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REMOTELY PILOTED VEHICLE SIMULATION STUDY

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Final Technical Report

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FINAL TECHNICAL REPORT

REMOTELY PILOTED VEHICLE SIMULATION STUDY

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April 1976

Display Systems and Human Factors Department
AEROSPACE GROUPS
Hughes Aircraft Company • Culver City, California

SUMMARY

In proposed RPV systems the quality of the video information displayed to the operator will greatly influence the probability of ground target strike mission success. Further, the susceptibility of the video data link to jamming will be a major determinant of video quality. The reported study examined the effects of three video frame rates (1.88, 7.5, and 15 frames per second) and three signal-to-noise ratios (30, 22, and 15 db) on operator target acquisition performance in a simulated RPV mission. Target type and location were pre-briefed.

An initial seven kilometer range-to-target and a 165 meter per second closing rate were simulated. At the beginning of the mission the operator viewed the target scene with a 26.9 by 19.9 grad sensor field of view. Once the target/target area was recognized, a 3 to 1 zoom was commanded by the operator to provide greater detail for target acquisition which was accomplished by slewing the sensor to position the target under fixed crosshairs. Performance measures were range-to-target at acquisition and probability of correct target acquisition.

Both signal-to-noise ratio and frame rate had large effects on operator performance. A three-to-one improvement in range-to-target at acquisition was achieved when signal-to-noise was increased from 15 to 22 db. Target acquisition probability increased by more than 100 percent from an average of 0.3 for 15 db to better than 0.7 when signal-to-noise was increased to 22 db.

Increasing frame rate from 1.88 to 15 frames per second improved target acquisition performance. A hypothesized interaction between signal-to-noise ratio and frame rate did not occur.

The results indicate that signal-to-noise ratio and frame rate can be varied independently of one another in terms of operator performance. Selection of a lower frame rate with the resulting reduced bandwidth and reduced susceptibility to jamming will result in improved operator performance because of the improved signal-to-noise ratio.

PREFACE

The research covered herein was initiated by the Philips Elecktronikindustrier AB of Järfälla, Sweden as part of a research program to development Remotely Piloted Vehicles. The research was concerned with the effect of video frame rate and signal-to-noise ratio on operator target acquisition. The Philips RPV Program Manager was Mr. Pentti Kölhi. The research was conducted by the Display Systems and Human Factors Department of Hughes Aircraft Company, Culver City, California, under Philips Order Number 606E11. Mr. D. W. Craig of Hughes Aircraft Company was Project Engineer.

Special acknowledgement of the following contributions to the performance of the research is gratefully made: Mr. P. Kölhi the Philips RPV Program Manager, for his contributions during the study definition phase of the research; Messrs. R. A. Andrews, J. A. Schrunk, and D. J. Ketcham for their efforts in the development and modification of the simulation hardware and software.

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Section 1

INTRODUCTION

Remote guidance of weapons systems has for some time been considered as a means of reducing loss of high cost manned aircraft during military engagements. Ground-to-ground missiles and remotely piloted vehicles are candidate weapons systems that could be employed in place of manned aircraft for precision ground strikes. Because many of these missions require video information for target acquisition, successful operation of wide-band video data links is a critical requirement for mission success.

The quality of the video information transmitted and displayed to the remote operator will determine the operator's ability to recognize and designate targets for weapon delivery. Enemy noise jamming can degrade the quality of displayed video information and result in degraded operator performance. Thus to achieve mission success utilizing remote guidance weapon systems, the data link must be protected against noise jamming.

The lower the data rate of a digital data link, the greater the possibility of maintaining its security. Reduced video frame rate is one of the more promising methods of reducing the video data rate. For example, a 3.75 frame per second frame rate would result in an 8:1 reduction in data rate compared to a standard 30 frame per second frame rate. The reduced data rate would provide an increased signal-to-jamming ratio (signal-to-noise ratio) and hence a more secure video data link and less degradation of operator performance due to jamming.

A potential disadvantage of operating with reduced frame rate in a noise jamming environment is that the visual integration of video signal information which occurs over time would be reduced. The human visual system has an integration period of approximately 0.1 second. Thus any visual signal repeated at a rate of 10 cycles per second or faster will result in integration of that signal. Because noise is random whereas ground sensor video is not, sensor video will be integrated to a greater extent than noise at high frame rates. At low frame rates, visual integration of signal and noise may be equivalent.

Frame rate reduction can, therefore, have two counteracting influences on operator target acquisition. Reduced frame rate reduces the video data rate and the susceptibility of the data link to noise jamming but it also reduces the visual integration of video signal relative to random noise.

The enhanced detectability of video signals in noise at high frame rates has been observed many times. However data which describe the relationship between frame rate and noise for a visual ground target acquisition task are not known to exist. It was the purpose of this study to obtain data that describe that relationship.

Communications engineers know the relationship between reduced data rate and signal-to-noise improvement, knowing the behavioral relationship between frame rate and signal-to-noise ratio, the designer will then have the necessary information to determine system performance with reduced frame rate.

