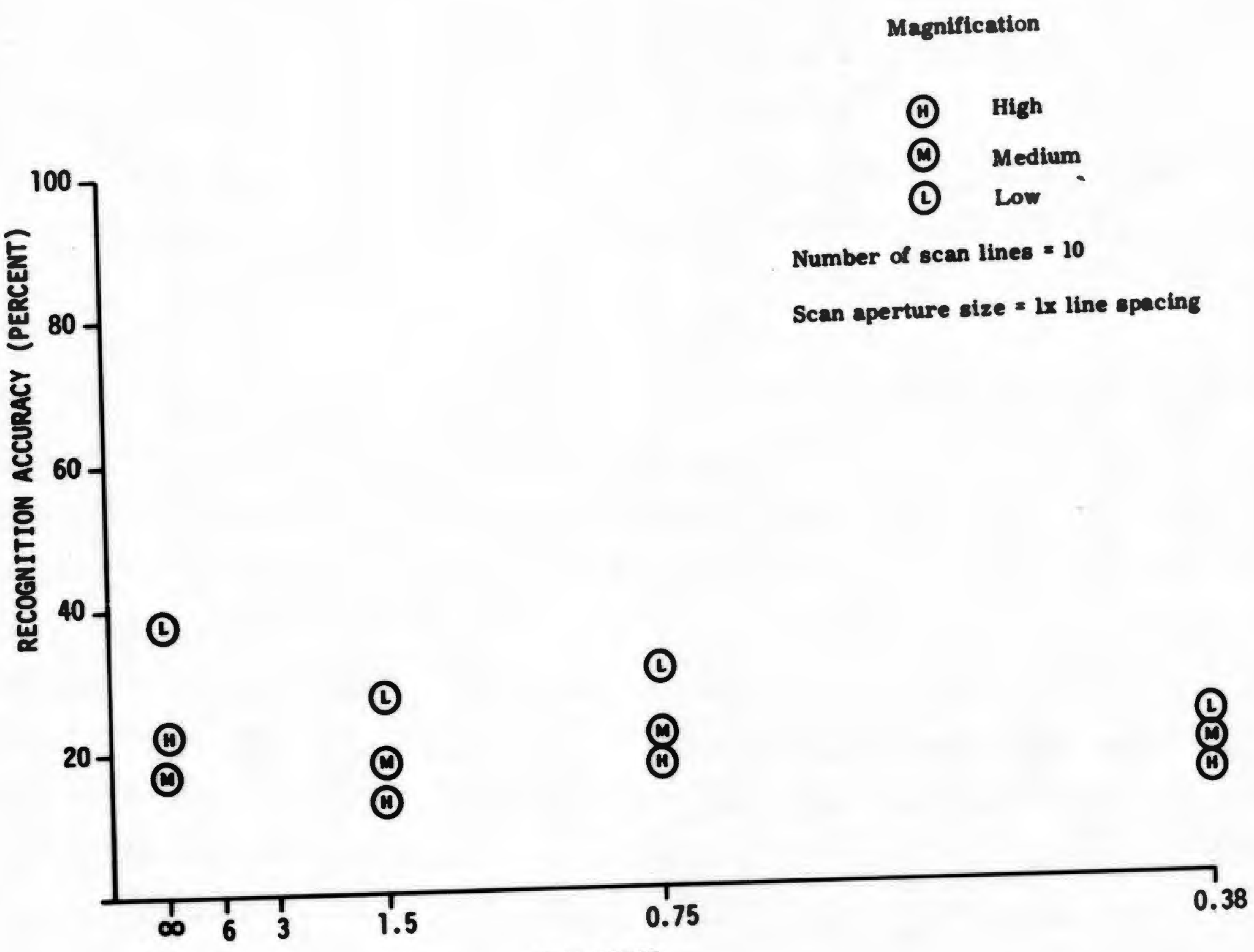


Figure 41. Low magnification improved recognition for highly degraded images.

No Noise

Number of Scan Lines	Scan Aperture Size			
83	1x 85	2x 83	4x 75	8x 55
42		1x 74	2x 76	4x 68
21			1x 70	2x 55
10				1x 26

S/N = 0.75

Number of Scan Lines	Scan Aperture Size			
83	1x	2x 23	4x 42	8x 47
42		1x 36	2x 40	4x 38
21			1x 27	2x 40
10				1x 23

SN = 1.5

Number of Scan Lines	Scan Aperture Size			
83	1x 45	2x 46	4x 62	8x 48
42		1x 46	2x 54	4x 54
21			1x 45	2x 44
10				1x 19

S/N = 0.38

Number of Scan Lines	Scan Aperture Size			
83	1x	2x	4x 31	8x 41
42		1x	2x 33	4x 26
21			1x 23	2x 32
10				1x 18

Figure 42. Recognition accuracy (%) as a function of number of scan lines and scan aperture size for four noise levels. Blank cells represent conditions which were excessively noisy and therefore not included in the study. (Scan aperture size is defined in terms of the line spacing. For example, 2x means that the scan aperture is 2 times the line spacing. Within each column, all scan apertures are the same size.)

System resolution--System resolution, measured with the 3-bar pattern and the new checkerboard pattern, is shown as a function of noise, scan aperture size, and number of scan lines in Figures 43 and 44, respectively. Comparing these data with those in Figure 42, a general correspondence can be seen between measures of resolution and recognition performance. For those cases where measured resolution was high, recognition performance also was generally found to be high. However, regression analysis showed that resolution measured using the checkerboard pattern correlated higher with performance than measures made with the 3-bar pattern. The reason can be seen in Figures 43 and 44. In general, noise had relatively little effect on the visibility of the 3-bar pattern. Since the visibility of the checkerboard pattern was affected by noise, it should not be surprising that it was a better predictor of recognition.

The relationship between measured resolution and recognition is shown in Figures 45 (as measured by the 3-bar pattern) and 46 (as measured by the checkerboard pattern). The effects of including noise in the relationship are shown in Figures 47 (for the 3-bar pattern) and 48 (for the checkerboard pattern). These data offer further support of the argument in the above paragraph. Namely, noise adds little to the effectiveness of checkerboard resolution as a predictor because this measure of resolution already reflects the effects of noise. Once again Figure indicates that this does not hold for the 3-bar measure of resolution.

Resolution and target size--In discussing the relationship of various target measures to recognition performance, we will first review the Johnson criterion for recognition.[1] In implementing this criterion, the number of resolvable cycles of the system is measured using a 3-bar pattern. If the pattern has the same contrast as the target, and if the minimum target dimension subtends four resolvable cycles, the predicted probability of recognition is 0.50. Johnson offers a theoretical basis for using the minimum target dimension as a measure of target size; however, the data from the present study did not confirm the usefulness of this criterion. Figure 49 shows that the probability of recognition was about 0.50 when the minimum target dimension subtended four resolvable cycles. However, this criterion was a very fuzzy predictor. That is, the gradient was so shallow that even at eight resolvable cycles, the probability of recognition was not much more than 0.50. A criticism of our data is that we were initially using a 100 percent contrast 3-bar pattern, whereas for a strict application of the Johnson criterion we should have used a pattern of the

No Noise		Scan Aperture Size			
Number of Scan Lines	83	1x 50	2x 38	4x 20	8x 10
	42		1x 28	2x 18	4x 10
	21			1x 14	2x 9
	10				1x 9

S/N = 0.75		Scan Aperture Size			
Number of Scan Lines	83	1x	2x 25	4x 16	8x 9
	42		1x 20	2x 16	4x 9
	21			1x 14	2x 9
	10				1x 8

S/N = 1.5					
Number of Scan Lines	83	1x 31	2x 30	4x 18	8x 10
	42		1x 25	2x 18	4x 9
	21			1x 13	2x 9
	10				1x 9

S/N = 0.38					
Number of Scan Lines	83	1x	2x	4x 16	8x 9
	42		1x	2x 13	4x 9
	21			1x 10	2x 8
	10				1x 6

Figure 43. Resolution (number of resolvable cycles per frame height) measured with the 3-bar pattern, as a function of number of scan lines and scan aperture size for four noise levels. (Measured at high magnification.) Blank cells represent conditions which were excessively noisy and not included in the study. (Scan aperture size is defined in terms of the line spacing. For example, 2x means that the scan aperture is 2 times the line spacing. Within each column, all scan apertures are the same size.)

No Noise

Number of Scan Lines	Scan Aperture Size			
83	1x 42	2x 42	4x 31	8x 10
42		1x 31	2x 21	4x 10
21			1x 10	2x 10
10				1x 8

S/N = 0.75

Number of Scan Lines	Scan Aperture Size			
83	1x	2x 5	4x 10	8x 8
42		1x 4	2x 10	4x 8
21			1x 8	2x 5
10				1x 8

S/N = 1.5

Number of Scan Lines				
83	1x 5	2x 10	4x 10	8x 8
42		1x 5	2x 10	4x 8
21			1x 8	2x 5
10				1x 8

S/N = 0.38

Number of Scan Lines				
83	1x	2x	4x 5	8x 5
42		1x	2x 4	4x 4
21			1x 4	2x 4
10				1x 4

Figure 44. Resolution (number of resolvable cycles per frame height) measured with the checkerboard pattern, as a function of number of scan lines and scan aperture size for four noise levels. (Measured at high magnification.) Blank cells represent conditions which were excessively noisy and not included in the study. (Scan aperture size is defined in terms of the line spacing. For example, 2x means that the scan aperture is 2 times the line spacing. Within each column, all scan apertures are the same size.)

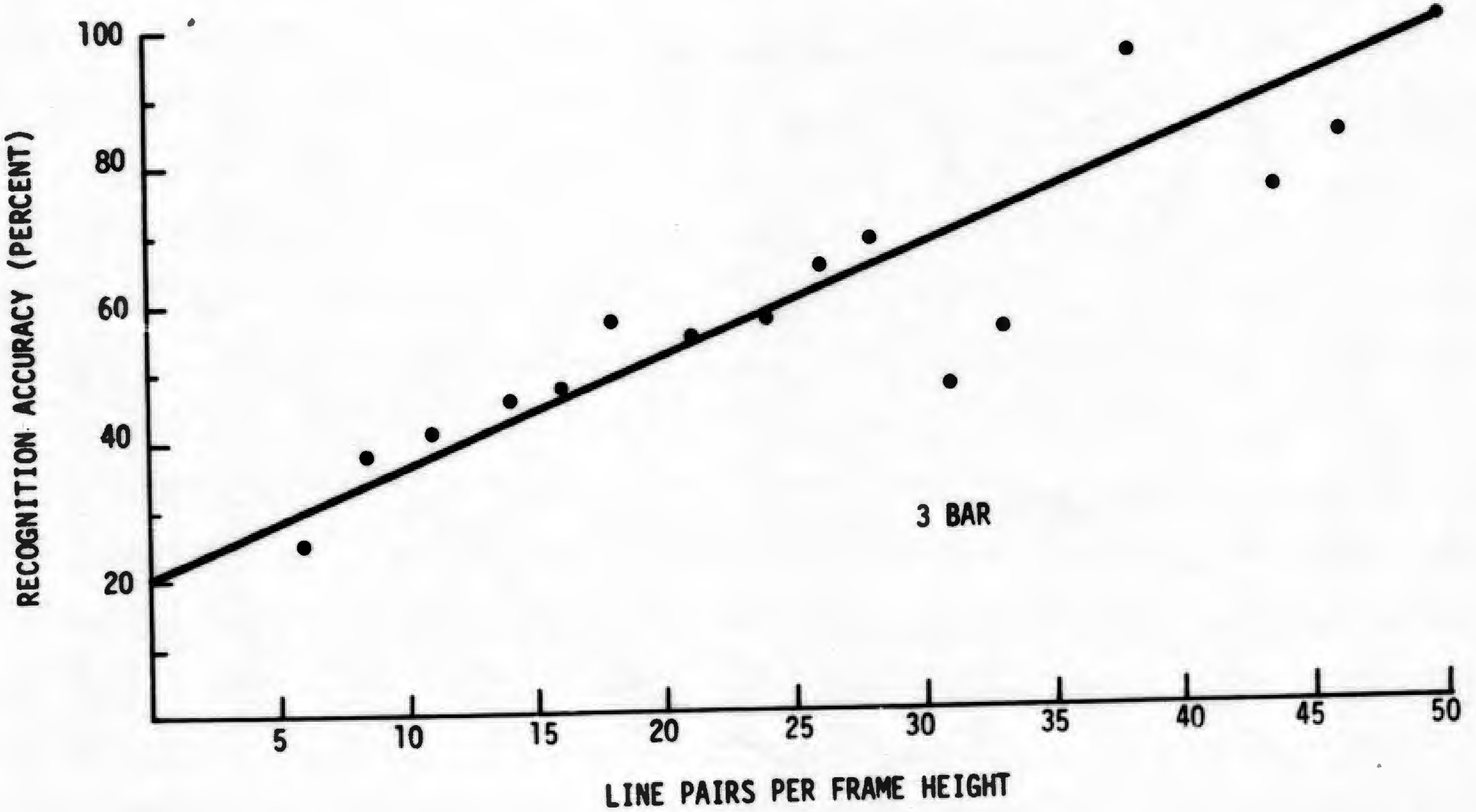


Figure 45. Recognition accuracy as a function of resolution as measured by the 3-bar pattern.

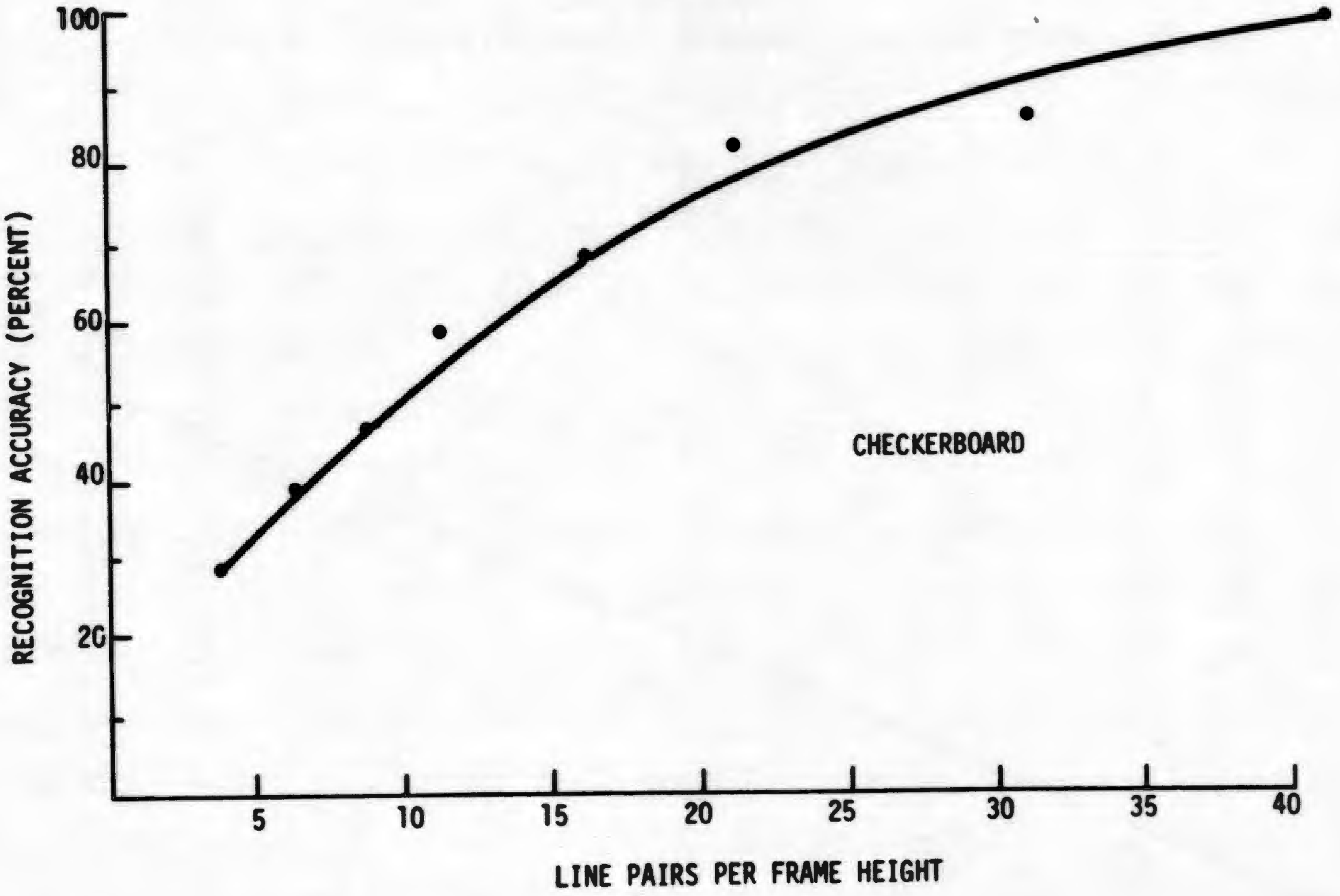


Figure 46. Recognition accuracy as a function of resolution as measured by the checkerboard pattern.

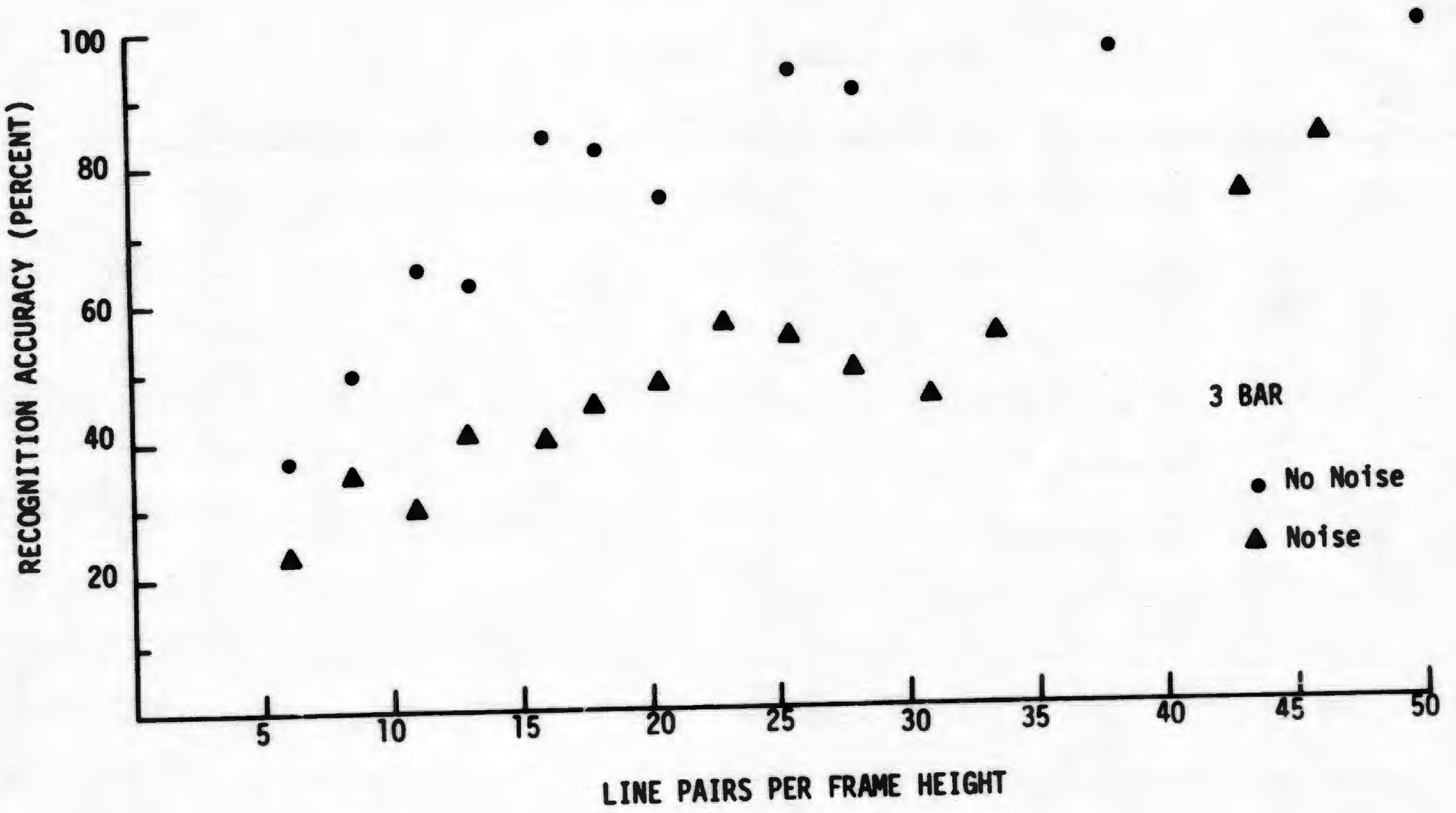


Figure 47. Recognition accuracy as a function of noise and resolution as measured by the 3-bar pattern.

