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SYNTHETIC APERTURE RADAR OPERATOR TACTICAL TARGET ACQUISITION RESEARCH

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SUMMARY

A radar target acquisition research study was conducted to access the effects of two levels of 13 radar sensor, display, and mission parameters on operator tactical target acquisition. A saturated fractional-factorial screening design was employed to examine these parameters. Data analysis computed ETA^2 values for main and second-order effects for the variables tested. Ranking of the research parameters in terms of importance to system design revealed four variables (radar coverage, radar resolution/multiple looks, display resolution, and display size) accounted for 50 percent of the target acquisition probability variance.

1.0 INTRODUCTION

Synthetic aperture radar (SAR) operator performance research was begun in the mid-1960's and has continued at a modest level to the present time. Most of this research has been directed towards defining SAR sensor characteristics for locating large, location known, fixed targets. Only recently have SAR sensors systems appeared suitable for operators to locate and designate small tactical targets. There have been several limited initial investigations of SAR operator performance for detection/recognition of small targets [1, 2, 3, 4, 5, 6].

The objective of this research study was to identify the important radar, display, and mission variables in a quick response tactical target acquisition mission. The results of the study would identify variables which have a major affect on operator/system performance and which variables are unimportant. This information would allow designers and mission planners to make better design decisions.

2.0 METHOD

To achieve the research objective, a number of variables must be varied and controlled. Recent work by Simon [7] has resulted in the development of economical multifactor behavioral research designs. The economy is based on the fact that there are very few meaningful interactions beyond the second order in behavioral research. Simon recommends a general behavioral research strategy that proceeds from a large multi-factor screening study to research in which functional relationships are described using central-composite designs and finally to performance prediction using system simulation. The first step of this research strategy was adopted for the present study.

The quick response mission scenario provided the foundation for the screening study in which two levels of 13 parameters were investigated. The 13 study parameters are summarized in Table 1.

2.1 RADAR IMAGERY, TEST EQUIPMENT, REFERENCE MATERIAL AND OPERATORS

High resolution UPD-4 synthetic aperture radar imagery recorded during military maneuvers in West Germany was used. The raw radar signal film was reprocessed to provide the two levels of radar resolution required in the study.

The imagery was screened for selection of 32 simple and complex background scenes in which radar tactical targets were embedded. The composite target scenes were mounted in glass slides and projected with a 12.7 cm optical projector onto a back-projection screen. The focus and projected image size on the screen was adjusted to produce the required levels of display resolution and display size.

Army Map Service (AMS) 1:50,000 topographic charts and mission/target descriptor information on 12.7- by 17.8-cm index cards served as briefing and reference materials. Operator/subjects used the charts during target briefing, and the charts were available during each test trial.

Tactical Air Command F-111 Weapon Systems Officers (WSOs) from Nellis Air Force Base served as radar operators in the study. Eight WSOs were selected from an initial sample of 60.

TABLE 1

STUDY PARAMETERS AND LEVELS

Parameter	Low Level	High Level
Radar Resolution/ Looks	12.2 meters/4 looks	High Resolution/ 1 look
Radar Coverage	4572 x 4572 meters	1524 x 1524 meters
Display Resolution	500 x 500 elements	2000 x 2000 elements
Display Size	12.7 x 12.7 cm	25.4 x 25.4 cm
Target Type	Convoy	AAA site
Background Complexity	Complex	Simple
Target Difficulty	Difficult	Easy
Target Intelligence	Low	High
Target Reference Point	No	Yes
Navigation System Error	±610 meters	±91 meters
Navigation Error Cursor Design	Crosshair	Circle
Operator Viewing Distance	71 cm	36 cm
Mission Time Available	20 seconds	60 seconds

2.2 EXPERIMENTAL DESIGN

The effects of 13 variables were examined using a fractional-factorial design. To completely specify the effects of 13 independent variables, each at two levels, and all of their interactions in a full factorial design would require 2^{13} or 8192 observations per subject. Clearly, this was an impracticably large number of conditions and some modification was necessary. In most behavioral research it is reasonable to assume that higher order interactions account for very little variance. With this assumption, a research strategy which, as a first step, examines only the main effects of each variable, is an economical research approach.

Simon [7] describes an economical sampling strategy, referred to as a screening design, which uses a fractional replicate of a 2^{13} factorial design. The basic design consists of 16 selected combinations of the 13 independent variables which is augmented with an additional 16 conditions. The 32 total experimental conditions allow an estimate of the main effects along with a number of aliased two-factor interaction strings.