Section 2

STUDY METHODOLOGY

STUDY APPROACH

The study approach was a laboratory simulation of a RPV strike mission against pre-briefed targets. Nine combinations of video frame rate and signal-to-noise ratio were investigated to access the effects of noise jamming at various frame rates on operator target acquisition performance.

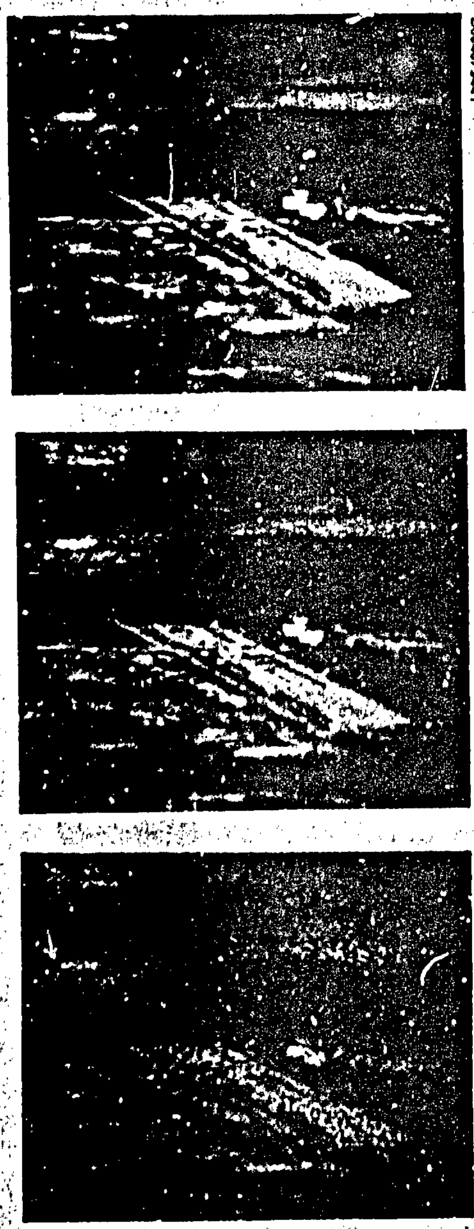
MISSION PROFILE

The Swedish RPV mission simulated a low altitude attack profile where the target type and location were known. The mission began with the RPV sensor activated at a pop-up altitude of 762 meters at a range-to-target of approximately 7 kilometers. Initial sensor field-of-view was 26.9 by 19.9 grads (24 by 18-degrees) with the sensor pointing angle depressed 22.2 grads (20 degrees) below the horizon. The target was always located within the sensor field-of-view when the mission began. The RPV closed at 165 meters per second on a 5 grad (4.5 degrees) dive angle. A 3 to 1 zoom was available to allow a magnified 8.9 x 6.7 grad (8 x 6 degrees) field-of-view. Upon recognizing the target/target area the operator would change field of view for target acquisition.

RESEARCH PARAMETERS

Video frame rate and signal-to-noise ratio were variable parameters in the simulation study. Video frame rates of 15, 7.5 and 1.875 frames per second were investigated in combination with signal-to-noise ratios of 30, 22, and 15 dB. The method for calculating signal-to-noise levels is described below. Examples of the three signal-to-noise levels used in the simulation are shown in Figure 1. The examples represent a TV resolution of 256 by 256 elements with 4 bit gray scale encoding.

Calibration of the signal-to-noise ratio required a determination of several parameters. These were the peak signal level, the inherent system noise level, and the gain through the noise insertion channel. Prior to any measurements, the video system was optimized to obtain the highest possible picture quality.



a. 30 dB signal-to-noise.

b. 22 dB signal-to-noise.

c. 15 dB signal-to-noise.

Figure 1. Example of signal-to-noise ratios used in RPV simulation study.

		Targets																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
OPERATORS	O_1	A1	A2	A3	A2	A1	A3	B2	B3	B1	B3	B2	B1	C3	C1	C2	C1	C3	C2
	O_2	A2	A3	A1	A3	A2	A1	C3	C1	C2	C1	C3	C2	B1	B2	B3	B2	B1	B3
	O_3	A3	A1	A2	A1	A3	A2	B1	B2	B3	B2	B1	B3	C2	C3	C1	C3	C2	C1
	O_4	B1	B2	B3	B2	B1	B3	C2	C3	C1	C3	C2	C1	A3	A1	A2	A1	A3	A2
	O_5	B2	B3	B1	B3	B2	B1	A3	A1	A2	A1	A3	A2	C1	C2	C3	C2	C1	C3
	O_6	B3	B1	B2	B1	B3	B2	C1	C2	C3	C2	C1	C3	A2	A3	A1	A3	A2	A1
	O_7	C1	C2	C3	C2	C1	C3	A2	A3	A1	A3	A2	A1	B3	B1	B2	B1	B3	B2
	O_8	C2	C3	C1	C3	C2	C1	B3	B1	B2	B1	B3	B2	A1	A2	A3	A2	A1	A3
	O_9	C3	C1	C2	C1	C3	C2	A1	A2	A3	A2	A1	A3	B2	B3	B1	B3	B2	B1

Key:

Video Frame Rate, frames per second

A = 15

B = 7.5

C = 1.875

Signal-to-Noise Ratio, dB

1 = 30

2 = 22

3 = 15

Figure 2. Research design used in video frame rate and signal-to-noise ratio study.