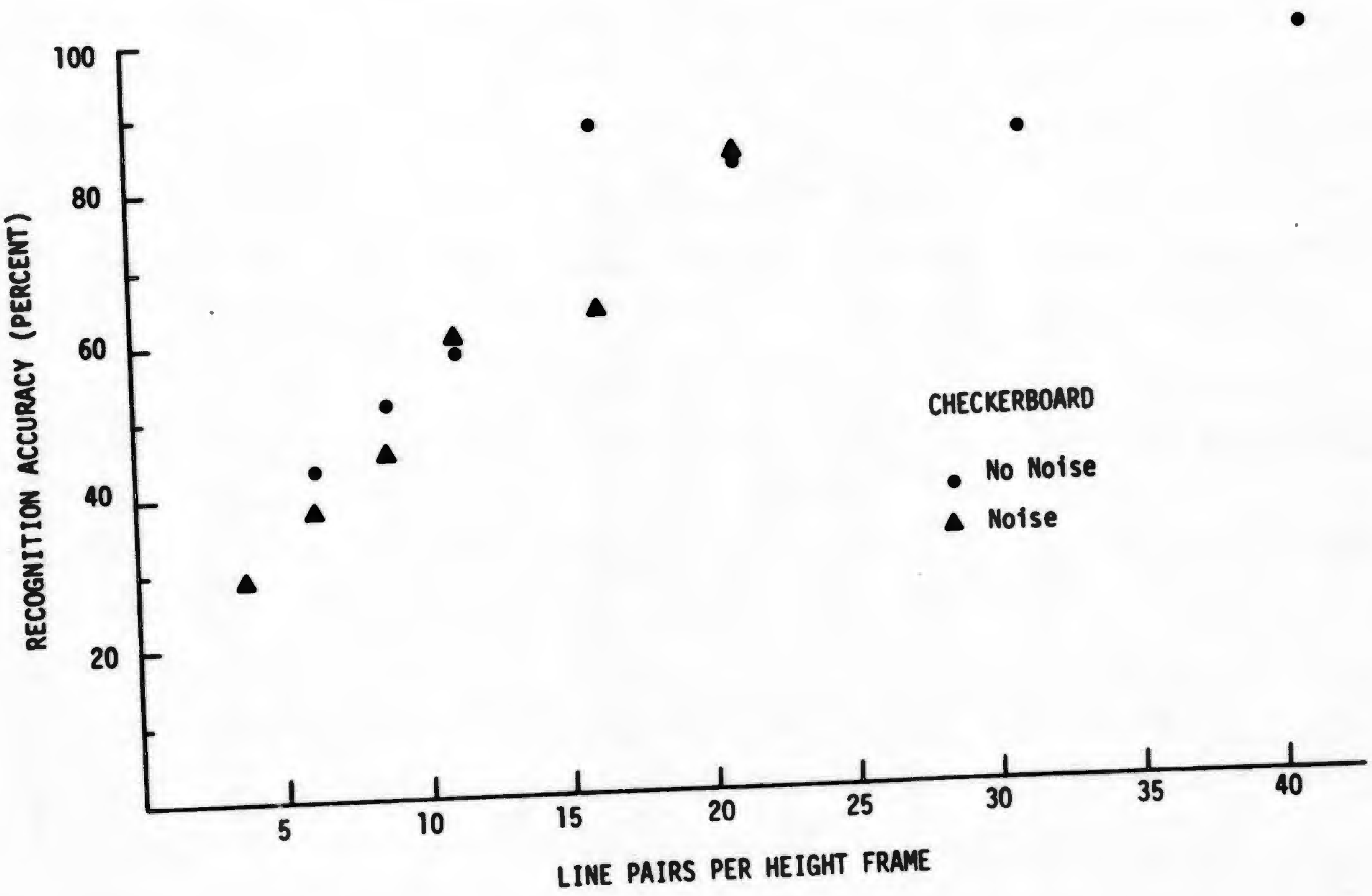


Figure 48. Recognition accuracy as a function of noise and resolution as measured by the checkerboard pattern.

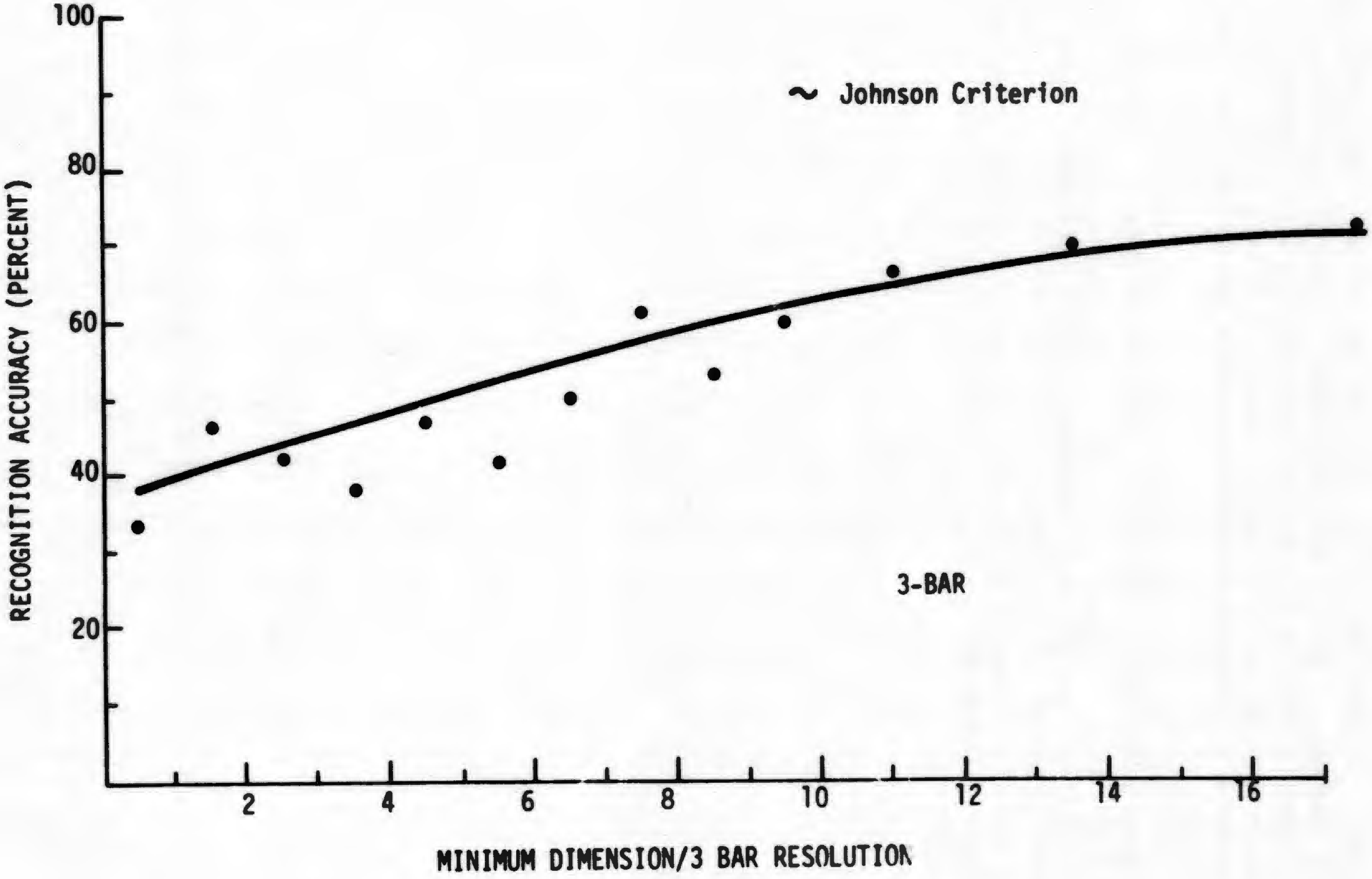


Figure 49. Recognition accuracy as a function of target size (minimum dimension) defined in terms of resolution (as measured by the 3-bar pattern).

same contrast as the target. Since the targets were of very high contrast (with an average contrast of 0.75), similar results were in fact obtained from subsequent measurements using a lower contrast set of patterns. When the checkerboard pattern was used to measure resolvable cycles (Figure 50), the minimum dimension improved as a predictor of recognition performance.

The maximum target dimension (Figure 51) provided a higher correlation with recognition performance than did the minimum dimension. The data show (Figure 52) that the maximum dimension, as compared with system resolution defined in terms of the checkerboard pattern, was the simplest, most useful predictor of recognition performance. This finding is possibly the major outcome of the study.

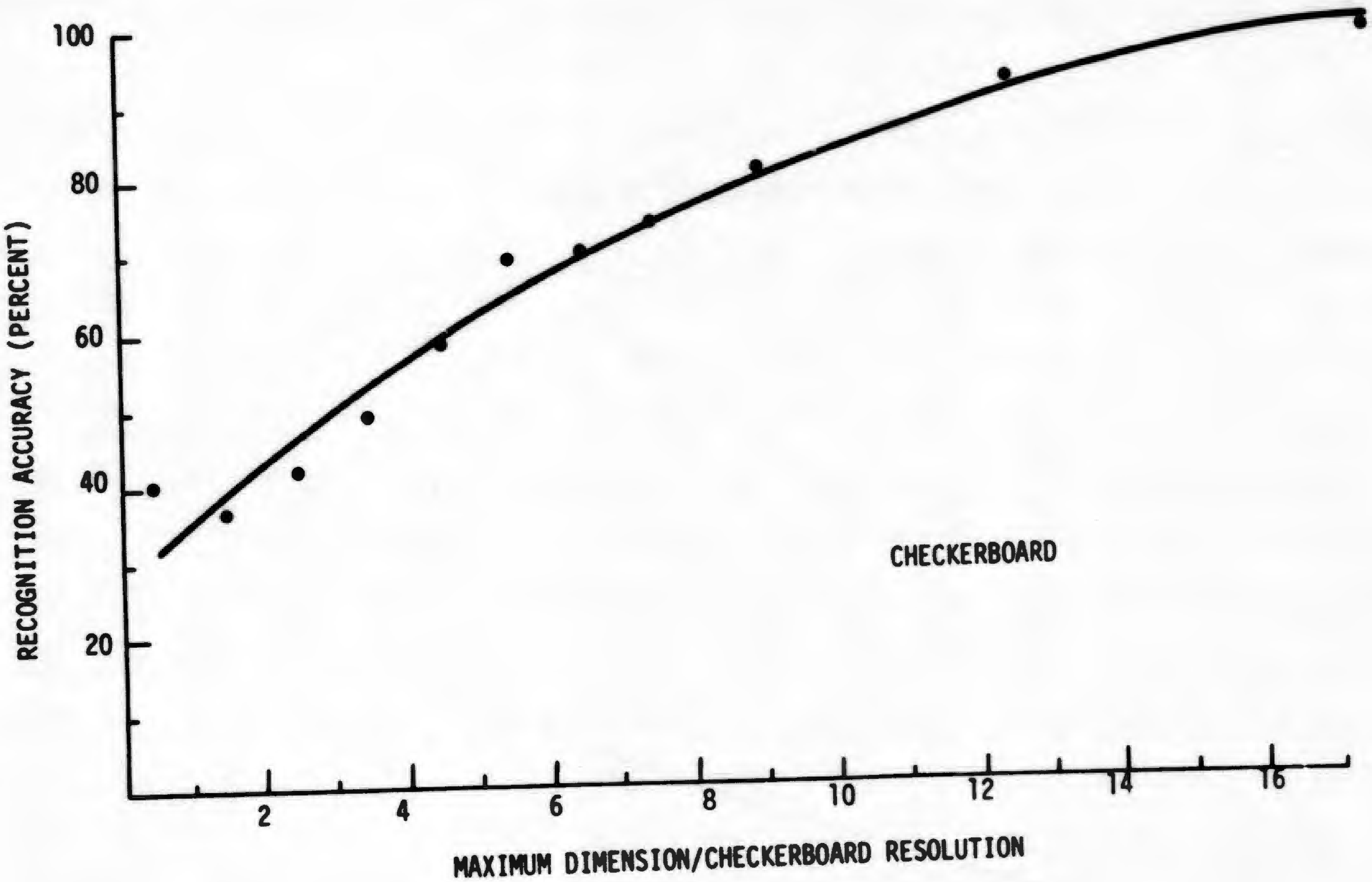


Figure 50. Recognition accuracy as a function of target size (minimum dimension) defined in terms of resolution (as measured by the checkerboard pattern).

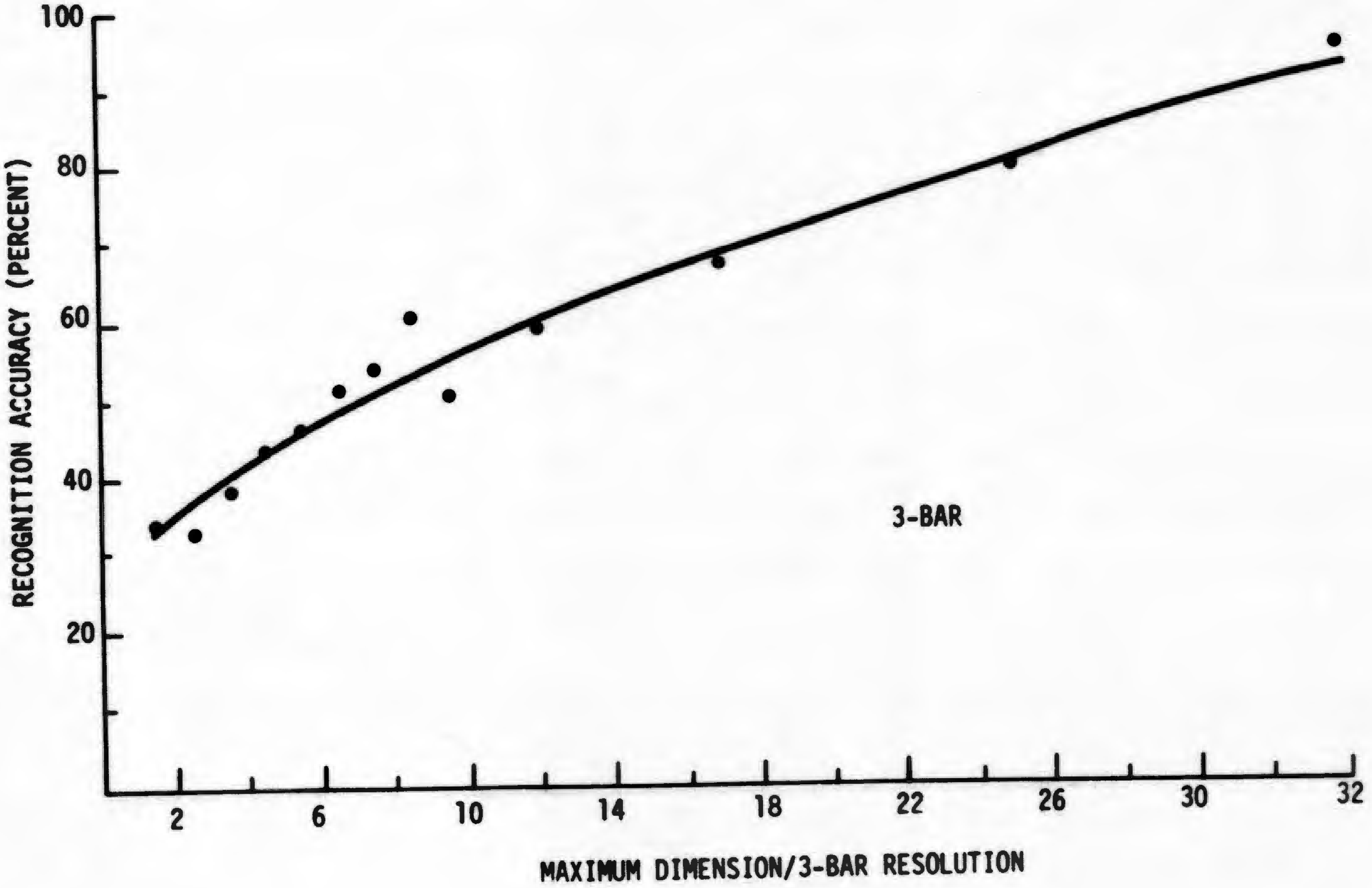


Figure 51. Recognition accuracy as a function of target size (maximum dimension) defined in terms of resolution (as measured by the 3-bar pattern).

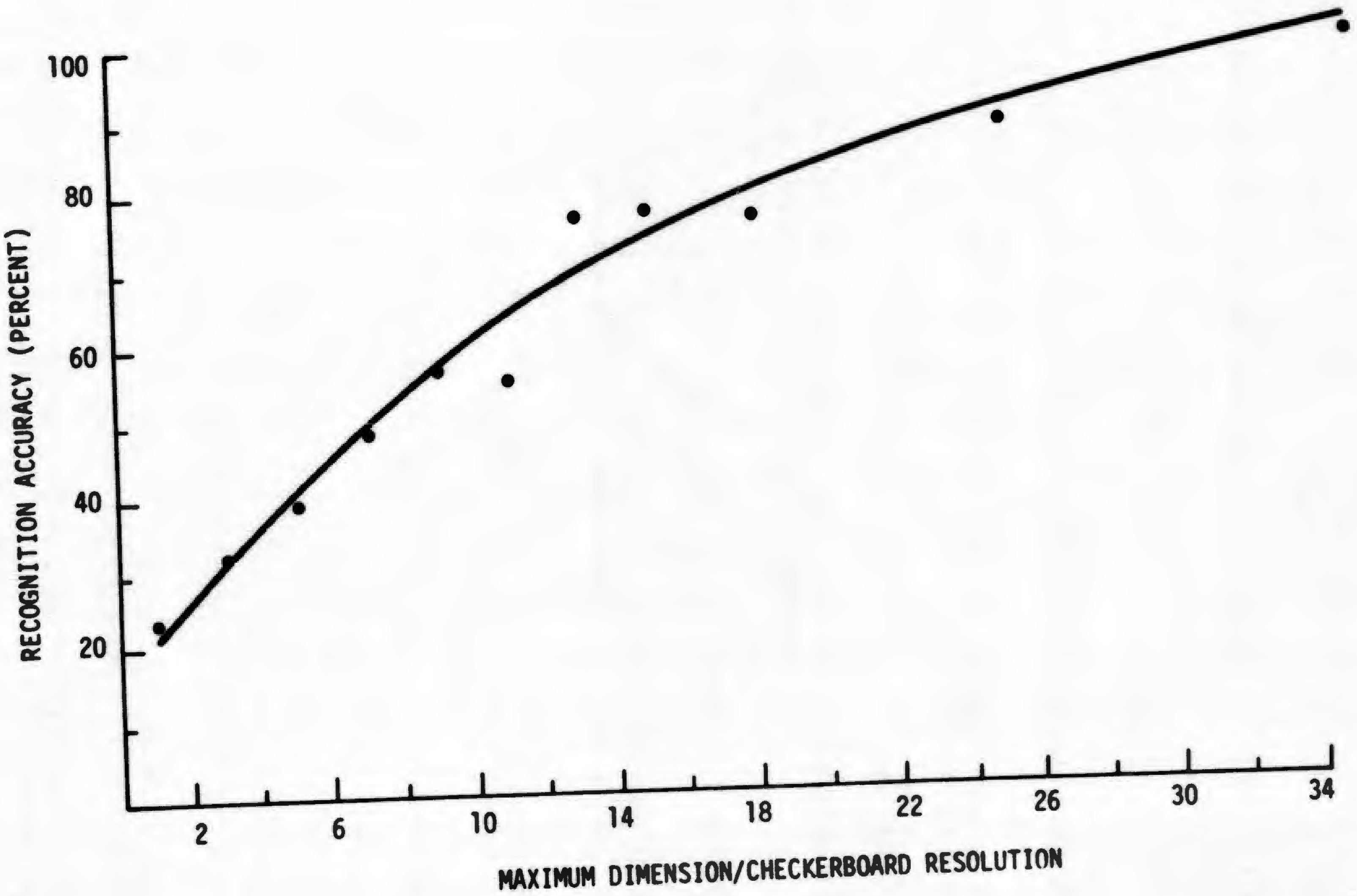


Figure 52. Recognition accuracy as a function of target size (maximum dimension) defined in terms of resolution (as measured by the checkerboard pattern).