2.3 PROCEDURES

Each operator received a one-hour familiarization briefing, 32 training trials, and 32 test trials over a two-day period. Each operator was given a verbal briefing which included: 1) a description of the study objectives and an overview of what the operator would be doing, 2) a discussion of the application of SAR to the quick response mission, 3) a description of the radar, display, and mission parameters the operator would experience during the study, 4) a review of the UTM map grid system, and 5) a series of training trials to familiarize the operator with the parameters under investigation. A warm-up trial was given before each test trial because of the large differences in conditions that existed among the test trials due to changes of the 13 study parameters from trial to trial. Target acquisition time, probability, and operator confidence estimates were the performance measures recorded.

3.0 RESULTS

The objective of this study was to determine what parameters are important determiners of operator performance in a simulated tactical strike mission. This screening study with 13 parameters was designed to accomplish this objective. In this type of study the percent of variance attributable to the different study parameters (ETA squared) is the measure used to make this determination. The ETA^2 values for each of the 13 parameters studied are given for the three performance measures--target acquisition time, probability of correct target acquisition, and operator confidence judgment.

The time measure used in the analysis was the percent of time used of the total mission time available. This measure was used to take incorrect target acquisitions into account in the analysis of the time data. If an

operator found the wrong target or ran out of time, the maximum time available, 20 or 60 seconds depending on the mission time available for that trial, was used as the time score. The ratio of time available to time taken to acquire the target was the value used in the analysis.

Operator confidence data were analyzed by assigning a value of 4 for "high" confidence, 3 for "medium" confidence, 2 for "low" confidence, and 1 for trials where the operators ran out of time. Although these values cannot be assumed to be on an interval scale which, strictly speaking, is required by the analysis for ETA^2, they allow an approximate estimation of ETA^2 values for the operator confidence judgment data.

Following the presentation of results for percent of variance attributable to the parameters studied, those parameters determined as important will be discussed.

3.1 VARIANCE ATTRIBUTABLE TO STUDY PARAMETERS

Evaluation of the ETA^2 values indicates that radar coverage, display resolution, and radar resolution were the principal parameters that affected operator target acquisition performance. Radar coverage was the most important variable (smaller coverage produced better performance) accounting for 30.1, 22.2, and 26.6 percent ETA^2 values for the time, probability, and confidence judgment measures. Display resolution, the second most important parameter, accounted for 13.2, 12.5, and 17.6 percent of variance, respectively, for the time, probability, and confidence judgment measures. Radar resolution was the third most important parameter for operator time and probability performance--9.1 and 10.5 percent ETA^2, respectively. Interestingly, radar resolution was not an important parameter in the operator's confidence judgments (0.8 percent ETA^2). The operator's judgments of their acquisition performance were unaffected by presentation of a high resolution/1-look or a 12.2 meter/4-look radar image.

A second group of three parameters had moderate effects on operator performance; these parameters were display size, navigation error, and target type. Display size was the most important of these parameters, accounting for 4.9, 7.0, and 3.9 percent of the variance for time, probability, and confidence judgment measures. Navigation error accounted for 5.6, 3.1, and 2.3 percent

of the variance for the time, probability, and confidence judgment measures. Although target type had a moderate effect on target acquisition time (5.4 percent of the variance), it had a small effect on target acquisition probability (1.4 percent of the variance) and no effect on the operator's confidence judgments (less than 0.1 percent of the variance).

Four of the six remaining parameters that accounted for a small but meaningful (2 to 3) percent of the variance included: navigation error cursor design, target reference point, target difficulty, and mission time available. The two variables having no affect on operator performance were the amount of target intelligence and operator viewing distance.

One second-order interaction which accounted for a relatively large percent of the variance was identified in the study. This was the interaction between radar coverage and display resolution. Display resolution had a much greater effect on time and probability performance with the large radar coverage. At the small coverage, the 2000-line display resolution was only slightly superior to the 500-line display.

In the remainder of this discussion of results, those parameters determined to be of major or moderate importance will be addressed separately. The implication of the results to SAR tactical strike systems design will be discussed, and recommendations for additional research to establish quantitative functional relationships among the parameters and operator performance will be made.

3.2 OPERATOR PERFORMANCE OBTAINED WITH THE STUDY PARAMETERS

The performance estimates that will be discussed for each of the two levels of the parameters are averaged across the high and low levels of the other 12 parameters.