RESEARCH EQUIPMENT

A computer-controlled sensor display simulator was used to present the test imagery to the operators. Displayed video originated with a television camera fitted with a servo driven 20 to 1 zoom lens focused on a film transparency mounted in a servo driven platform. The two directions of platform translatory motion were used to simulate the azimuth and elevation sensor pointing degrees of freedom. The zoom lens was used to simulate vehicle range closure and the 3 to 1 field of view change required in the simulation.

The test imagery was illuminated with a strobe light which was flashed at 15, 7.5 or 1.875 frames per second, depending upon the particular frame rate being simulated. A white noise generator was used to achieve the three signal-to-noise levels investigated.

The operator viewed a 20.3 cm by 15.2 cm standard television display from a distance of approximately 61 cm. A rate controlling-hand control with zoom and target designate switches was located for easy activation with the right hand. A digital clock that counted seconds into the mission was located directly to the left of the display adjacent to where the operators positioned their briefing materials.

The experimenter's console provided various switches and controls which allowed the experimenter to direct the computer simulation. The computer used was a Xerox Data Systems Sigma 5 which was interfaced to the simulation equipment described above. A real-time computer program was written to provide the required closing speed, dive angle, zoom activation, automatic parameter setting, and automatic data collection. The computer program recorded time at zoom, and range from target at target designation. All data, including subject number, trial and target number, parameter data, and time were printed out. A detailed description of the total sensor system simulator capability appears as a separate appendix to this report.

TEST IMAGERY AND TARGETS

The eighteen test and six training images used in the simulation study were low altitude oblique photographs of rural and urban areas in the mid-west and north-east United States. All of the images represented a 762 meter (2500-foot) altitude. A variety of targets were sampled, including: industrial complexes, petroleum - oil - lubricants storage tanks, bridges, vehicles, railroad marshalling yards, and isolated buildings.

Examples of two targets used in the simulation are shown in Figures 3 and 4. These examples show the target at both long and short range. Figures 5 and 6, present three target views as seen on the operator's display in the 30 dB signal-to-noise condition and approximated what the operator saw as the mission progressed from start to finish.

BRIEFING AND REFERENCE MATERIAL

The briefing and reference materials used in the simulation study included a briefing packet that contained three different oblique aerial photographs and a written description of the target and local area cues. Two of the aerial photos depicted views of the target as seen from ranges of 2 and 5 kilometers at slightly different aspect angles from the attack profile. The target was circled on the photos. The third photo was an enlargement of the target with the target aimpoint annotated. The 2 and 5 kilometer range photos were intended to give the operator contexual information along his attack profile that would aid him in quickly recognizing the target. The photo enlargement was to show the operator the point on the target he was to designate.

The written description informed the operator of the target type, the specific aimpoint he was to designate, and contexual cues present in the scene that would aid him in quick recognition of the target. Prior to beginning a trial the operator spent several minutes studying the contents of the briefing packet. The packet was available to the operator during the trial.

SUBJECT/OPERATORS

Nine Hughes engineering personnel participated as test subjects in the simulation. All of the test subjects had participated in previous electro-optical sensor simulations.

PROCEDURES

At the beginning of the experimental session, the operator was given a set of standardized written instructions describing the objective of the simulation and the task he would be performing. When the operator had read the instructions the experimenter summarized the salient points and answered any questions. Six training trials were given to familiarize the operators with the types of targets and study parameters he would be experiencing during the experiment. Each combination of signal-to-noise and video frame rate was demonstrated to the operator during these trials.

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Figure 3. Target number 16 "Building".