SECTION IV

EXPERIMENT III: The Effects of Dynamic Noise on FLIR Target Recognition

SUMMARY

Objective: to determine the effect of dynamic noise on recognition of FLIR targets;

to compare the effects of dynamic and static noise over a range of image quality conditions.

Independent Variables:

1. Noise (Dynamic)--the random variation in luminance at each point in the display varied in time. Specifically, each point took on 24 discrete values per second.
2. Number of scan lines--the number of horizontal scan lines within the stimulus frame viewed by the subject.
3. Scan aperture size--the scanning aperture is assumed to be square. In the present study it was either 1, 2, 4, or 8 times as large as the scan line spacing.
4. Magnification--the angular size of the display. In the present study the display height was either 0.5, 1, or 2 degrees.
5. Target category--jeep, truck, gun, van, tank.

Results: Recognition accuracy data from 14,256 trials (24 subjects) were reduced and compared with the results of Experiment II.

1. Recognition accuracy for the different targets and the effects of main variables were highly consistant with the results of Experiment II.
2. Overall, at each noise level there was an average of 8 percent improvement in recognition when the noise was dynamic.
3. There were negligible differences between Experiments II and III in overall accuracy for the no noise condition.

METHOD

Design

The experimental design was essentially that used in Experiment II (Figure 3-1). The degradation conditions and stimuli of Experiments II and III were similar, the basic difference being that in Experiment III the noise was time-varying, as it is in real FLIR systems. These time varying fluctuations in luminance were simulated by producing film strips from individual frames (with noise) which were equivalent to the stimuli of Experiment II. The reason for comparing the two kinds of noise was largely methodological--i.e., to provide a basis for applying experimental results from static noise to displays containing dynamic noise. The following independent variables were investigated in this experiment:

Number of scan lines--It was assumed that a scan aperture (or detector) sweeps the frame horizontally. There were either 83, 42, 21, or 10 scan lines for the frame.

Scan aperture size--The square scan aperture had either the same dimension as the spacing between scan lines (nominal case) or was 2, 4 or 8 times as large (overscanning).

Noise--Four noise levels were used for each combination of number of scan lines and scan aperture size. Noise for a single frame was defined, as in Experiment II, as a modification of the luminance of each elementary unit of area in the scene. If the noiseless luminance was B, then the luminance with noise was $B + N_i$, where N_i was a random variable having a gaussian distribution with zero mean and a variance which depended on the selected noise level. Since much more noise can be tolerated at coarser resolution (fewer scan lines or larger aperture), higher noise levels were used for those conditions. For each resolution condition, the levels of noise were selected so the highest level would usually obliterate the target.

Magnification--Display heights of 0.5, 1, or 2 degrees were produced by varying the distance between the subject and the display.

Target category--The original target imagery for this experiment was the same as that in Experiment II. The five target categories were: jeep, truck, gun, van, and tank. Based on the target difficulty data, the eleven target examples that were omitted from further analysis in the previous study were also omitted from this study (see Figure 3-9). Film processing problems also caused a number of other degraded target examples to be excluded from the final stimulus film, resulting in an unequal number of target examples in each condition. The final stimulus film contained a total of 198 degraded target examples.

Twenty-four college students were paid for their participation in the experiment. Each pair of subjects were trained on 140 static target slides. The movie film containing the 198 degraded targets was presented to each pair of subjects at three viewing distances corresponding to the three magnification conditions. The order in which the size conditions were experienced was balanced across pairs of subjects. The experimental data consisted of recognition accuracy scores from a total of 14,256 trials.

Stimuli

Film strips of 198 degraded targets were produced by digital image processing and animation techniques. The steps involved in the image processing are shown in Figure 53.

The magnetic tape representations of the original target examples of Experiment II (Figure 30) served as input for the processing. See Appendix A for a description of the procedure used to obtain the original FLIR imagery. As in Experiment II, each original target image was then degraded by computer according to specific levels of number of scan lines, scan aperture size, and noise. A description of this computer processing may be found in Appendix B. Each time a target was processed, different values of noise were randomly selected from the distribution and added to the image. A positive transparency of each image was then produced using the Optronics film-writer (Appendix B). Figure 54 shows several targets at this stage of the process.

Each of the six 50 x 100 mm transparencies of a degraded target were then photographed four times with the animation camera according to a pseudo-random schedule. See Appendix D for a detailed description of the animation process and facility. This resulted in a filmstrip containing 24 frames, each a 18.8 x 24.4 mm negative of the target.

The filmstrip of each degraded target was then copied five times by a Bell & Howell contact copier, so that the resultant positive strips consisted of 120 frames. These target strips, with numbered spacers between, were then spliced together to form the stimulus movie film. When projected by a 35 mm projector at 24 frames per second, each target appeared on the display for five seconds, with a two second interval between each trial as in Experiment II.

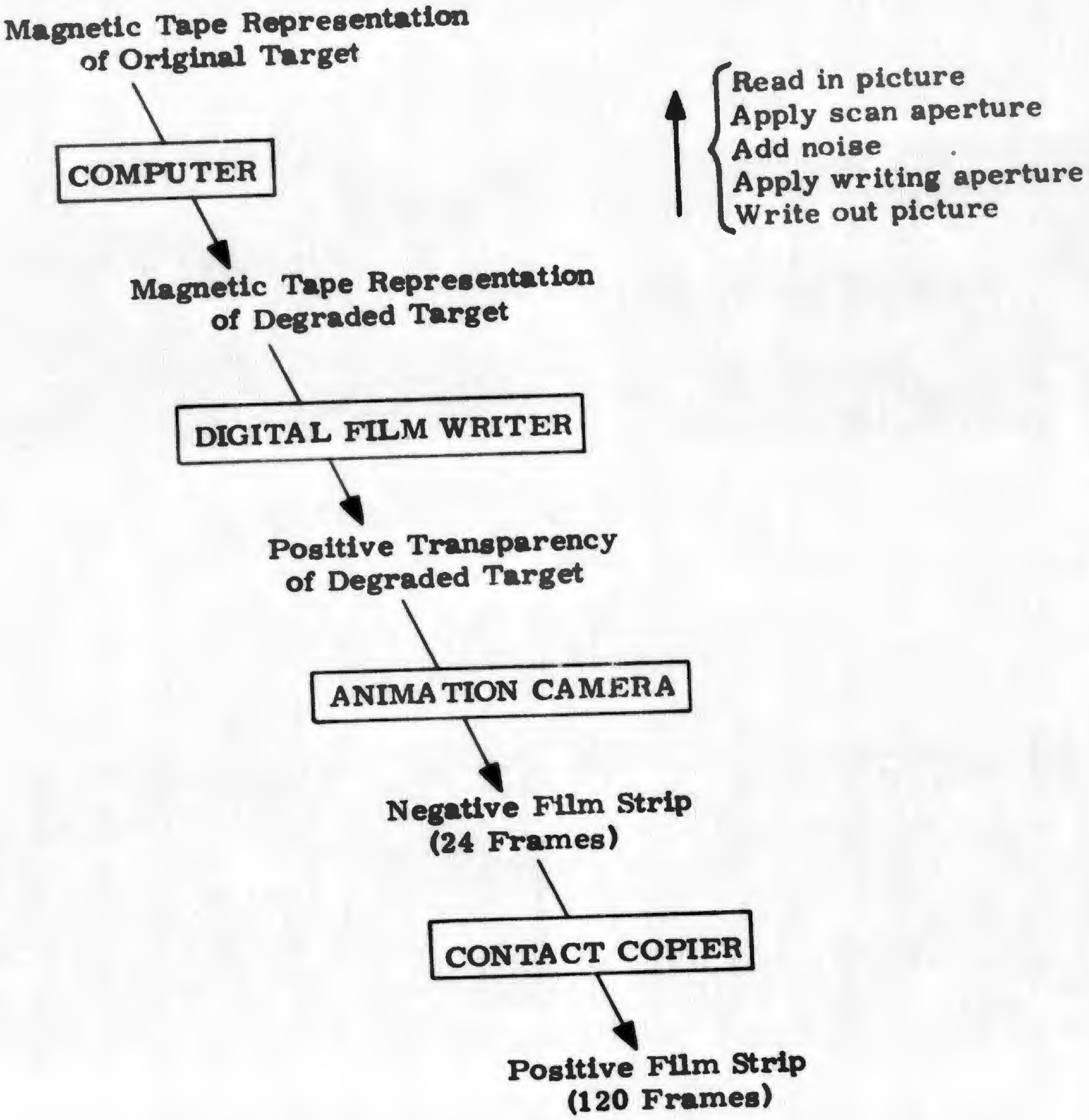


Figure 53. Image processing steps of Experiment III.

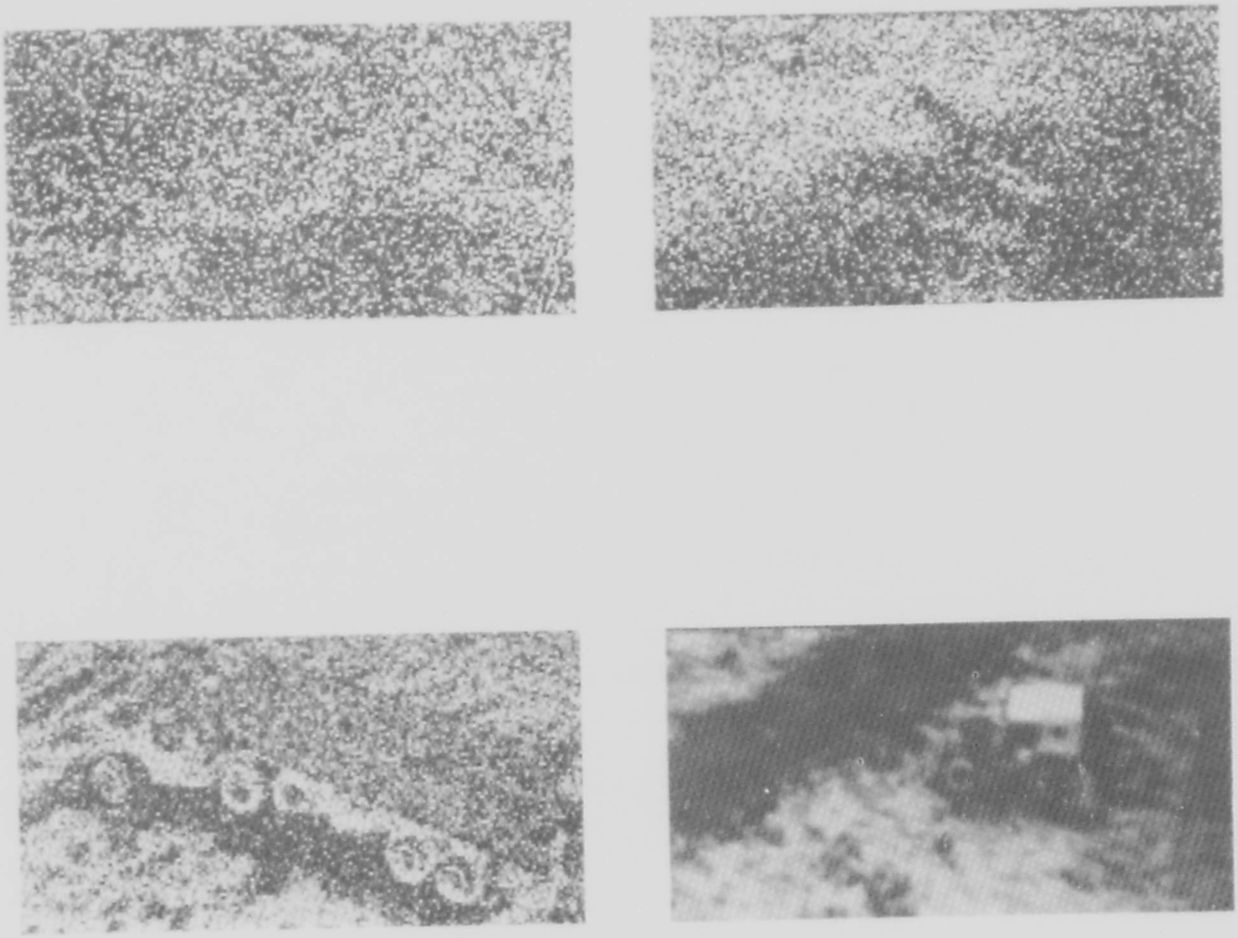


Figure 54. Target transparencies produced by digital image processing techniques. Each of the above targets was processed under the same scan line/scan aperture condition, but at a different noise level.

Apparatus

The main components of the experimental apparatus are shown in Figure 55 and listed below.

- 35 mm movie projector--to present the stimulus movie film
- Rear projection screen--a high quality practically grainless screen having a gain of 2.0
- Background projector--to project a target frame surround of neutral content
- Training slide projector--to project the slides containing training targets
- Rear projection screen for training slides

The stimulus film was projected by a 35 mm Super Simplex projector (a standard theatre type unit) with a seven-inch Kodak projection lens. Light was supplied by a conventional carbon arc lamp and adjusted so the average luminance of the projected targets was 92.5 cd/m^2 (27 fL). The frame registration of the projector was within .038 mm, and the film was projected at a rate of 24 frames per second. The section of film containing each target was 120 frames long and appeared on the display for five seconds. There was a two second interval between targets during which the number of the next trial was displayed.

The size of the frame containing the dynamic targets was 21 x 38 mm on the rear projection screen. The dynamic targets were surrounded by a 180 x 230 mm field of neutral content to reduce the glare of the target frame. This field was projected by a Kodak Carousel projector with a three-inch lens. A beam converger (Figure 56) was used to combine the stimulus and background. Size variation of the targets was achieved by adjusting the distance between the subject and the display. Subjects were seated either 61, 122, or 244 cm (2, 4, or 8 ft.) from the display for the three magnification conditions.

The training targets, projected by a Kodak Ectagraphic projector, were 21 x 38 mm on the training rear projection screen.

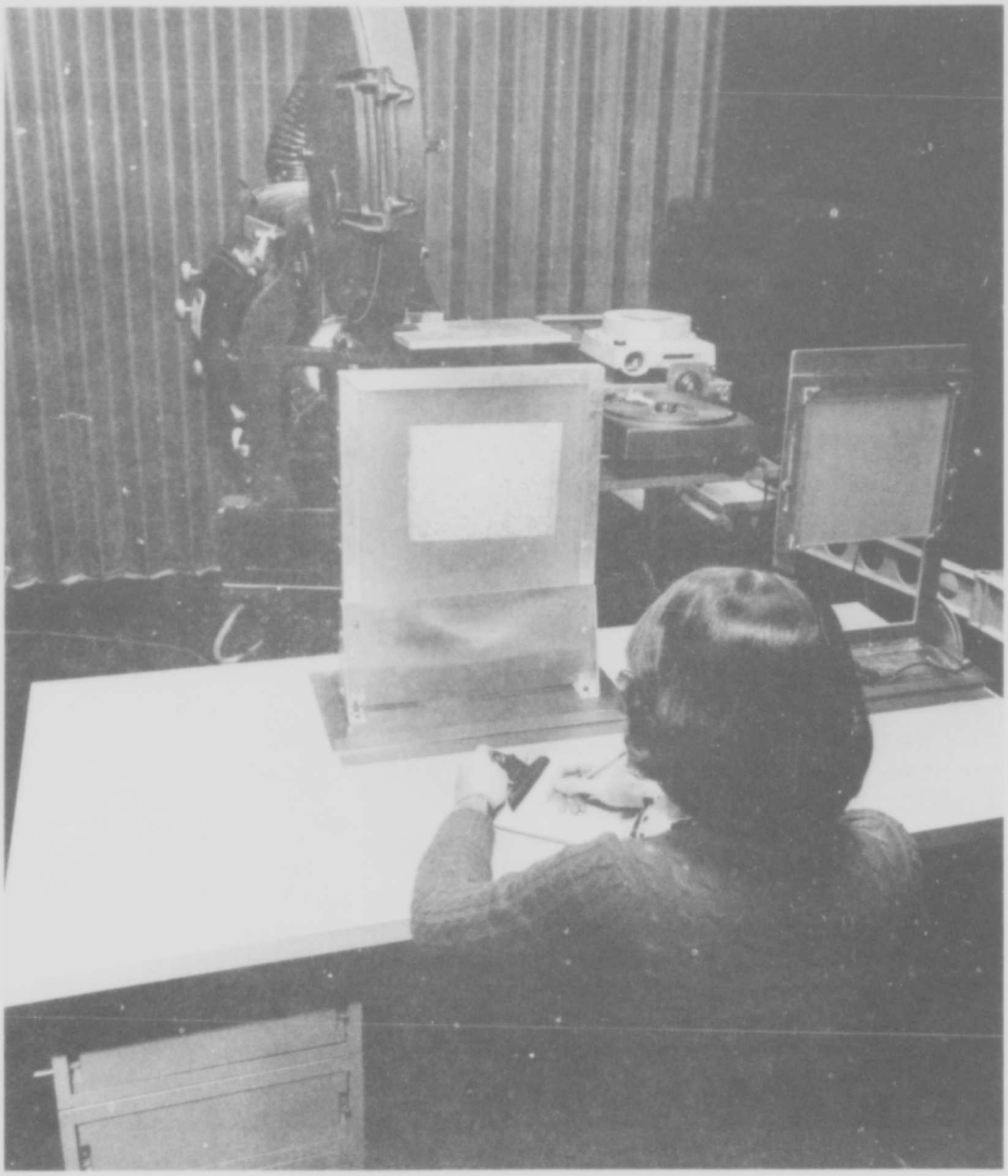


Figure 55. The experimental apparatus (from left to right): 35 mm movie projector; rear projection screen; background projector; training slide projector; training rear projection screen.

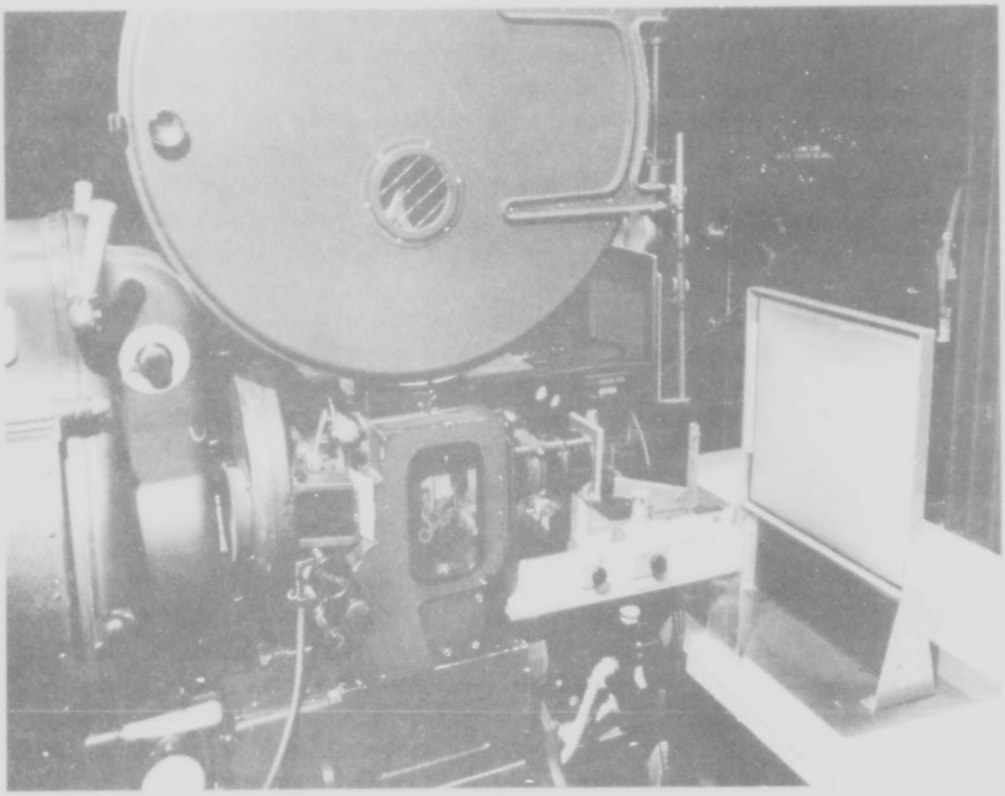


Figure 56. Side view of apparatus: 35 mm movie projector; background projector; beam converger; and rear projection screen.