3.2.1 RADAR COVERAGE

The 1524-meter coverage resulted in the best performance. The large effect of radar coverage in favor of the smaller coverage was a surprising result. Past SAR tactical target acquisition research [3] found a small effect due to radar coverage in favor of larger coverage.

Inspection of radar scenes at the two coverages indicates that scale factor is probably the underlying cause. At the 4572-meter coverage, the individual target returns that made up the linear and pattern targets are small and difficult to see; even the complete target made up of several radar returns was small at the 4572-meter coverage. With the 1524-meter coverage, the targets are much easier to see. The increased performance obtained with the larger display size, discussed later, supports this hypothesis. For small targets, displayed scale factor of the SAR scenes is an important design consideration, which would argue for a small radar coverage.

3.2.2 DISPLAY RESOLUTION

The second most important parameter was display resolution. The 2000-line display resolution was determined to be considerably better than the 500-line resolution display. Previous research [4] found that operator acquisition of large targets was not affected by variation of display resolution; although, qualitative evaluation of tactical targets in that same study indicated that tactical targets might be affected by display resolution.

In the current study, display resolution was varied by defocusing the optical projection system and adding TV line structure to the radar images. Therefore, two factors were varied in the two display resolutions--resolution and line structure. The interaction between display resolution and radar coverage indicates that line structure was probably the more important factor. At 1524-meter coverage, there was only a small performance advantage for the 2000-line resolution display over the 500-line display, while at the 5472-meter coverage performance was significantly better with the 2000-line resolution display.

The hypothesis is that the coarse line structure of the 500-line resolution display interferred with the target patterns at the 4572-meter radar coverage, because the line structure was large relative to the size of the target returns. The line structure of the 2000-line resolution display was small relative to the target patterns at the 4572-meter coverage and hence did not interfere with target patterns. At 1524-meter coverage, the line structure of the 500-line resolution display did not interfere with the

target return patterns, and performance was only slightly poorer compared to the 2000-line resolution display.

3.2.3 RESOLUTION/MULTIPLE LOOKS

As expected, resolution/multiple looks had a major effect on operator target acquisition. The high resolution/1-look condition resulted in substantially improved performance over the 12.2-meter resolution/4-look condition. Future research should be conducted to establish functional relationships among radar resolution, radar multiple looks, and operator target acquisition performance for use by radar systems designers. The high resolution/1-look and 12.2-meter/4-look conditions represent reasonable upper and lower bounds for such research.

3.2.4 NAVIGATION SYSTEM ERROR

The ±91-meter and ±610-meter navigation errors investigated had a moderate affect on operator performance. The smaller navigation error, as one would expect, resulted in more rapid operator target acquisition and higher probability of correct target acquisition.

3.2.5 DISPLAY SIZE

All other things being equal, a large display size allows SAR video to be displayed at a larger scale factor than a small display size. As discussed previously, displayed SAR video scale factor may be an important factor in SAR operator tactical target acquisition. The 25.4-cm (larger scale factor) display resulted in better performance than did the 12.7-cm display.

Display size coupled with display resolution, radar coverage, radar resolution, and operator viewing distance determine the operator's ability to extract displayed sensor information. In this screening study, it was not possible to determine the potentially complex interactions among these parameters. Since the scale factor of the displayed SAR video appears to be an important factor in SAR operator target acquisition performance and since cockpit real estate is precious in attack aircraft, it is important that future research be conducted to determine the relationships among display size, radar coverage, radar resolution, and operator viewing distance. If aircraft cockpit considerations dictate a small display, other design

options may have to be exercised to avoid unnecessarily limiting the operator's performance potential. The suggested research would provide the data to make intelligent design decisions.

3.2.6 TARGET TYPE

Target/background characteristics are known to be major sources of variance in ground mapping sensor target acquisition studies. Target type, background complexity, and target difficulty were controlled variables in this study, primarily to extract and measure this source of variance. Of these three variables, target type caused the most performance variation. The extended targets (convoys) were acquired faster and more often than were the pattern targets (AAAs). Post hoc analysis of the radar images leads us to conclude that scene clutter and raster structure tended to interfere more with the perception of the pattern targets than the linear targets, hence the poorer performance obtained with pattern targets.

4.0 CONCLUSION

This research was performed to establish the relative importance among radar sensor, display, and mission variables on operator tactical target acquisition performance for application to the quick response mission. The results of the research provided the data necessary to identify which were the important variables as a first step towards defining a viable system and future research requirements.

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