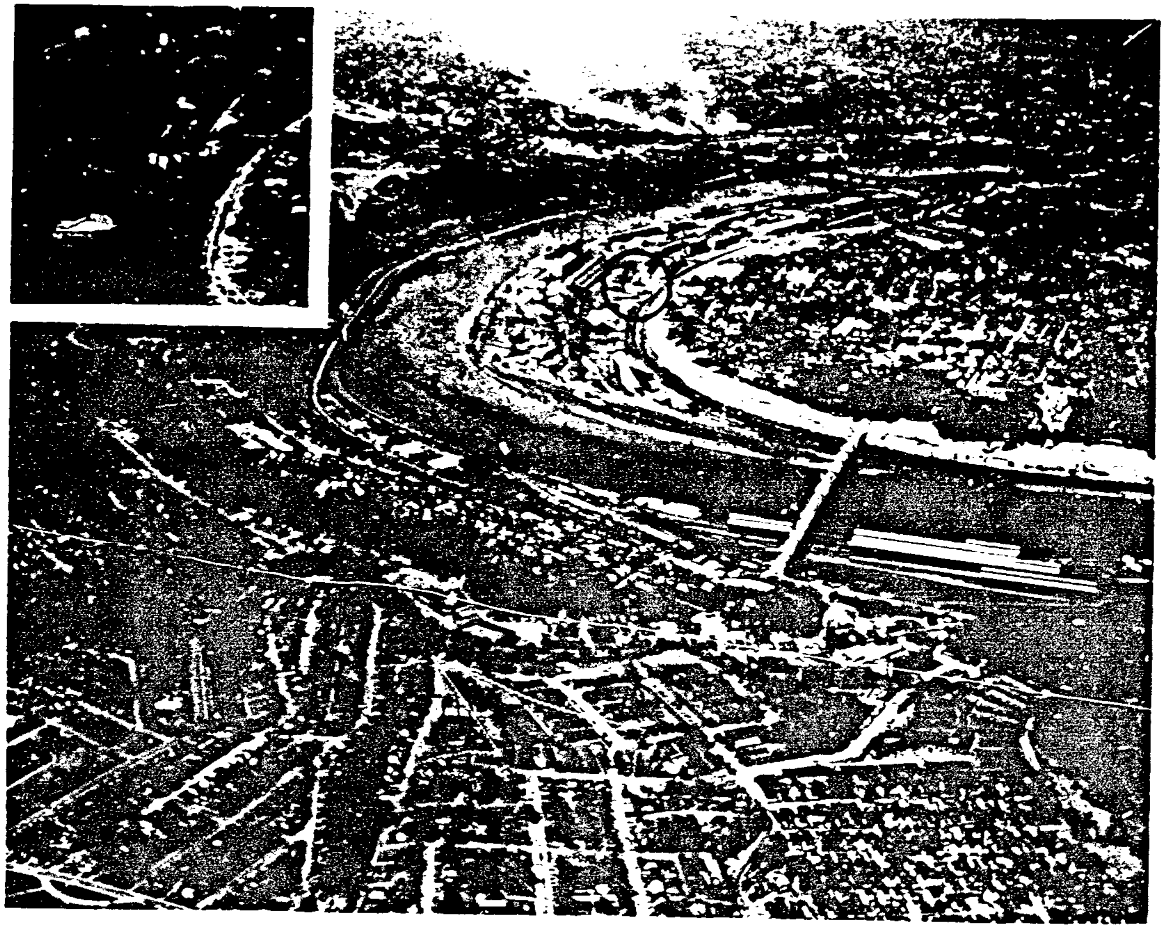
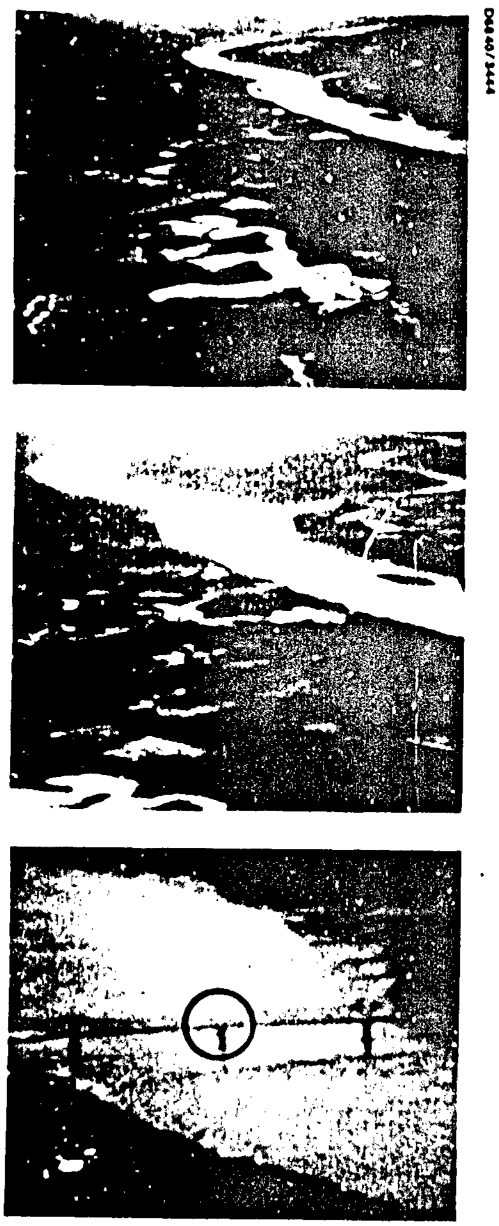


Figure 4. Target number 4 "POL Storage".



a. Range 7 kilometers.

b. Range 3 kilometers

c. Range 0.4 kilometers.

Figure 5. Target number 5 "Bridge".

a. Range 5 kilometers.

b. Range 2 kilometers.

c. Range 0.2 kilometers.