Procedure

Data were collected from two subjects per session. The near acuity of each subject was first tested using a Titmus Optical T/O Vision Tester. Subjects were required to have at least 20/20 near acuity with refractive correction. Instructions were then read to the subjects to acquaint them with the experimental task (Appendix C).

The training session was similar to that in Experiment II. Subjects were seated 61 cm (2 ft.) from the screen for the entire training session. All training targets were therefore viewed at the highest magnification. The first set of forty slides consisted of targets with no noise. Subjects were encouraged to respond verbally to these slides. The slides were manually advanced by the experimenter, who indicated the correct response for each slide. The second set of forty slides was automatically timed so that each slide was presented for 8 seconds. These slides contained a low level of noise. The experimenter continued to give feedback while the subjects checked their responses on the response sheet.

The third set of sixty slides, which contained a higher level of noise, was also automatically timed so that each slide was presented for 8 seconds. For this set, no feedback was given and subjects indicated their response to each trial on a response sheet. In order to participate in the main experiment, subjects were required to meet a criterion level of performance on this set.

The reel of movie film contained 198 targets and took approximately 25 minutes per showing. A target was displayed for five seconds, with a two second interval between trials. During this interval, the number of the next trial was displayed to prevent subjects from losing their place on the response sheet. For a given trial, a response was made by writing the initial or first two letters of the target type next to the trial number. Each pair of subjects viewed the film at all three distances, with about a five minute break between sessions while the film was rewound.

RESULTS

The results from the present experiment are highly consistant with those from Experiment II. Recognition accuracy for the different targets (Figure 57), the effects of magnification (Figures 58, 59, 60), and, most important, the main variable effects (Figure 61) are much the same as in Experiment II. However, there appears to be considerably more variability

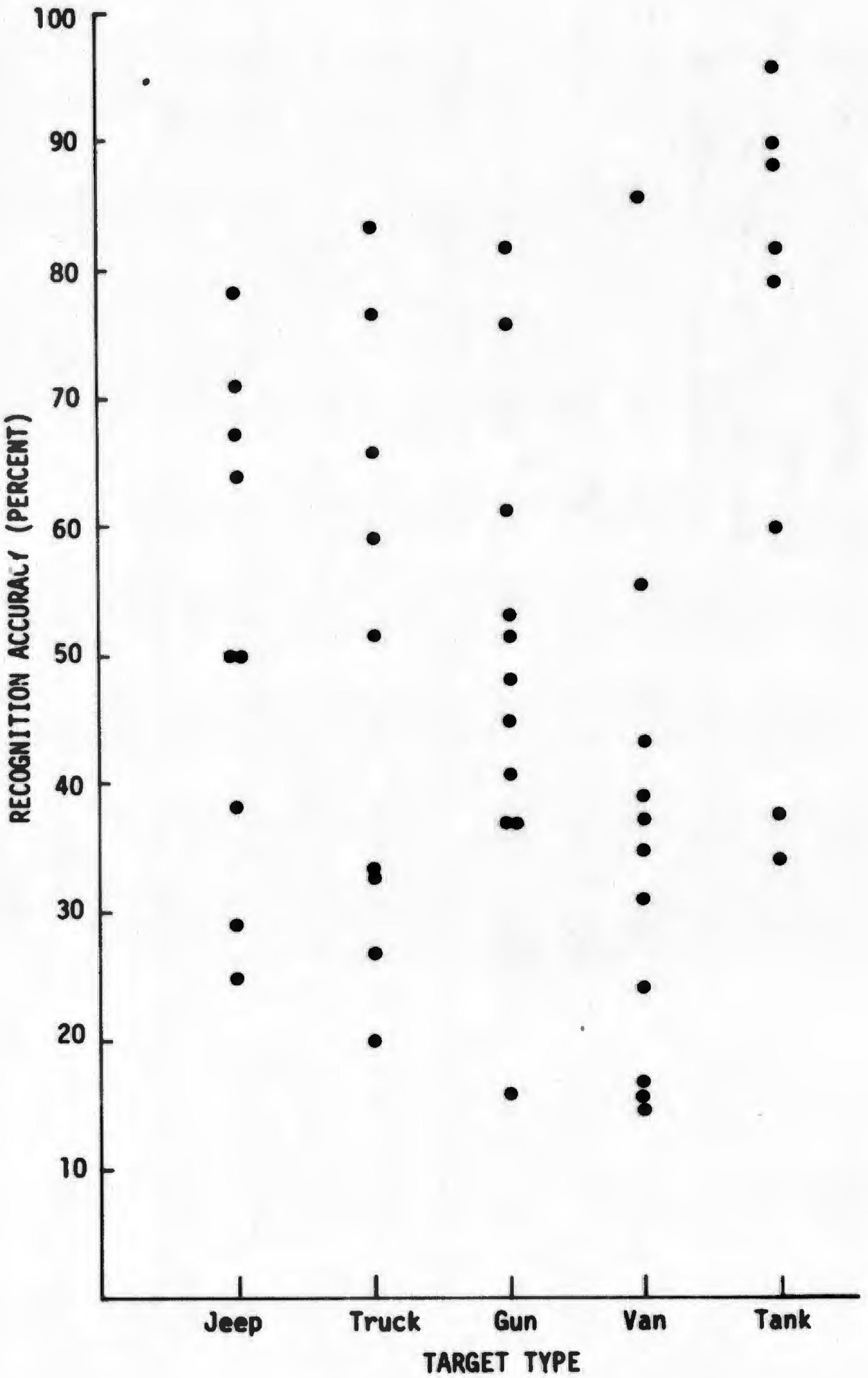


Figure 57. Recognition accuracy for the five target categories. Each dot represents a target example.

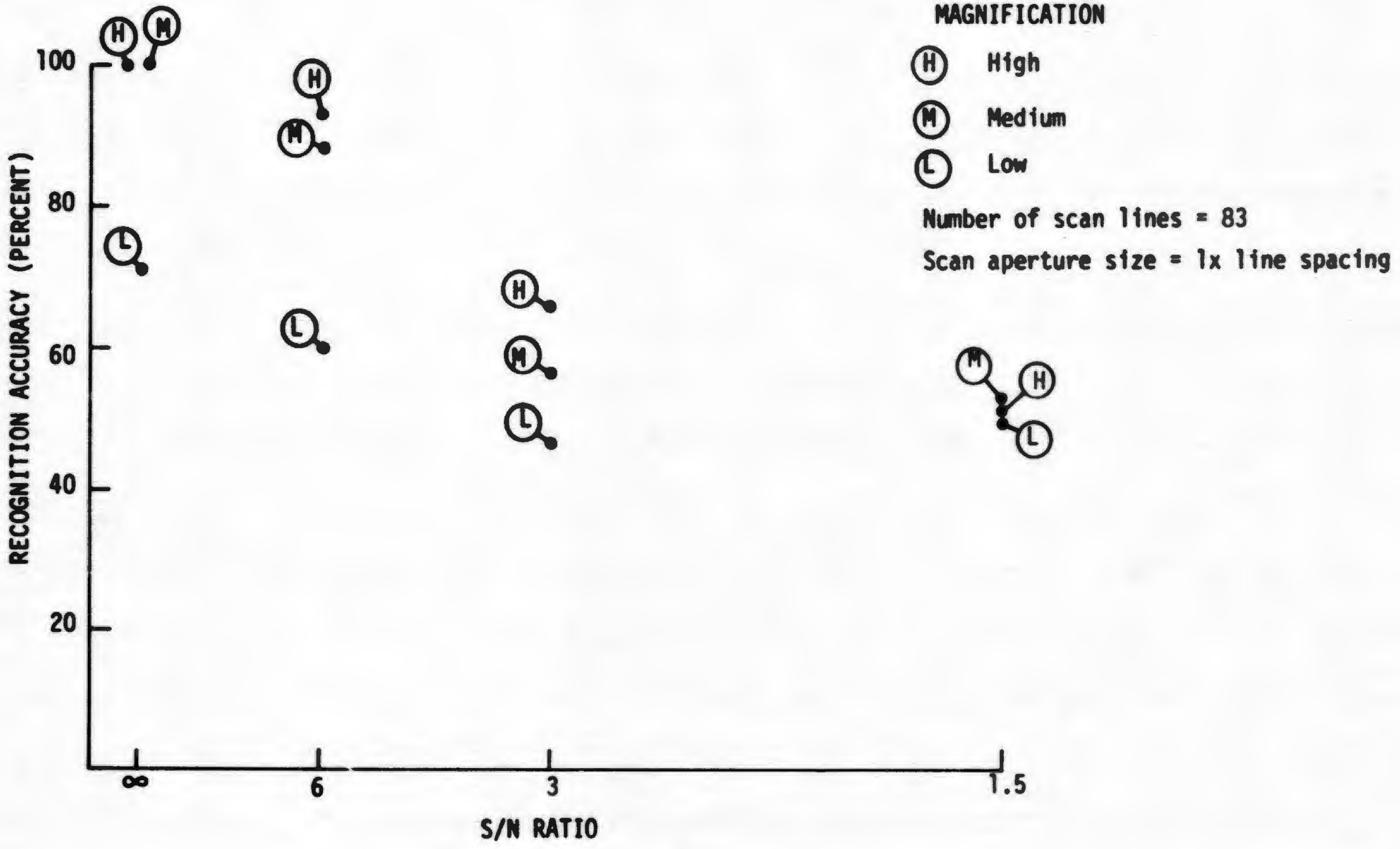


Figure 58. High magnification improved recognition for high resolution and high S/N.

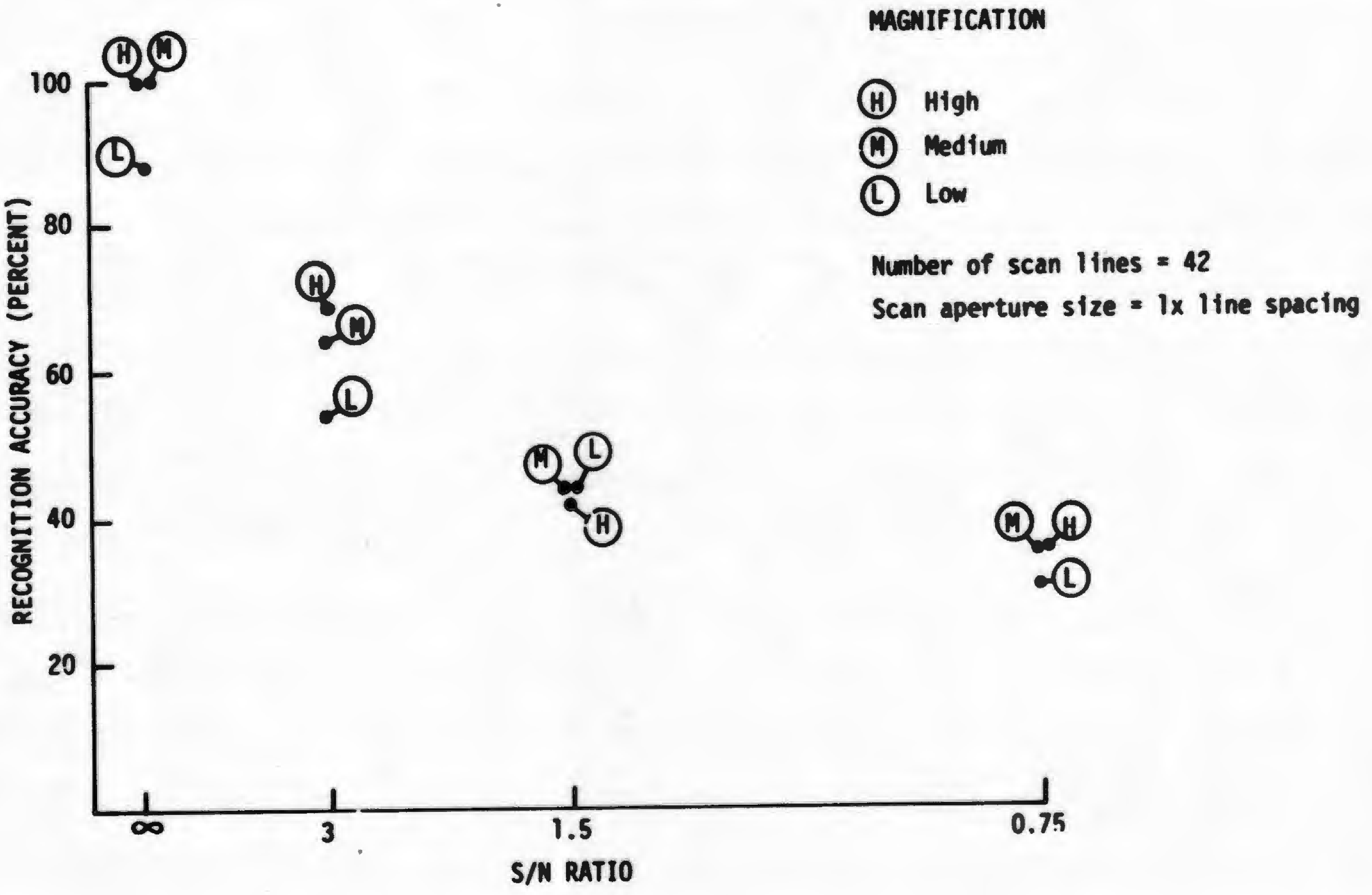


Figure 59. High magnification did not improve recognition in the typical case, where either the resolution was not high or there was some amount of noise.

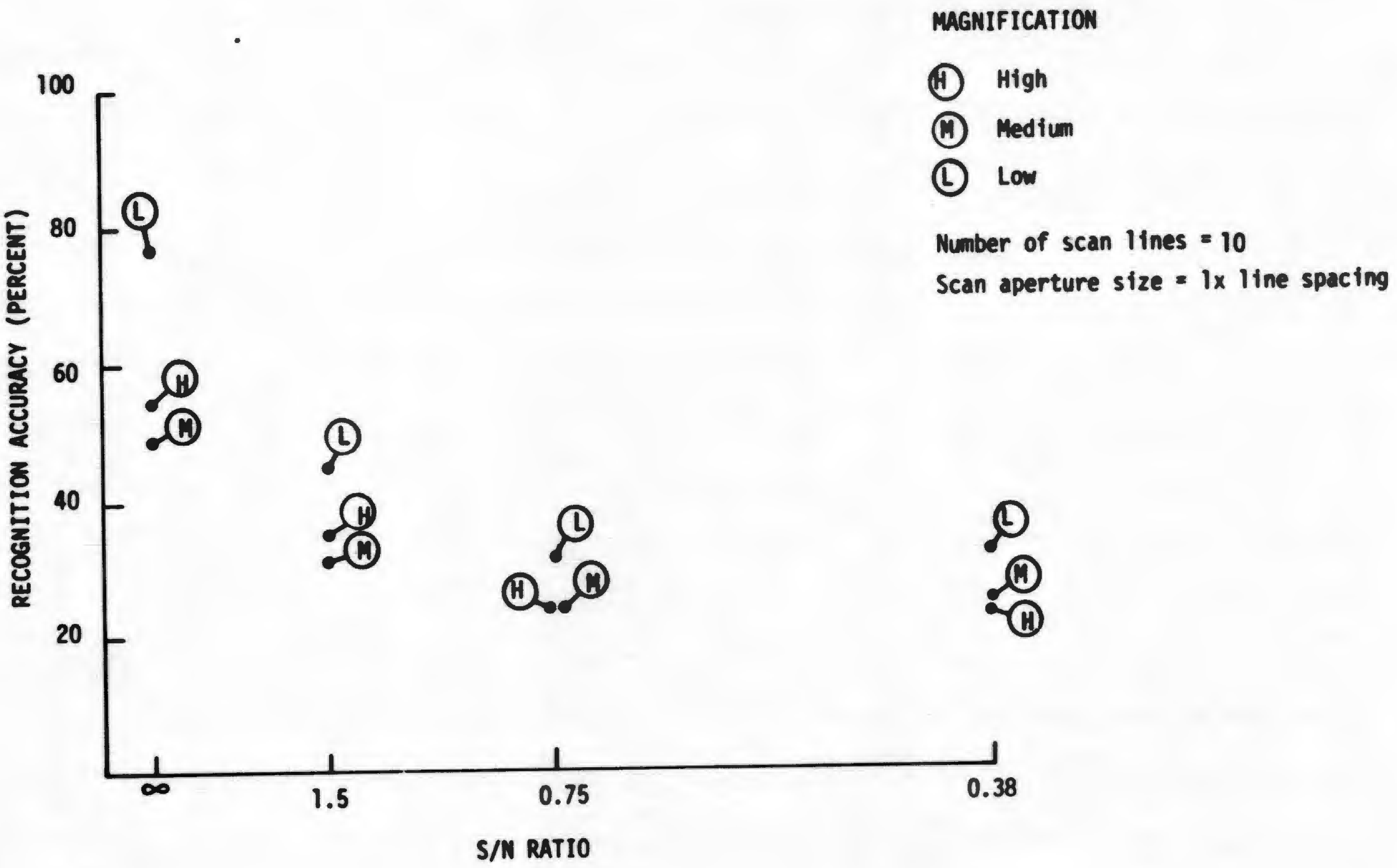


Figure 60. Low magnification improved recognition for a highly degraded image.

No Noise

Scan Aperture Size

Number of Scan Lines	1x	2x	4x	8x
83	90	69	51	93
42		1x 96	2x 96	4x 59
21			1x 67	2x 13
10				1x 60

S/N = .75

Scan Aperture Size

Number of Scan Lines	1x	2x	4x	8x
83		-	78	46
42		1x 33	2x 46	4x 38
21			1x 36	2x 47
10				1x 26

S/N = 1.5

Scan Aperture Size

Number of Scan Lines	1x	2x	4x	8x
83	52	50	81	46
42		1x 43	2x 55	4x 47
21			1x 43	2x 63
10				1x 38

S/N = .38

Scan Aperture Size

Number of Scan Lines	1x	2x	4x	8x
83			32	46
42		1x	2x -	4x 49
21			1x 44	2x 27
10				1x 26

Figure 61. Recognition accuracy (%) as a function of number of scan lines and scan aperture size for four noise levels. Blank cells represent conditions which were excessively noisy and not included in the study. (Scan aperture size is defined in terms of the line spacing. For example, 2x means that the scan aperture is 2 times the line spacing. Within each column, all scan apertures are the same size.)

in the data from this experiment, due presumably to the uneven number of trials within each condition.

Overall, at each noise level there was an average of 8 percent improvement in recognition when the noise was dynamic. This is approximately equivalent to the effect of doubling the signal-to-noise ratio. The mean recognition accuracies for the main levels of S/N in Experiments II and III are shown in Table 9. The negligible difference in overall accuracy for the no-noise condition (the small number of target examples in the individual cells led to the variation therin), supports the valid comparison of the experimental results from the two experiments despite the differences in the image processing systems.

Table 9. RECOGNITION ACCURACY (%) AS A FUNCTION OF S/N IN EXPERIMENTS II AND III (FROM FIGURES 42 AND 61).

		S/N			
		None	1.5	.75	.38
Type of Noise	Static	67	46	35	29
	Dynamic	69	52	44	37

The objective of the present experiment was to determine the relative effects of static and dynamic noise. The results indicate a degree of equivalence and provide a basis for extending experimental results from static imagery to systems of dynamic imagery.

SECTION 5

DISCUSSION

How do sensor-display system variables affect the recognition of targets? The answer can be understood in terms of the framework illustrated in Figure 62. The various system parameters (such as number of scan lines, scan aperture size, magnification) affect image quality. The characteristics of the real target also affect image quality, since the target signal strength is a factor in determining system gain, which, in turn, affects the display noise. The target characteristics together with the quality of the image define the displayed information--the displayed target. The probability of recognizing the target then depends on the displayed target relative to the information required to recognize that target.