Figure 6. Target number 17 "Bunker".

Following training the operators received 18 test trials. Prior to the beginning of each test trial the operator was handed a briefing packet and informed of the video frame rate and signal-to-noise values for the trial. After the operator had studied the briefing packet, any questions were answered. The trial began with the display blanked and the digital timer zeroed. When the operator had arranged his briefing materials and indicated he was ready, the display was unblanked and the timer started. The operator began searching the display to locate the target/target area as vehicle closed on the target. After recognizing the target/target area the operator positioned the target under the fixed crosshairs at the center of the display using the hand control and activated 3:1 zoom. With the reduced 8.9 by 6.7 grad (8 by 6 degrees) field of view the operator re-acquired the target aimpoint and positioned it under the crosshairs for final designation using a lock-on button on the hand control. The entire session including training required approximately one and a quarter hours.

PERFORMANCE MEASURES

Range-to-target and probability of correct target acquisition were measured and recorded for each simulation trial. Range-to-target at acquisition was measured to the nearest meter. These data were used to perform descriptive and inferential statistical data analyses presented in the following section.

Section 3

RESULTS AND DISCUSSION

This simulation study was conducted to investigate the effects of noise jamming on RPV operator target acquisition with frame rates ranging from 1.88 to 15 frames per second. The study had two principle objectives: 1) test a hypothesized interaction between video signal-to-noise jamming and video-frame rate and 2) obtain preliminary data on the operators' ability to acquire targets with a simulated Swedish RPV system. Range-to-target at acquisition (target recognized and designated) was the primary performance measure used to allow these two objectives to be met.

The range-to-target at acquisition data were subjected to an analysis of variance to test the reliability of the effects of signal-to-noise ratio and frame rate on operator performance and were used to prepare plots which describe the obtained relationships. The effect of signal-to-noise ratio had a highly statistically reliable effect on operator performance. The probability that the differences obtained among the 15, 22, and 30 dB signal-to-noise ratios could be due to chance was less than one out of one thousand ($p < 0.001$). Frame rate was statistically reliable between the 0.05 and 0.10 probability levels. The hypothesized interaction between signal-to-noise ratio and frame rate did not occur. The probability of there not being an interaction effect was greater than 0.25.

VIDEO SIGNAL-TO-NOISE RATIO

Figure 7 shows mean target acquisition range for the nine combinations of signal-to-noise ratio and frame rate tested. Figure 8 shows the overall effect of signal-to-noise ratio (SNR) and clearly demonstrates that the 15 dB signal-to-noise ratio resulted in operator performance that was significantly degraded compared to the 22 and 30 dB SNR's. Mean target acquisition range was 1110 meters at 15 dB SNR compared to 3109 meters at 22 dB SNR — nearly a three fold improvement in operator performance. Performance continued to improve as SNR increased from 22 to 30 dB, although not as dramatically as between the 15 and 22 dB SNR's. The mean target acquisition ranges for the 22 and 30 dB SNR's were 3109 and 3831 meters, respectively, a 23 percent performance improvement.

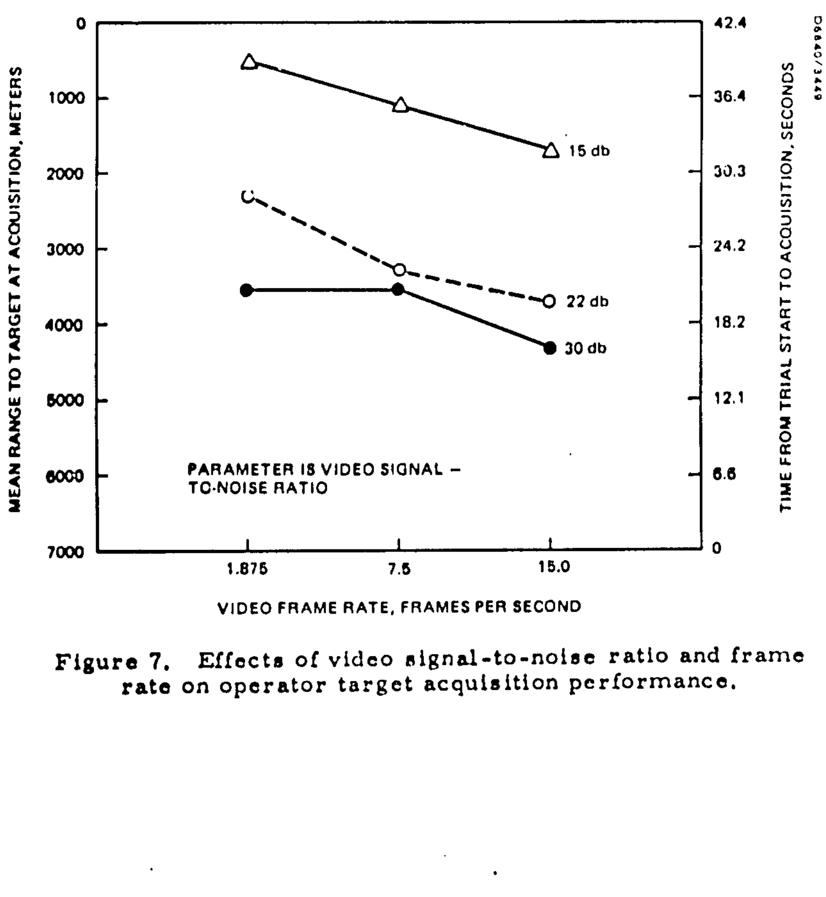


Figure 7. Effects of video signal-to-noise ratio and frame rate on operator target acquisition performance.

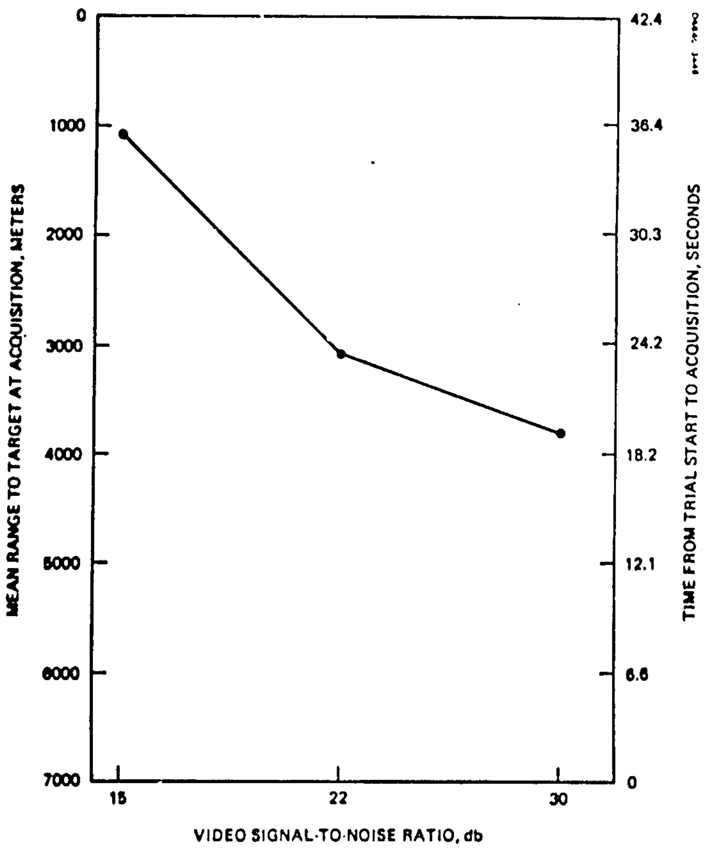


Figure 8. Effects of video signal-to-noise ratio on operator target acquisition performance.

Noise jamming that results in video signal-to-noise ratios as low as 15 dB are clearly unacceptable. The results of this study indicate that operator target acquisition performance improves as SNR increases up to 30 dB. Previous research (Hillman, 1967) has shown that SNRs above 30 dB do not result in improved operator target acquisition performance and 20 dB SNR is the minimum acceptable SNR for military target acquisition tasks. The findings of the present study generally agree with the previous research findings.

VIDEO FRAME RATE

Increasing frame rate from 1.88 to 15 frames per second resulted in improved operator target acquisition performance. Greater improvement at the lower SNRs with high frame rates (the hypothesized interaction), however, did not occur.

The nearly linear effect of frame rate on operator target acquisition performance shown in Figure 9 was not anticipated. Past research (Self and Heckart, 1973) has indicated that frame rates from 1 to 24 frames per second have no effect on operator target recognition performance. Thus it is unlikely that variations in frame rate can cause perceptual differences that affect the operators' ability to visually search for and recognize targets.

It is generally agreed that low frame rates (frame rates less than 4 frames per second) cause degraded operator control performance. In this study, image motion compensation was used to eliminate the problem of sensor slewing (operator control of sensor pointing) with the 1.88 per second frame rate. Thus if neither target recognition performance or sensor slewing performance should have been affected by frame rate, then why did operator target acquisition performance improve as frame rate was increased?

One possible explanation is that even at 30 dB SNR, high frame rates improve the video image quality because of visual integration. A second explanation is that the sample size (18 trials per each of the nine combinations of SNR and frame rate) was not large enough to describe the true relationship between SNR and frame rate. A larger, more comprehensive simulation study than could be conducted in this program will be required to resolve the issue.