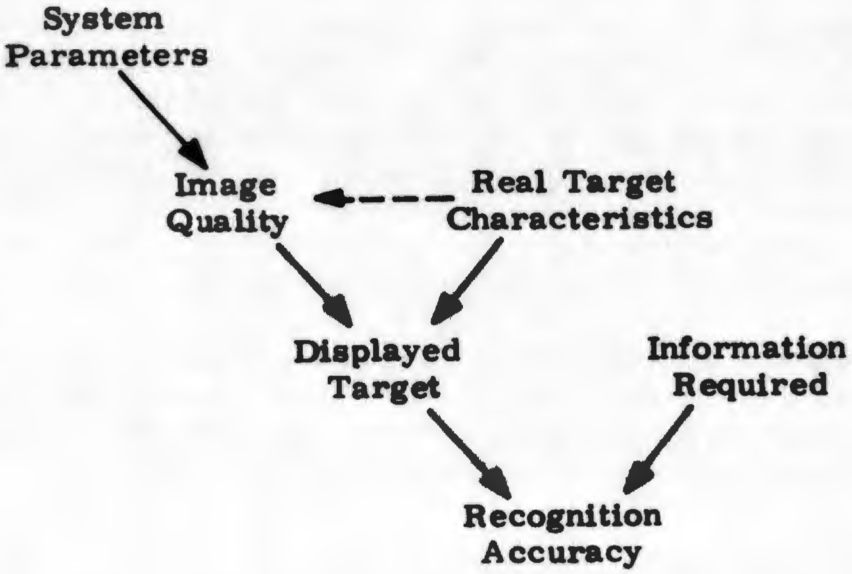


Figure 62. Factors affecting target recognition.

We now will discuss how the results of our studies aid in the understanding of the relationships shown in Figure 62.

SYSTEM PARAMETERS

Our studies indicate which system parameters affect image quality. It is clear that raster sampling dominated image quality and that the frequency response along the line (i.e., MTF) had negligible effect over a relatively broad range of values. Noise had a large effect on image quality. However, the effective signal-to-noise ratio could be improved by increasing the scan aperture size. By doing this, the loss in resolving power was more than compensated for by the reduction in noise.

These findings lead us to hypothesize that a more effective way to increase the scanning aperture is to increase it only in the direction of scan (horizontally). By doing this, noise would be reduced only at the cost of MTF. But since the loss of MTF would have little effect on image quality, we would expect greater overall improvement than if we increased the scanning aperture both horizontally and vertically. This may be considered to be a question for future research.

We found that magnification (or display size) can help, up to a point. No improvement was found when the target's minimum dimension was increased beyond 40 arc minutes. In fact, the recognition of a target at 40 arc minutes was better than at 20 arc minutes only when the resolution was high and the noise was low. Thus, it is often sufficient for the target's minimum dimension to be about 20 arc minutes. When system resolution is very low, magnification hurts rather than helps. Then, the minimum dimension should be even less than 20 arc minutes.

Finally, we found that both static and dynamic noise had the same type of effect on image quality. Thus, results from experiments using static presentations can be validly applied to dynamic scenes if the matter of perspective change is of no significance.

IMAGE QUALITY

A good measure of image quality is required to predict target recognition. Although there are a number of proposed measures of image quality, only one has been systematically related to target recognition. Specifically, the 3-bar pattern has been effectively used to measure resolving power. Then, the probability of recognition is predicted by relating target size to the number of resolvable cycles defined by a set of size graded 3-bar patterns. This defines the Johnson criterion for recognition. However, we have found that a checkerboard test pattern was a better measure of image quality. A major reason for stating that it is better is that over the 40 main conditions (number of scan lines x scan aperture size x noise) in Experiment II, it had a much higher correlation with recognition accuracy than did the 3-bar pattern. The correlations with accuracy were 0.81 and 0.63 for the checkerboard measure and the 3-bar measure, respectively. The relative effectiveness of the two measures when related to target size can be seen in Figures 49 through 52. The main reason that the checkerboard measure is more effective is that it is more dependent on noise than is the 3-bar measure. The correlations between noise level and number of resolvable cycles over the 40 main conditions in Experiment II was 0.69 when using the checkerboard pattern and 0.44 when using the 3-bar pattern. Thus, the 3-bar pattern is not so sensitive to the effect of noise on target recognition as is the checkerboard pattern. In the noise-free case we would expect much less, if any, difference between the two measures. Otherwise, we strongly recommend using the checkerboard pattern to measure image quality. It is also recommended that a study be made of other alternative test patterns to select a best such pattern.

In practice, there are two ways for estimating the image quality of different systems: experimental and analytic. We could apply the actual or simulated system to a set of test patterns and measure the resolution. Alternatively, if the system configuration were well enough understood, its resolution could be predicted by mathematical analysis.

TARGET CHARACTERISTICS

The data showed that a measure of target size, such as maximum dimension or perimeter, in conjunction with a measure of system resolution was a good predictor of recognition accuracy. Specifically, the probability was 0.5 of recognizing a target whose maximum dimension equalled eight resolvable cycles. This result supports the general view that target size is a basic component for predicting recognition. However, this prediction is clearly inadequate, as shown by the great variance in recognizability for targets of the same size. Although it is generally believed that size and contrast are the basic target features for predicting recognition (and visibility), something more is needed.

To recognize a particular target, information is needed from the display regarding its size, shape, internal structure, details, light and dark regions, and so on. However, those features which must be seen are different for different targets even when they are of the same size. For one target it may be necessary to see a small detail. For another it may be necessary to see a large blob. What is really important is the size and contrast of those target features needed for recognition.

It may be that the best simple predictor is target size (perhaps augmented by contrast). But we believe that the size and contrast of the internal detail would provide a better base for prediction. At Honeywell, we have carried out a series of experiments on the visibility of target gratings and grids as a function of their spatial frequency (internal detail size) and modulation (internal detail contrast).[11] The visibility of this type of target depends neither on its size or its contrast with the background (which often has a value of zero). We believe that it is necessary and important to conduct an experimental study of this problem--to develop a simple method for characterizing target internal structure and contrast to be used in conjunction with a measure of system resolution to predict recognition accuracy.

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[11] L. G. Williams and J. M. Erickson, Dynamic Contrast Requirements, Honeywell Contract Report No. N00014-74-0076, February 1976.

APPENDIX A

OBTAINING ORIGINAL TARGET IMAGER

APPENDIX A

OBTAINING ORIGINAL TARGET IMAGERY

The original target imagery was obtained at the Honeywell Proving Grounds, an area of 2300 acres of varied and suitable terrain 37 miles northwest of Minneapolis. An infrared sensor was placed at the top level of a 50-foot tower to simulate the geometry of the FLIR mission (Figure A-1). The sensor could be rotated over a 360-degree range to view targets at various sites. Figure A-2 is a view from the tower. The targets were placed so that they would be viewed at a mean depression angle of 20 degrees and at a mean slant range of 140 feet. The actual depression angles and slant ranges were varied somewhat to create size and aspect variation in the resultant images and also to permit background variation.

A Barnes Engineering Model T-102 was selected as the best of the infrared sensors available to us. Its important characteristics are summarized below:

- Type: Model T-102 indium antimonide
- Spectral range· 1.0 to 5.5 microns
- Number of raster lines: 160
- Number of horizontal picture elements: 225
- Field of view: 25 degrees wide x 12.5 degrees high
- IFOV: 0.1 degree (1.7 milliradians)
- Minimum detectable temperatures: 0.1°C for a 30°C target
- Frame rate: 2 frames per second

The Model T-102 consisted of two units: an optical head located on the tower for sensing the energy; and a control and display unit, which was basically an oscilloscope, for displaying the thermal image. The writing time for one complete frame was 0.5 second. The image on the oscilloscope was then photographed using Kodak Tri-X film. The resulting negatives served as input for subsequent digital film scanning.

Ten targets were used: gun, jeep, truck, tank, van, tractor, horses, men, barrels and landscape. Figures A-3, A-4, and A-5 show some of

Figure A-1. Sensor units mounted on tower.

Figure A-2. View from the tower.

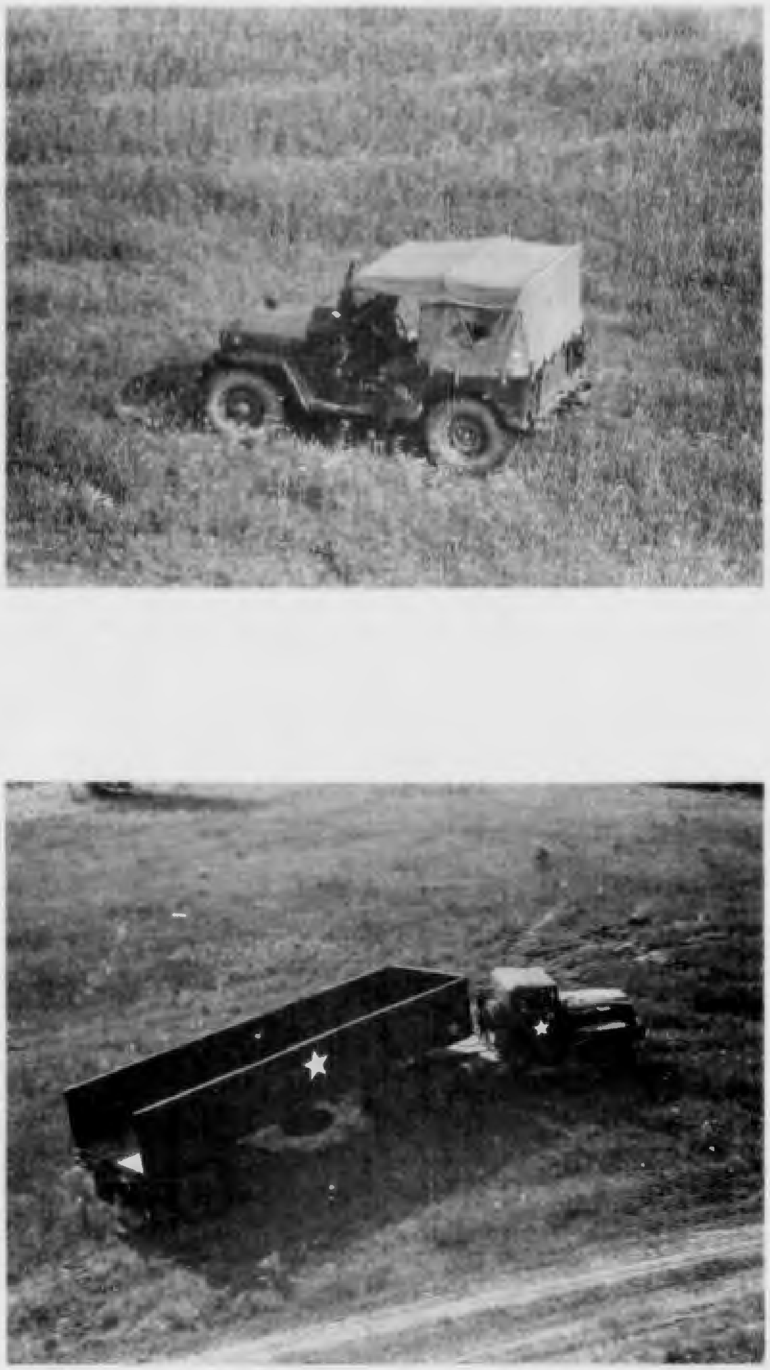


Figure A-3. Jeep and truck

Figure A-4. Gun and tank

Figure A-5. Van and tractor

the targets. For most of the target types (men, horses, barrels, and landscape were exceptions), the pictures were made at each of four temperature conditions: day, hot target; day, cold target; night, hot target; and night, cold target. For the vehicles, a hot target had its engine running, whereas the engine of a cold target had been off for at least two hours. In most cases the cold targets were towed into place for each new picture. Different views (front, side, rear, etc.) of each target were used. Figures A-6, A-7, A-8, and A-9 show some of the resultant infrared targets. At least 20 pictures were produced for each of the 10 target types.

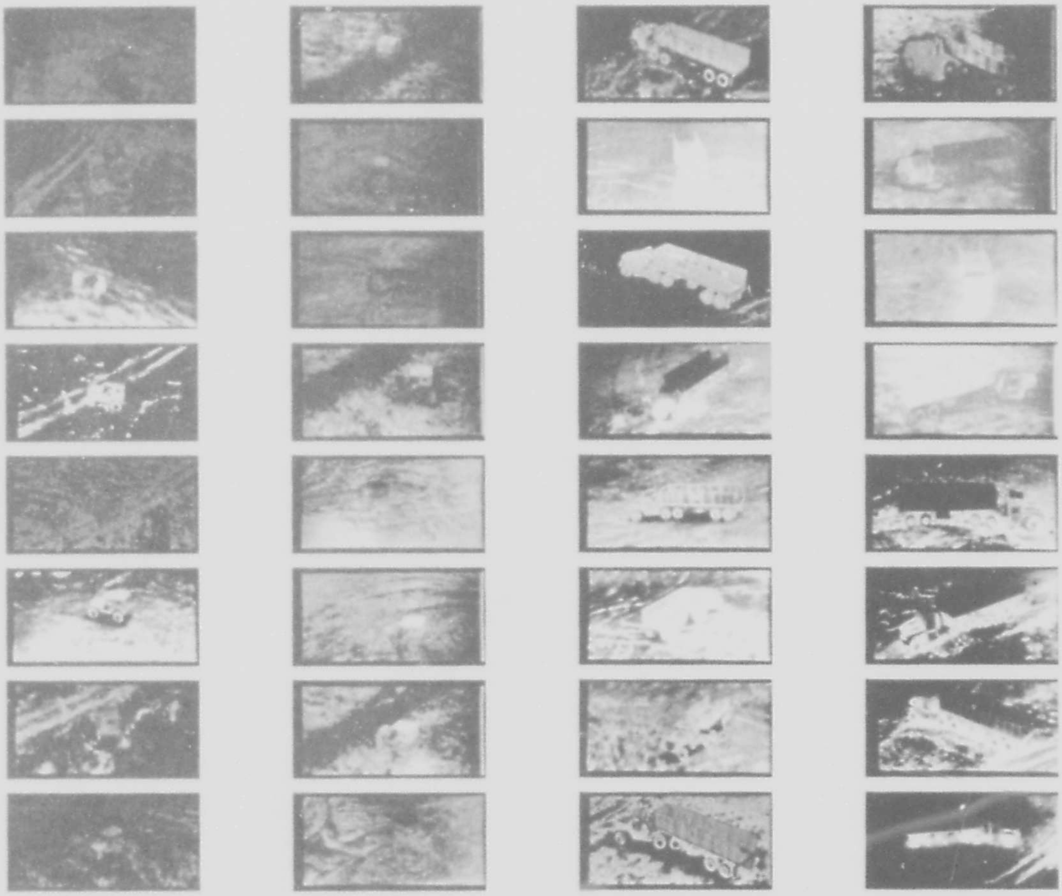


Figure A-6. Original infrared targets (jeep and truck).

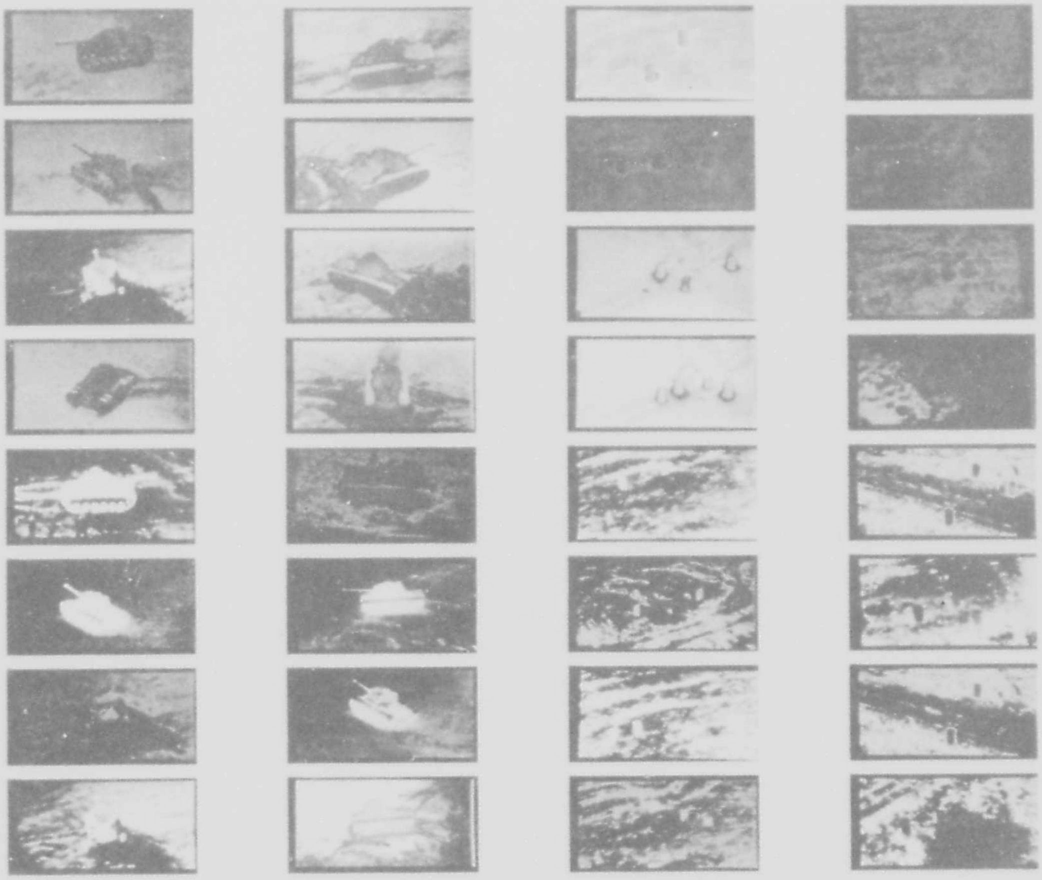


Figure A-7. Original infrared targets (tank and barrels).

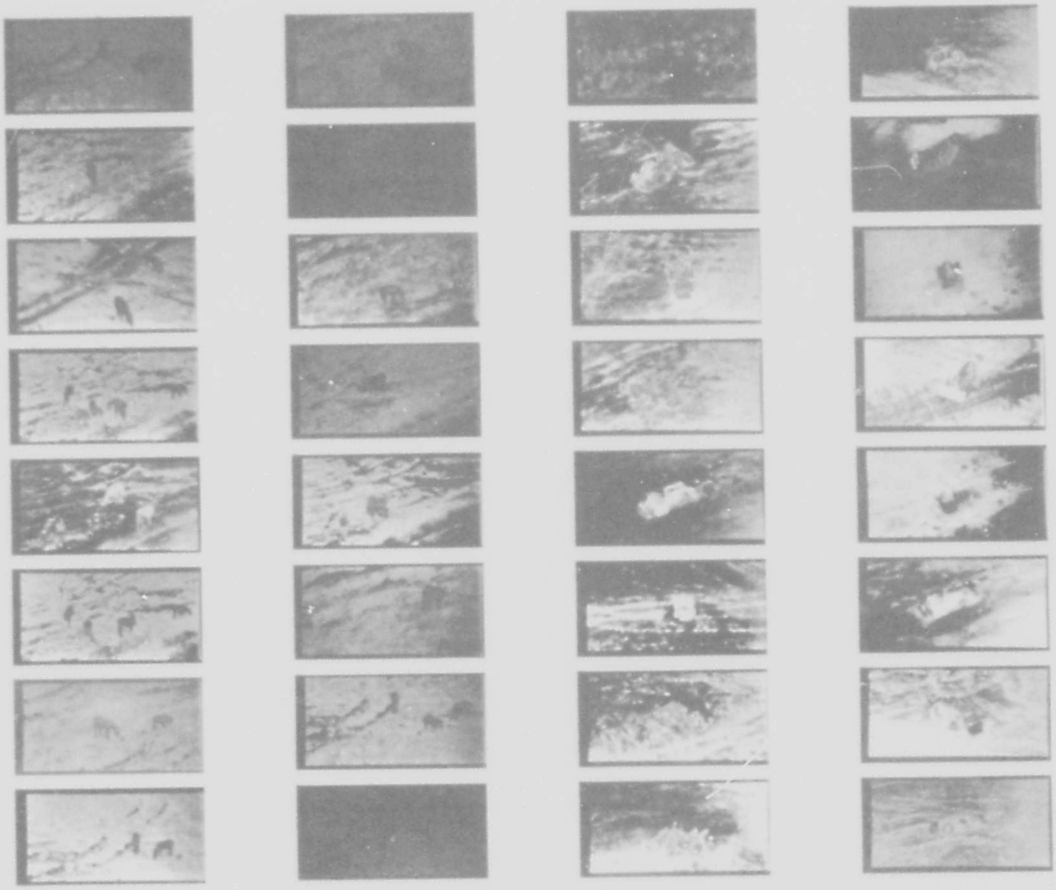


Figure A-8. Original infrared targets (horses and tractor).