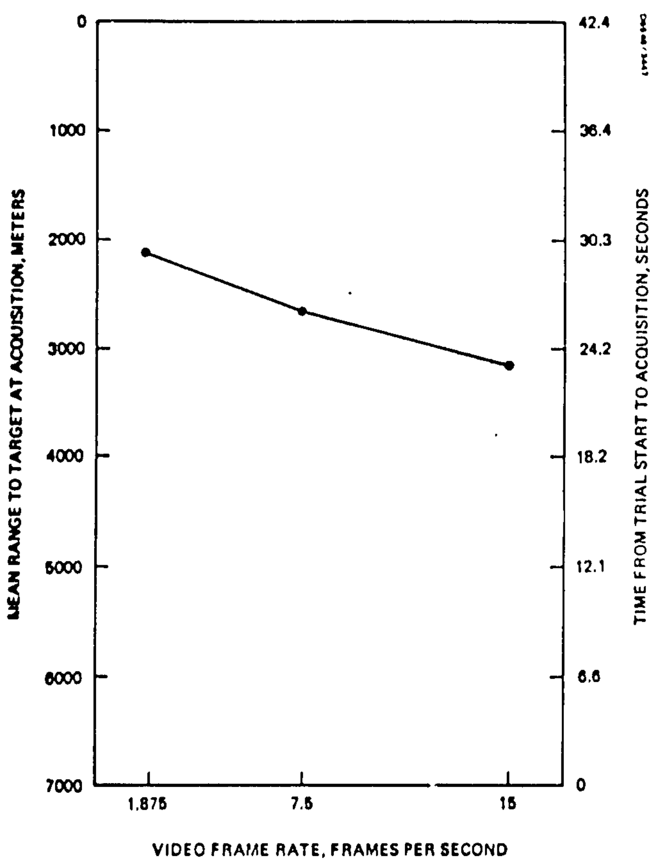


Figure 9. Effects of frame rate on operator target acquisition performance.

SYSTEM PERFORMANCE

The second objective of the simulation study was to obtain preliminary data to determine the level of operator/RPV system performance that could be expected in an operational system. Figures 10, 11, and 12 contain plots of cumulative probability of correct target acquisition as a function of range from target at acquisition. The three figures are for the three frame rates investigated. Each figure gives the performance obtained for the three SNR's examined.

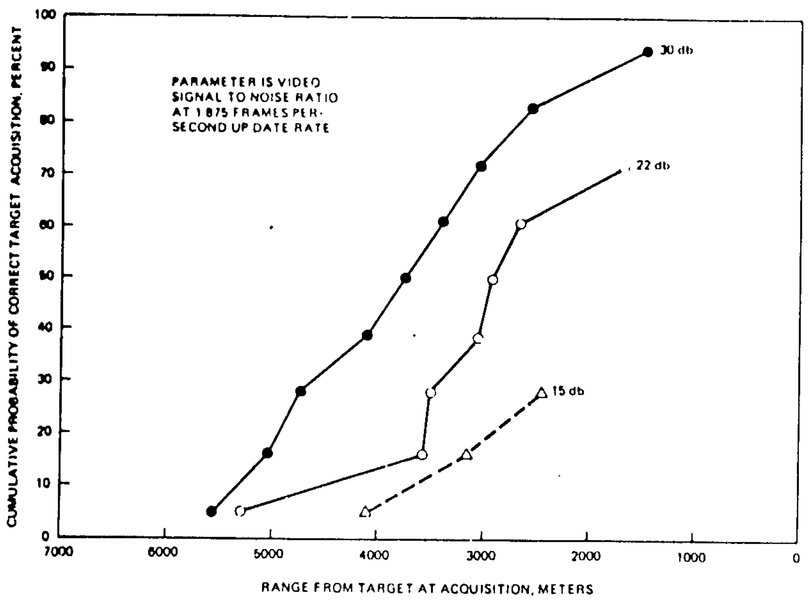


Figure 10. Effects of video signal-to-noise ratio at 15 frames per second up-date rate.

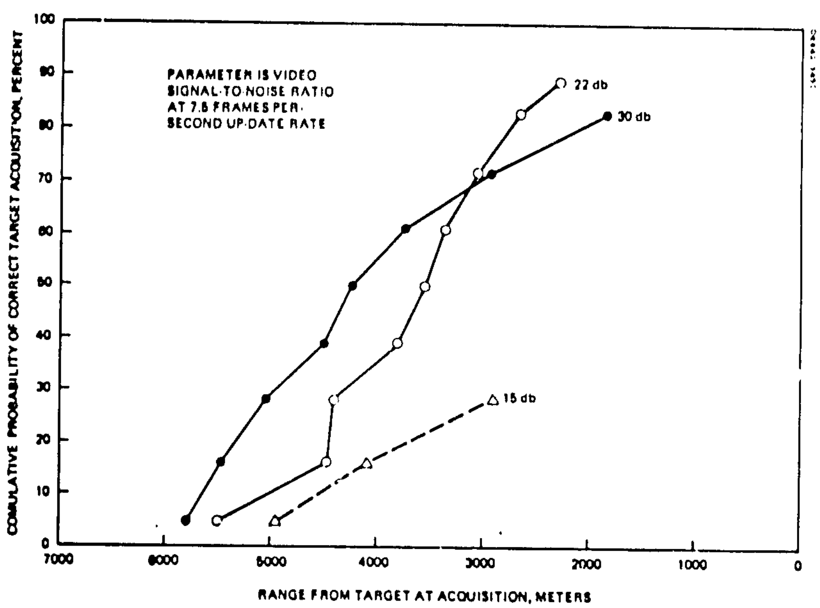


Figure 11. Effects of video signal-to-noise ratio at 7.5 frames per second up-date rate.

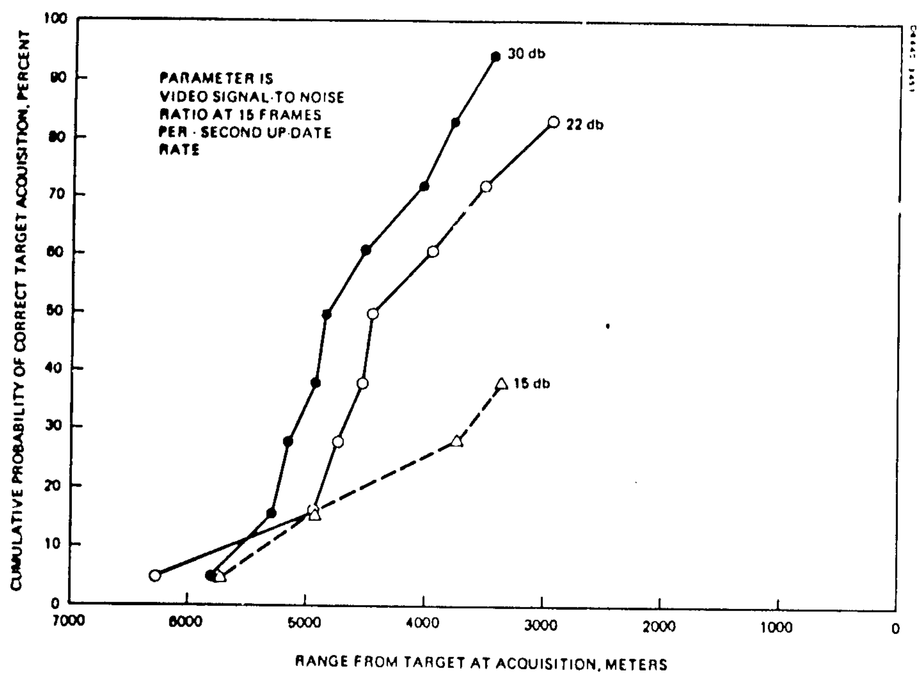


Figure 12. Effects of video signal-to-noise ratio at 1.875 frames per second up-date rate.

In any simulation of this type the difficulty of the target scenes plays a large part in the level of operator target acquisition performance obtained. In the simulation, target scenes representative of the types of terrain and targets to be expected in an operation situation were selected. The selected target scenes were, on a scale of low to high difficulty, in the moderate to high difficulty region. Thus the range-to-target at acquisition results are probably a conservative estimate of potential operator/system performance. For example, with a 30 dB SNR, 30 frames per second frame rate system one could expect to obtain target acquisition at ranges between 4000 and 5000 meters with a probability of mission success greater than 0.90. At the other extreme, with a 15 dB SNR, 1.88 frame per second frame rate system, one could expect target acquisition at 1000 meters with a probability of correct target acquisition of less than 0.20. The curves in Figures 10, 11, and 12 contain the basic performance data which the reader can use to assess system performance capability.

Section 4

CONCLUSIONS AND RECOMMENDATIONS

Both video signal-to-noise ratio and video frame rate reliability affected operator target acquisition performance. The postulated interaction between signal-to-noise ratio and frame rate, however, did not occur. Thus selection of a particular value of signal-to-noise ratio can be accomplished without consideration of frame rate, and vice versa, from the standpoint of visual integration and operator target acquisition performance. In other words, it appears that the designer would be better advised to use a low frame rate to reduce video bandwidth and thereby gain improved image quality through noise immunity than to use a high frame rate for improved image quality from operator visual integration with less immunity to noise jamming.

The finding that performance improved with increasing frame rate across all signal-to-noise ratios is difficult to explain. Past research, laboratory observations, and prevailing theory do not support the obtained results. Additional research is required to determine the effects of video frame rate on operator target recognition and sensor slewing performance to resolve this issue.

The results indicate that video signal-to-noise ratio is a more important determinant of operator target acquisition performance than is video frame rate for the ranges of these variables tested. Thus without any other data, the operator performance tradeoff favors high signal-to-noise ratio over reduced frame rate. Clearly the video data link must be protected to the extent that a video signal-to-noise ratio of 20 dB or greater is maintained to obtain acceptable operator/system performance. With a 22 to 30 dB signal-to-noise ratio system, a high probability of mission success can be expected. Protection of the wideband video data to achieve a 22 to 30 dB signal-to-noise ratio is therefore of paramount importance. Bandwidth reduction to achieve this objective can best be achieved by frame rate reduction and transform coding (bandwidth compression) techniques. Future research efforts should concentrate in these two areas.

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