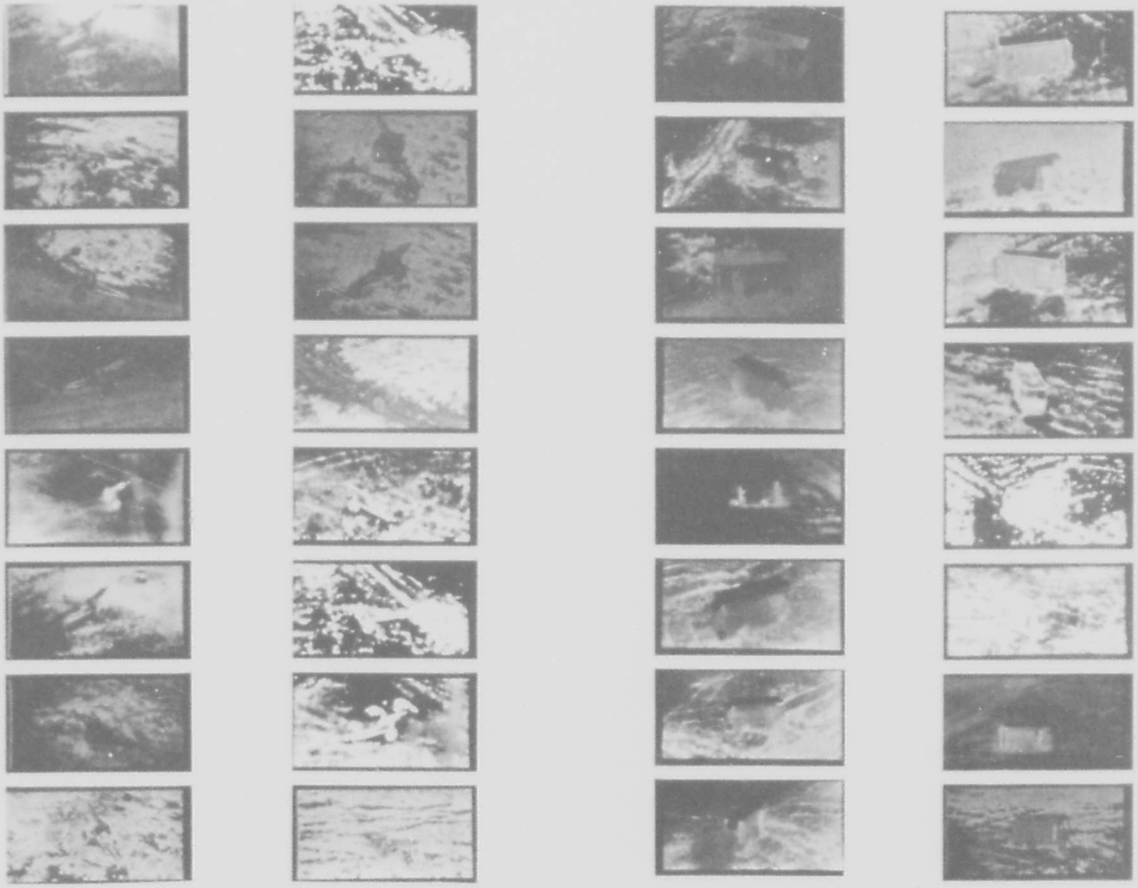


Figure A-9. Original infrared targets (gun and van).

APPENDIX B

DIGITAL IMAGE PROCESSING

APPENDIX B

DIGITAL IMAGE PROCESSING

Digital image processing is based on the fact that pictures can be adequately described by an array of numbers. An image may be represented by a two dimensional array of small unit areas of constant luminance, called picture elements. Figure B-1 shows the general image processing steps used in this study. As indicated in Appendix A, the negatives produced by photographing the target image from the infrared sensor served as input for the digital image processing.

In transforming the original image to an array of numbers, the light intensity transmitted through the film image was scanned incrementally (picture element by picture element) and measured by a photodetector. Each picture element was assigned a numeric value according to its brightness. The film scanner looked at one line at a time of the image on film. It measured the film density at each picture element and then recorded the information on magnetic tape.

In the present study, a scanning aperture of 100μ was used. Starting with a 25 x 50 mm negative (Figure B-2), the picture was represented in digital form as 250 x 500 picture elements--250 scan lines each containing 500 picture elements. The densities were recorded at 64 levels over a range from 0 to 2.5. As the digital scanner scanned one line as shown in the diagram, a total of 500 values was recorded as one record on magnetic tape. Then, when the next line of the picture was scanned, another set of 500 densities was recorded as a second record on magnetic tape. In this way a total of 250 records was produced.

In this numeric form, the images were then degraded by computer processing according to the main experimental variables of each study. The computer processing used to achieve the desired image degradations for the three experiments is described in the following pages.

Each degraded image was then constructed on film on a picture element by picture element basis. The film writing process converted the intensity codes on magnetic tape to film images in somewhat the reverse of the digitizing process. Picture elements were formed on photographic film by focusing a spot of light at each plotting point. In this way, the writer took each record on magnetic tape and wrote it as one line of picture elements on film. There were 64 output densities ranging from 0.2 to 2.5.

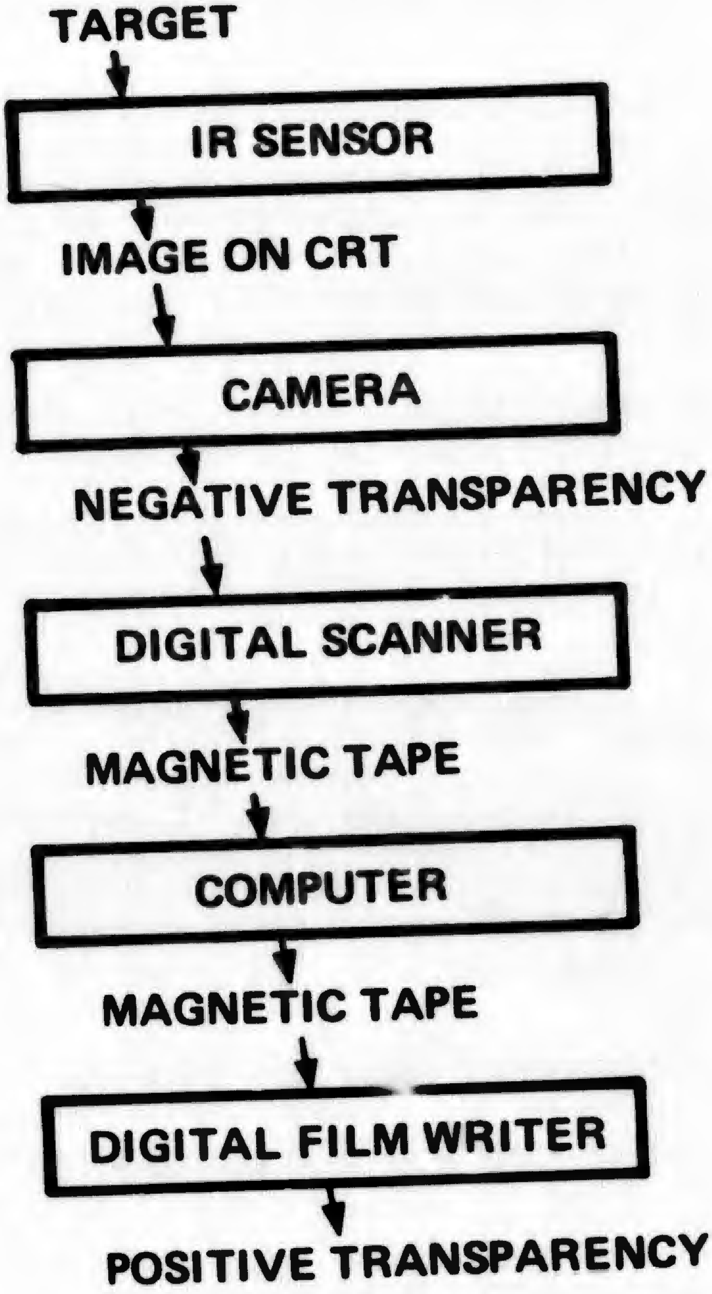


Figure B-1. General image processing steps.

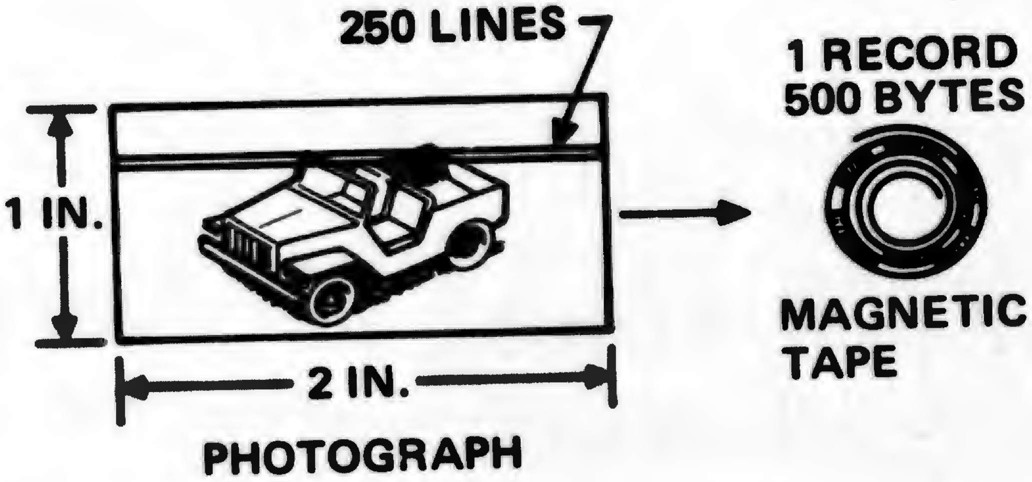


Figure B-2. Magnetic tape representation of a target.

There were, therefore, basically three digital image processing modes:

1.) Film scanning--The image on film was transferred to magnetic tape.
2.) Computer processing--The information on magnetic tape was processed by digital computer and written out again on magnetic tape.
3.) Film writing--The information on magnetic tape was transformed into a film transparency.

The scanning and writing steps were accomplished by an electromechanical system, the Optronics Photomation International shown in Figures B-3 and B-4. This system, which has a resolution of up to 1000 picture elements per inch, provided accurate digital representations of each of the film images. With this device, the system was uniform over the entire film frame and the response was linear over the full density range. The Honeywell DDP-24 and XDS 9300 digital computers were used for the computer processing.

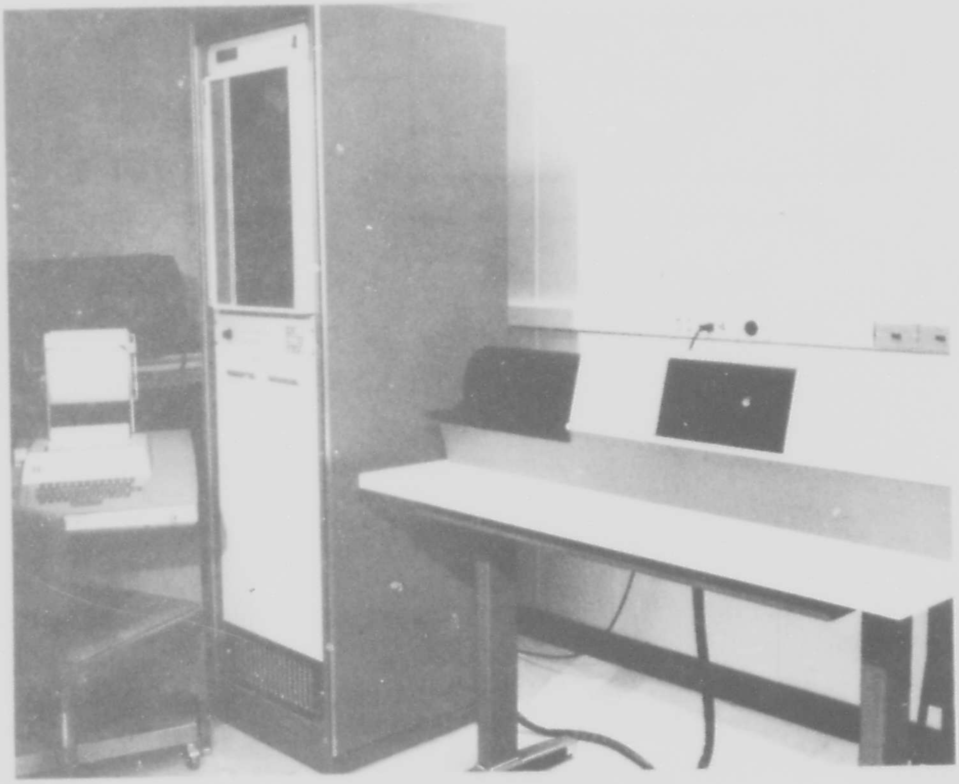


Figure B-3. Optronics film scanning and writing device.

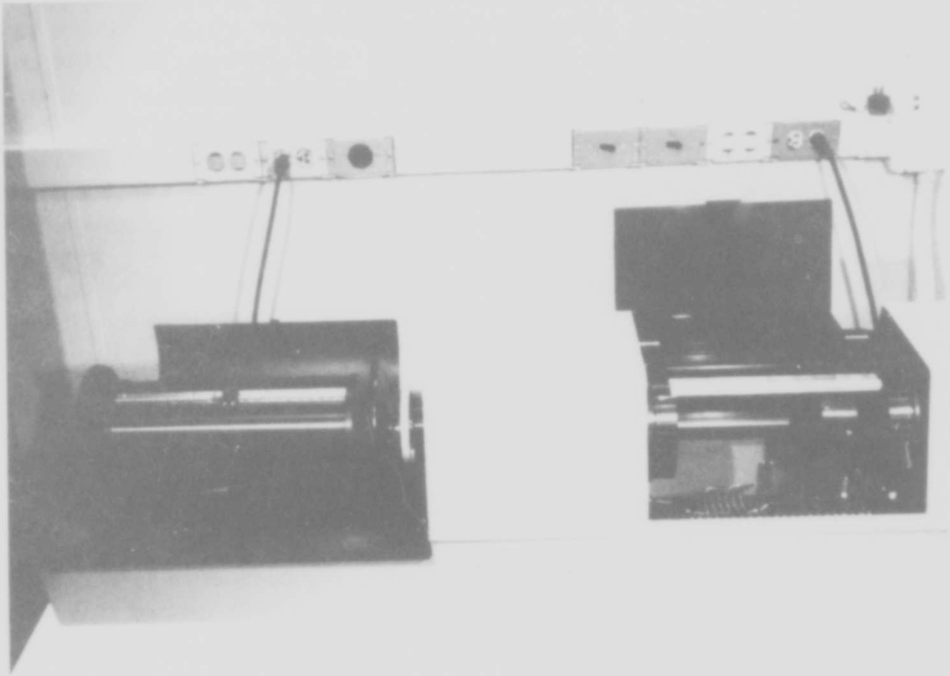


Figure B-4. The film scanner (right) and the film writer (left). Because unexposed film is wrapped around the drum of the film writer, the cover is closed during operation.

Computer Processing Details--Experiment I

An example illustrates how the imagery was processed in Experiment I. In this example, it is assumed that a picture is being created having 21 lines, with an MTF of 0.233. The original picture consists of 280 by 540 elements, because the image scanning includes material outside of the picture proper. To produce the degradation, it is necessary to sample only one line in four and to sample only one cell out of every four in each line as shown in Figure B-5. Thus, the picture is reduced to 70 x 135 cells. The energy at each sampled cell is first distributed to five cells above and five cells below it (Figure B-6). This is equivalent to spreading the energy over ±20 cells in the original (Figure B-7). At this point the gaussian noise is added to each sample cell (Figure B-8). Then the picture must be enlarged from 70 x 135 to 280 x 540. The next step in this process is to fill in each line by linear interpolation (Figure B-9). By doing this each line again becomes 540 cells. Finally, the line structure is created by spreading the energy of each horizontal line over 12 lines for this condition. This energy is spread by a gaussian function (Figure B-10). The effect is to create a set of dark raster lines halfway between each of the main information lines.

Computer Processing Details--Experiments II and III

The main steps of the computer processing for experiments II and III are shown in Figure B-11 and are described below. Definitions of the relevant image processing concepts are shown in Figure B-12.

Input--The input to the computer simulation was the magnetic tape representation of the target picture. The picture was a 250 line array of densities with each line containing 500 picture elements. The magnetic tape was read into the computer one record (line) at a time. The density of each picture element was converted to a transmission value for subsequent computer processing.

Scan aperture--The input was scanned by the aperture as shown in Figure B-12. The center-to-center spacing (line spacing) was determined by the number of scan lines. The scan apertures were square, having dimensions of 1x, 2x, 4x, and 8x the line spacing. However, the aperture was not permitted to be larger than one-tenth the frame height. In terms of the elementary picture elements, the size of the aperture was 3x3, 6x6, 12x12, or 24x24 picture elements. During the scanning operation, the aperture moved one picture element (pixel) at a time, summing the values of the pixels at each

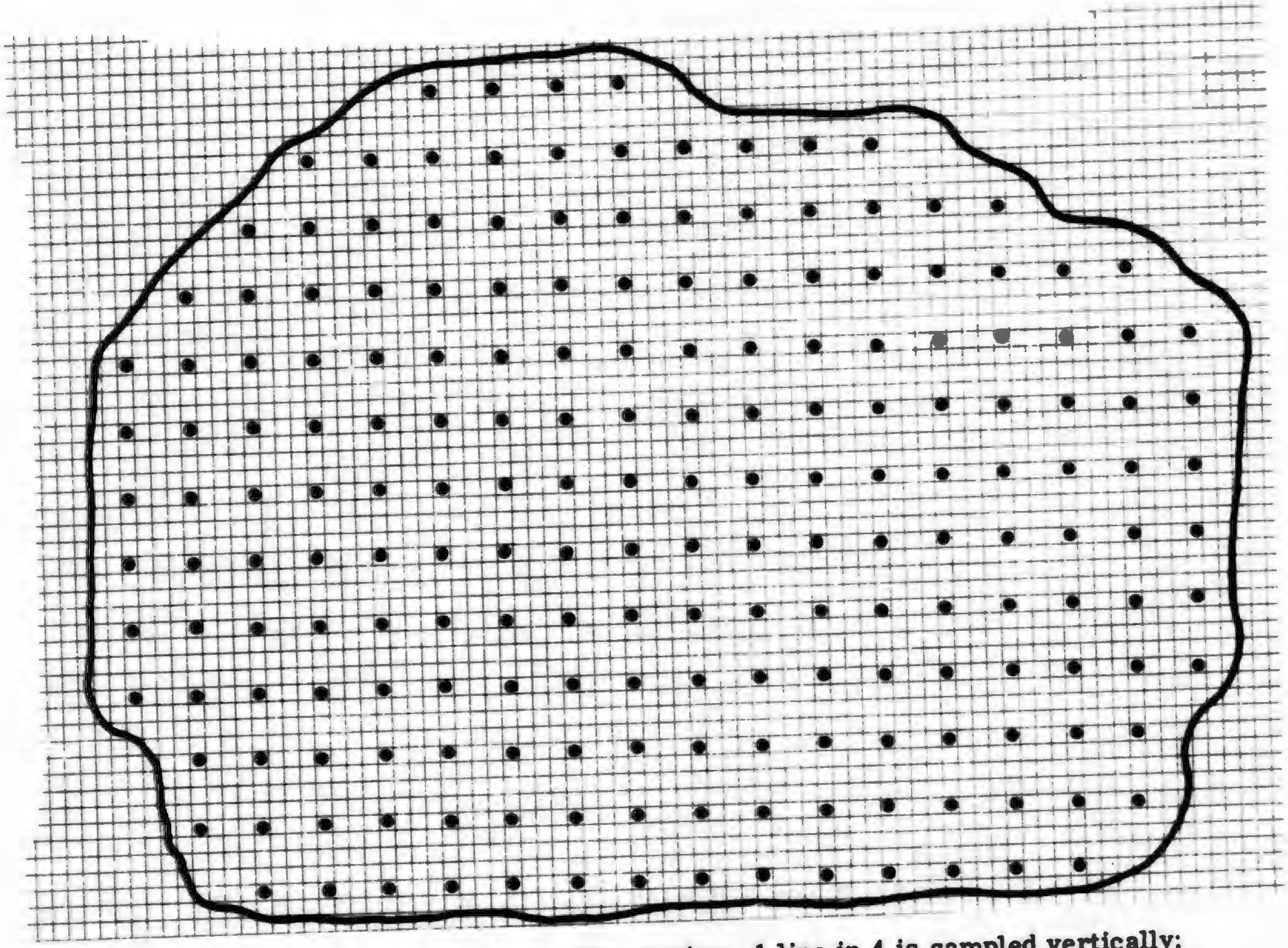


Figure B-5. Picture processing illustration: 1 line in 4 is sampled vertically; 1 cell in 4 is sampled horizontally; the picture is reduced to 70 x 135 values.

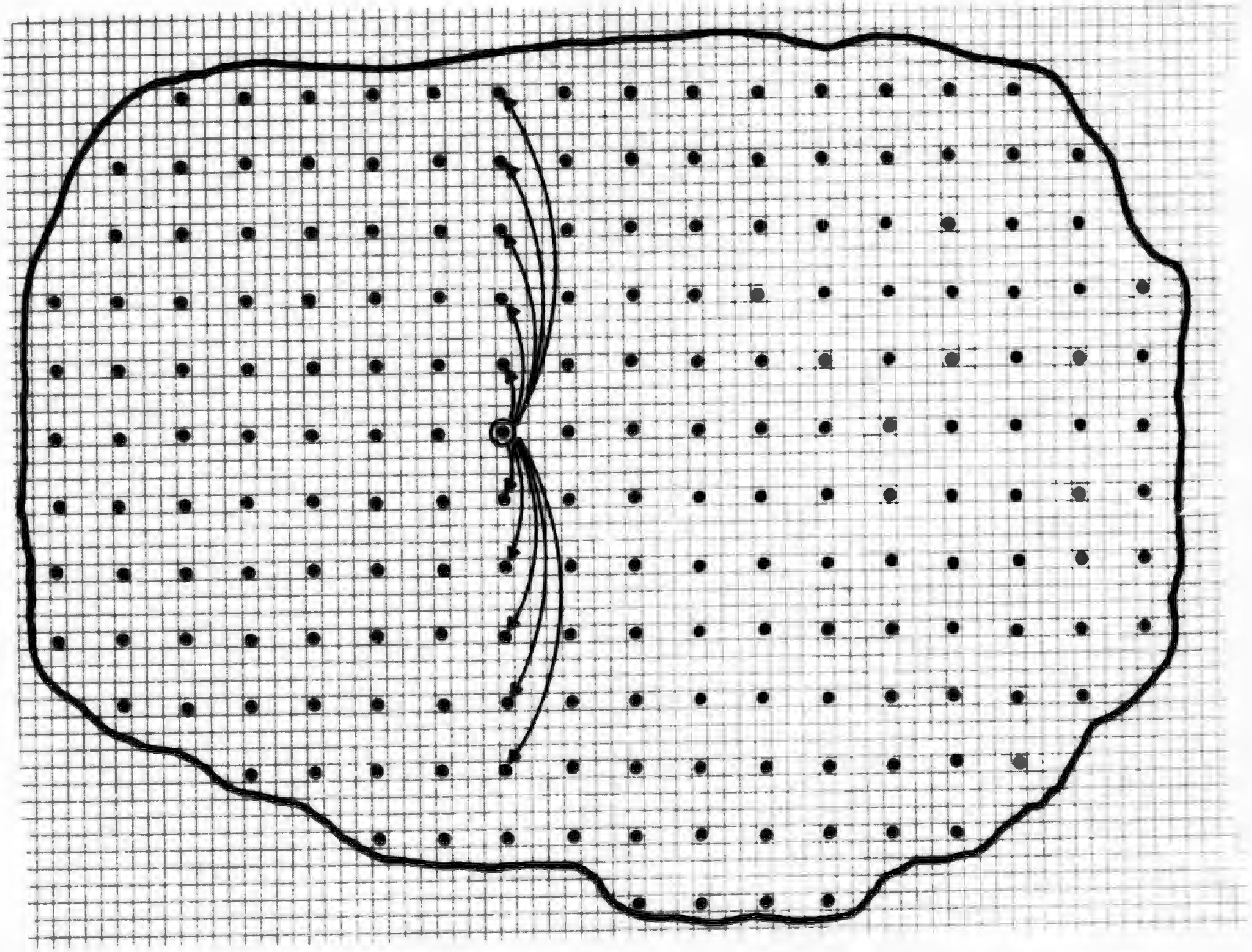


Figure B-6. Picture processing illustration: Each value is spread vertically ±5 cells as indicated for 1 cell according to gaussian spread function. The σ of the distribution depends on L and MTF.

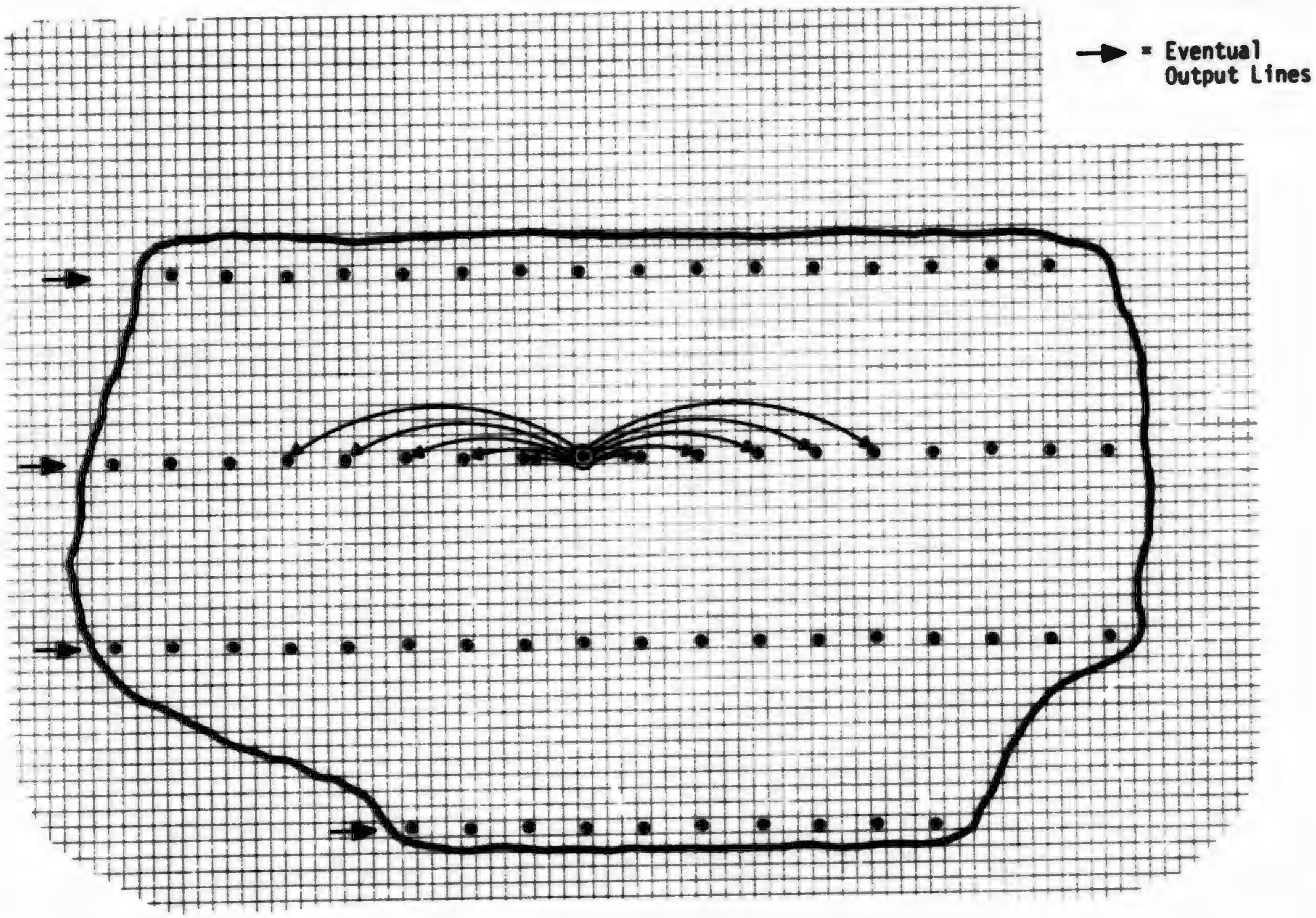


Figure B-7. Picture processing illustration: Each value is spread horizontally ±5 cells according to the same gaussian spread function.

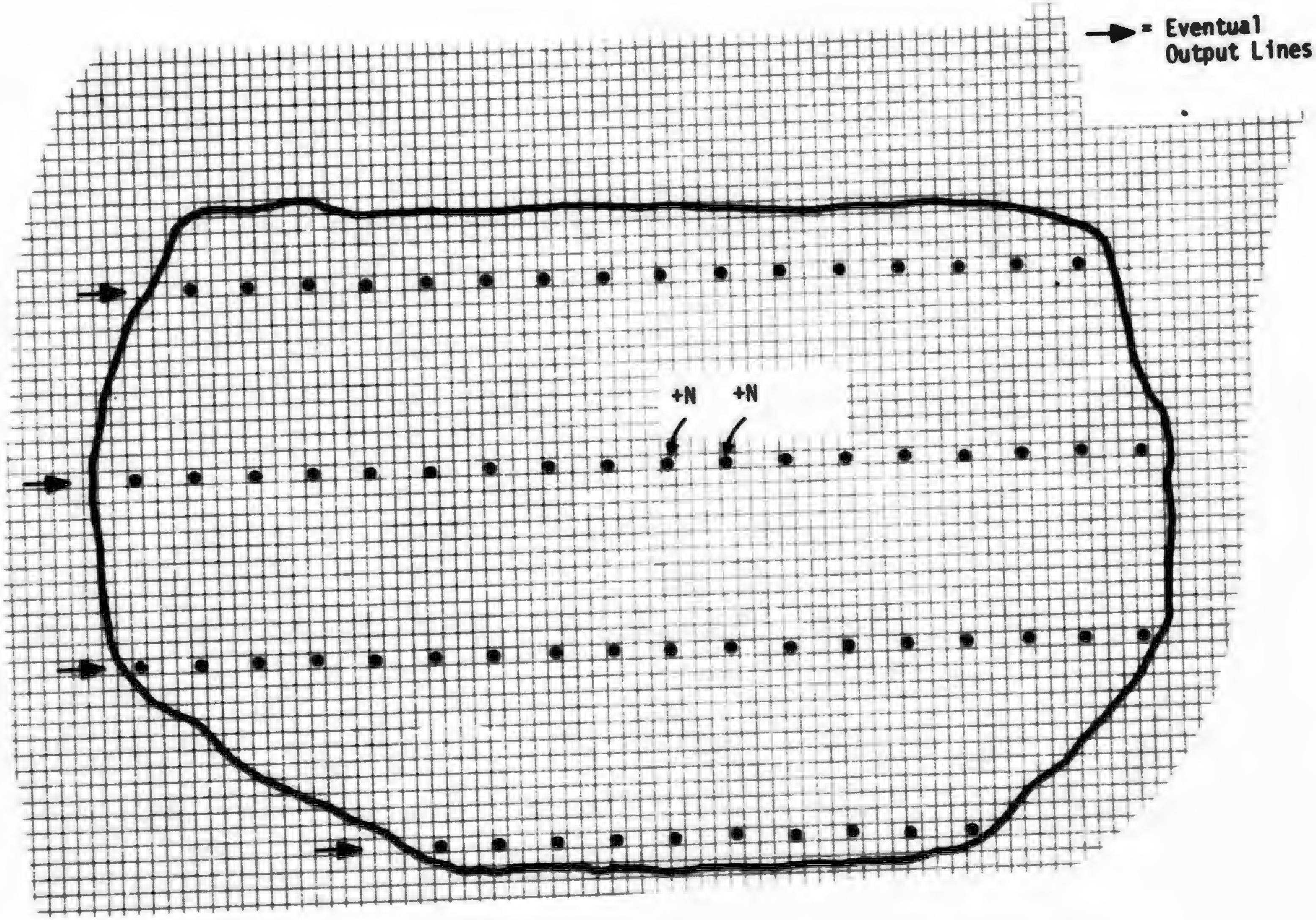


Figure B-8. Picture processing illustration: Gaussian noise is added to each sample cell in the lines which are to become output lines. In this example, this occurs for one out of every three sample lines as shown.

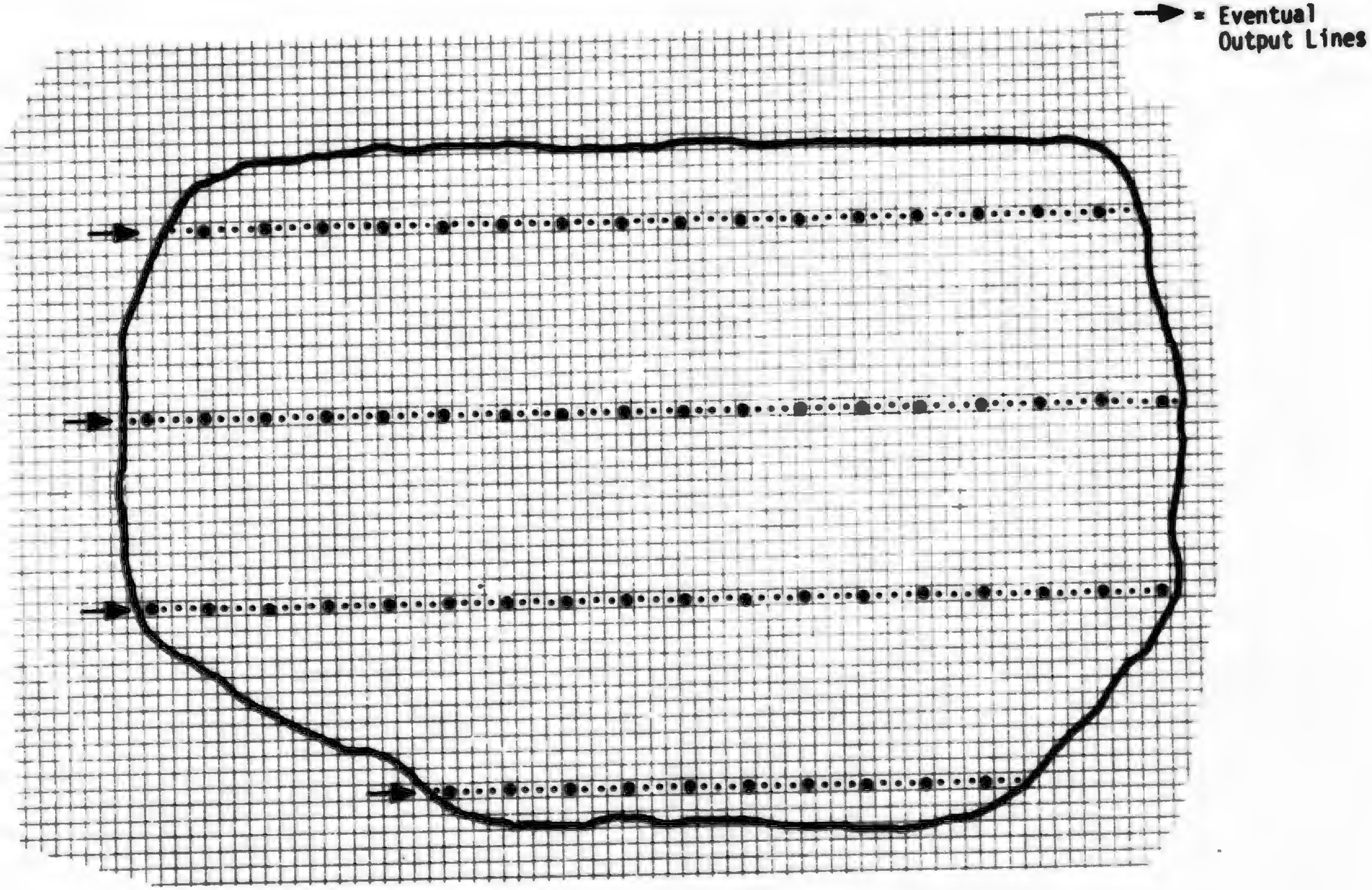


Figure B-9. Picture processing illustration: Picture is filled in horizontally by linear interpolation for the eventual output lines.

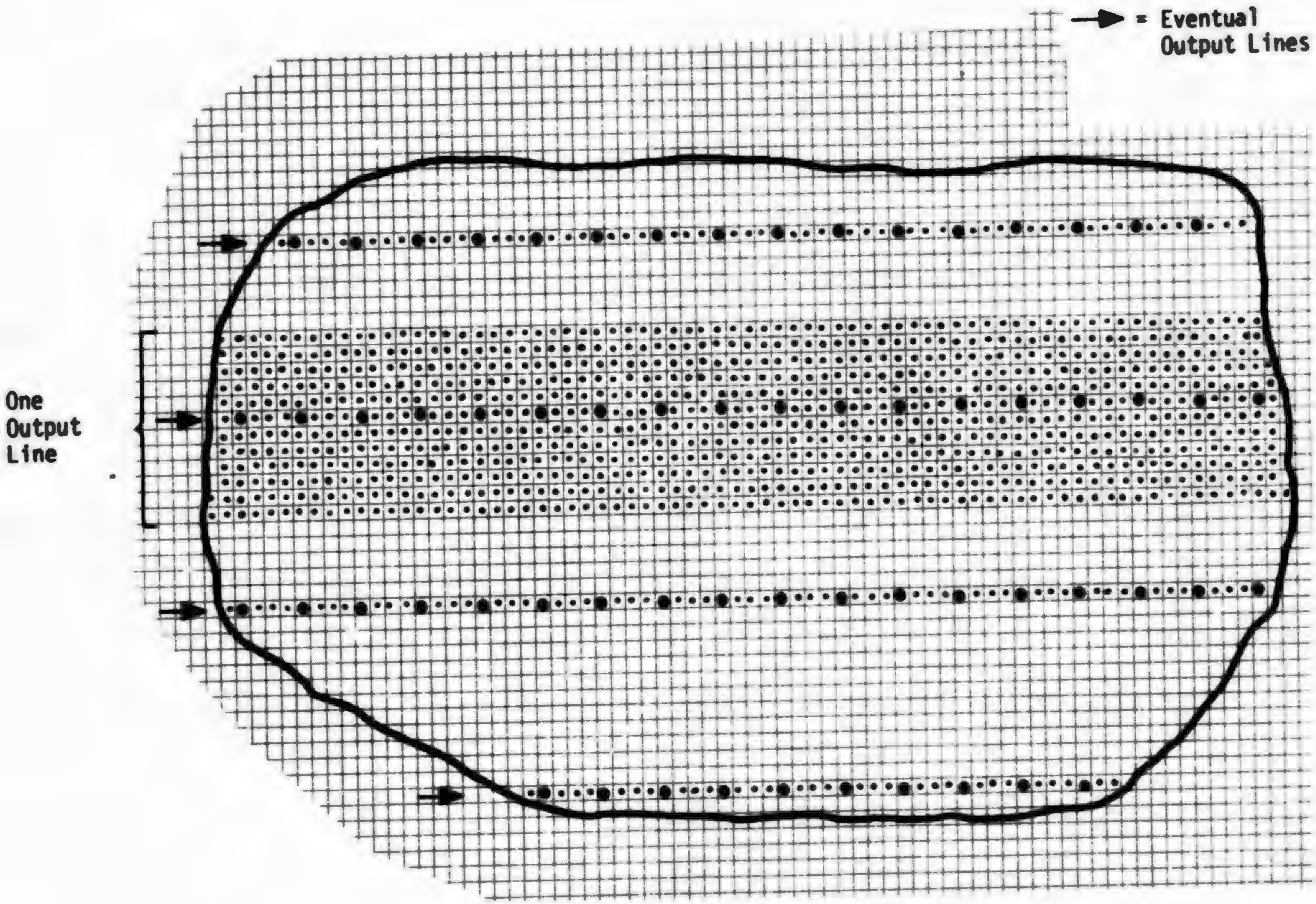


Figure B-10. Picture processing illustration: Line structure is created by gaussian spread - shown here for one output line.

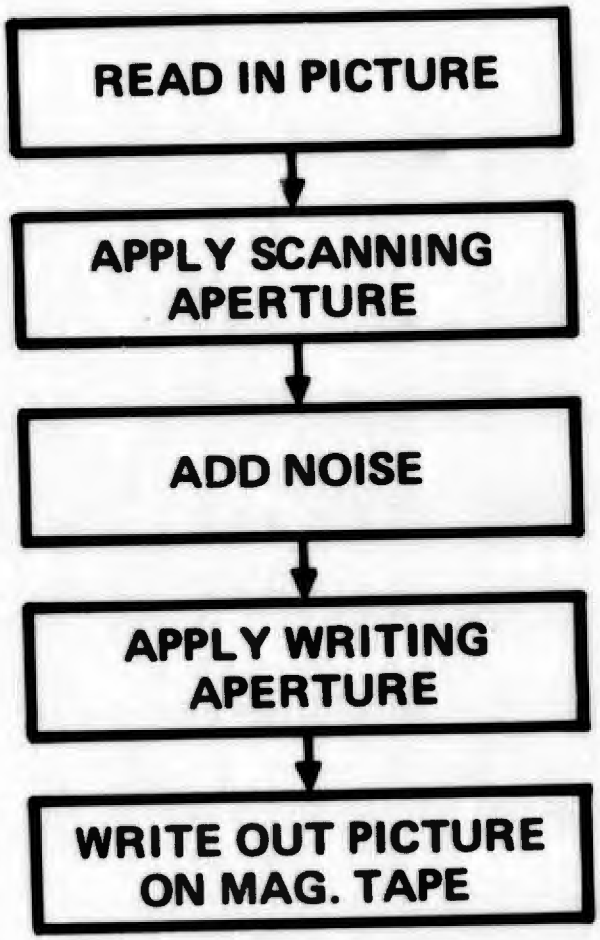
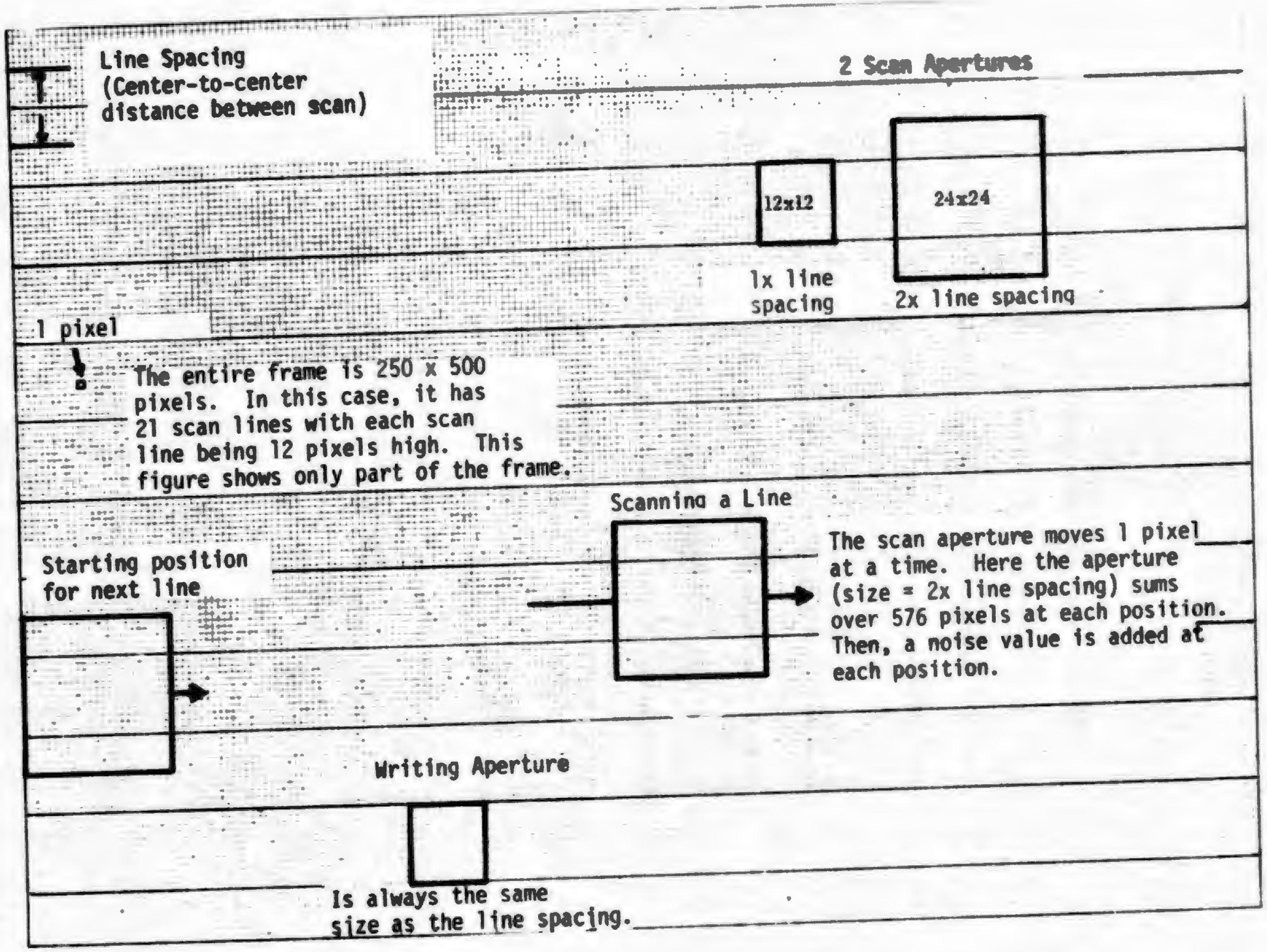


Figure B-11. Computer processing steps of Experiment II.



The entire frame is 250 x 500 pixels. In this case, it has 21 scan lines with each scan line being 12 pixels high. This figure shows only part of the frame.

The scan aperture moves 1 pixel at a time. Here the aperture (size = 2x line spacing) sums over 576 pixels at each position. Then, a noise value is added at each position.

Is always the same size as the line spacing.

Figure B-12. Digital image processing definitions. (Illustrated for the 21 scan lines case.)

position (i.e., summing 9, 36, 144, or 576 values, depending on the aperture size). The output of this process was a close approximation to a continuous scan with almost 500 values for each line. This process was repeated for each line of the frame. For apertures larger than the line spacing, this process resulted in overscan.

Noise--Four levels of noise were used for each combination of number of scan lines and scan aperture size. These levels ranged from no noise to a high level of noise which would often obliterate the target. The RMS values were in the ratios of 1:2:4 for the three higher noise levels. If noise is associated with energy fluctuations in the object space, then the S/N ratio will increase as the as the aperture size increases. In the computer simulation, noise was introduced by adding a random number, sampled from a gaussian distribution with a specified variance, to the output of the scanning aperture at each scan position.

Writing aperture--The writing aperture deposits energy over a two-dimensional space. In the present study, a square aperture, whose height was the same as the line spacing for each condition, was simulated. The writing process was a reverse of the scanning process. That is, the output of each scan position, including the noise value, was written out in all the picture elements making up that aperture size. The writing aperture then moved over the width of one picture element and wrote the next value in the pixels making up that aperture position--overlapping the values from the previous position.

Output--The magnetic tape information was then written out on film.

APPENDIX C

INSTRUCTIONS TO THE SUBJECTS

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INSTRUCTIONS TO THE SUBJECTS

The instructions were basically the same for each of the three experiments and were read to the subjects before the training session.

(Subjects were shown a list of the target categories.) "In this experiment, these objects have been photographed using an infrared sensor. As you can see, most of the objects are military related. If you have any objections to viewing this type of object, or feel that it will interfere with your performance in any way, we would like you to discontinue the experiment at this point. Do you have any objections to participating in this experiment?

(Subjects were shown several examples of infrared photography.) "As I was saying, the objects for this experiment have been photographed using an infrared sensor. Here are some examples of infrared photography. Infrared is a type of radiation similar to light but located in a different portion of the spectrum. When an infrared sensor is used in photography, the resultant picture looks much like a negative of a photographic print. This is because the sensor is sensitive to different things than a light camera. For our purposes, we can say that infrared is sensitive to heat and cold. A hot portion of an object shows up as white and a cold portion shows up as black. In these infrared photographs, the hot portions show up as white, while the colder portions are dark." (The hot portions were pointed out.)

(Subjects were shown a standard black and white photograph of each target.) "These are standard photographs of the objects you will be viewing during the experiment. Take some time now to become very familiar with these objects, paying particular attention to their details and identifying characteristics. (The most pertinent characteristics of each target were emphasized.) Remembering that infrared photographs show hot and cold contrast, what would infrared photographs of these objects look like? (For example: the portion above the engine would be white if vehicle had been running; if the objects had been moved at all, the wheels would be white; if the gun or tank had been fired, the barrel would show up as white.)"

(A transparency containing several infrared photographs of each of the targets was placed over a light box.) "Here are some examples of each of the objects photographed using an infrared sensor. This is the type of imagery you will be viewing during the experiment. Pay close attention to the characteristics of each target that could be helpful in identification. The objects have been photographed at many different angles, but always at a slightly downward angle. Each picture will contain only one target." (The infrared characteristics of each of the examples were emphasized.)

(Transparencies containing degraded 3-bar test charts were placed over the light box.) "The pictures you will see during the experiment will not be as clear as those you just saw. Instead, the pictures have been degraded in a manner similar to these test charts. The targets will range in degradation from those that are fairly easy to see to those that are almost impossible to see. (The degradations were briefly described.) Do you have any questions about the type of pictures you will see during the experiment?"

"Pictures of the objects will be presented to you on this screen and you are to determine which type of object it is. To acquaint you with the type of pictures you will see and with the responses you must make, we will have three sets of practice trials." (The procedures for the training session and experimental session were explained in detail before beginning each session.)

APPENDIX D

ANIMATION PROCESS

APPENDIX D

ANIMATION PROCESS

Figure D-1 is a flow chart of the animation process used in Experiment III. The Kodak 2498 film, from Kodak's RAR family, was selected to be used in the animation camera because it worked well at moderate illumination levels (the F/11 region on the 150 mm lens) and because its characteristics were similar to the film used in the Optronics film writer, Kodak 2496. Kodak 5374 television recording film was selected to make the animation copies because it provided the correct gray scale.

The animation facility (Figure D-2) consisted of an animation stand, a single frame pulsed 35 mm animation camera, and pulsed circuits and counters. The structural members of the animation stand were fabricated from 76.2 x 6.3 mm steel angle. The animation plane was 38.1 mm thick laminated wood, 81.28 cm wide by 121.9 cm long. It was located 81.28 cm above the floor. The heavy steel frame and woodwork surface eliminated any vibrations which might have reduced the MTF of the system. The animation plane could be illuminated from above or below by tungsten Hologin flood lamps. When illuminated from below, opel glass diffused the light to provide uniform illumination. The camera base had a range of 15.2 cm to 121.9 cm above the animation plane, ±50.8 cm in the x axis, and ±5.08 cm in the y axis. Screw jacks were used to raise and lower the camera base.

The main features of the 35 mm Automax G-1 animation camera are listed below:

- Pin registration of the film
- 1/64 sec. exposure time
- Pulsed, single frame exposure
- 150 mm Pentax lens
- Mitchell type film magazines, 60.96 to 30.48 m capacity
- Lucite focusing screen

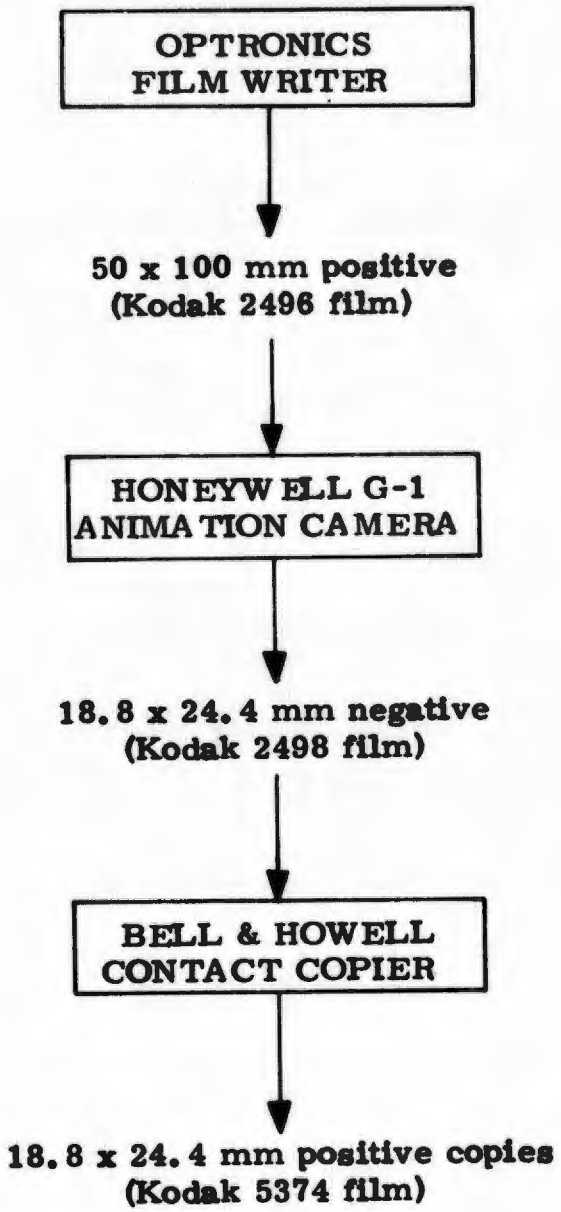

Figure D-1. Animation process.

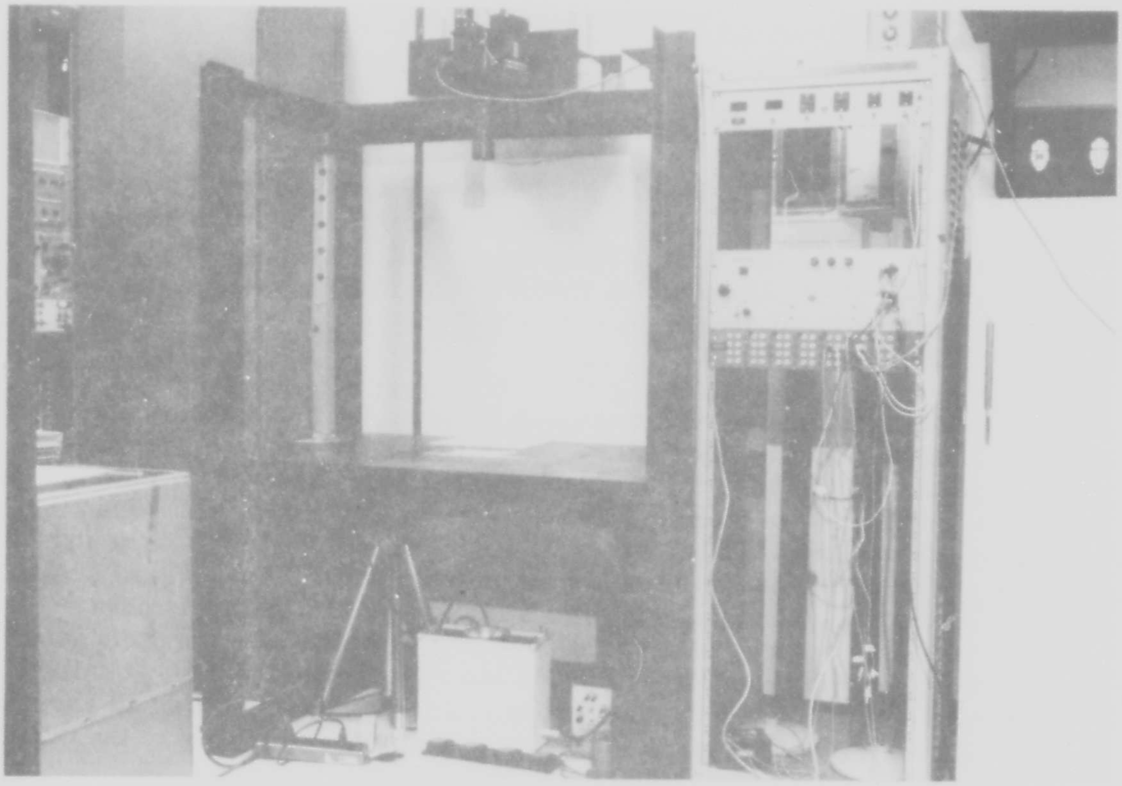

Figure D-2. The animation facility.

An R-C network provided a 66 msec pulse which advanced and exposed one frame of film. The pulse also drove three Sodico counters which could be independently reset. The command for a pulse was received from a foot switch.

The 50 x 100 mm transparencies produced by the Optronics filmwriter were optically registered over the back illuminated opel glass within ±.102 mm. The 35 mm film in the camera was registered within ±.038 mm. Considering the optical reduction from the animation plane to the film plane, total maximum frame registration error of the 35 mm film was about ±.051 mm.

The experimental design of Experiment III required that the animated pictures have a quality identical to that of the static pictures used in Experiment II, thus permitting direct comparison between the two studies. For our purposes, we considered the image quality comparable when the MTF of each system, static and dynamic, exceeded the MTF of the input image and when the output of each system had identical linear gray scales. Image motion (registration errors in aligning the film in the camera, etc.) limits the system MTF. Careful selection of the animation equipment, however, provided proper registration which controlled MTF. Equally careful selection of the film and processing techniques provided an appropriate gray scale. We therefore considered the image quality of the dynamic and static systems comparable.

REFERENCES

1. J. Johnson, Analysis of image forming systems. In Proceedings of the Image Intensifier Symposium of October 1958. 249-273. A. D. No. 220160

2. M. F. Elias, A. M. Snadowsky, and Rizy. Identification of televised symbols as a function of symbol resolution. Perceptual and Motor Skills, 1965, 21, 91-99.

3. M. Marsetta and D. Shurtloff, Studies in display symbol legibility. Part XIV. The legibility of military map symbols on television. Mitre Corp. Doc. MTR-264, 1966.

4. C. A. Baker and R. M. Nicholson, Raster scan parameters and target identification. In Proceedings of the 19th Annual National Aerospace Electronics Conference (NAECON), 1967, 285-290.

5. A. Bennett, H. Winterstein, and E. Kent, Image quality and target recognition. Human Factors, 1967, 9, 5-32.

6. F. Scott and P. A. Hollanda, The informative value of sampled images as a function of number of scans per scene object. Photographic Sci. and Eng., 1970, 14, 21-27.

7. P. A. Hollanda and F. Scott, The informative value of sampled images as a function of number of scan lines per scene object and the signal-to-noise ratio. Photographic Sci. and Eng., 1970, 14, 407-412.

8. R. L. Krumm and A. J. Farina, Jr., Rapid identification and interpretation techniques. RADC-TDR-63-421, November 1963.

9. H. Martinek and R. Sadacca, Error keys as reference aids in image interpretation. U.S. Army Personnel Research Office, Support Systems Research Laboratory. Technical Research Note 153, June 1965.

10. N. R. Draper and H. Smith, Applied Regression Analysis, New York: Wiley, 1967.

11. L. G. Williams and J. M. Erickson, Dynamic Contrast Requirements, Honeywell Contract Report No. N00014-74-0076, February 1976.

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