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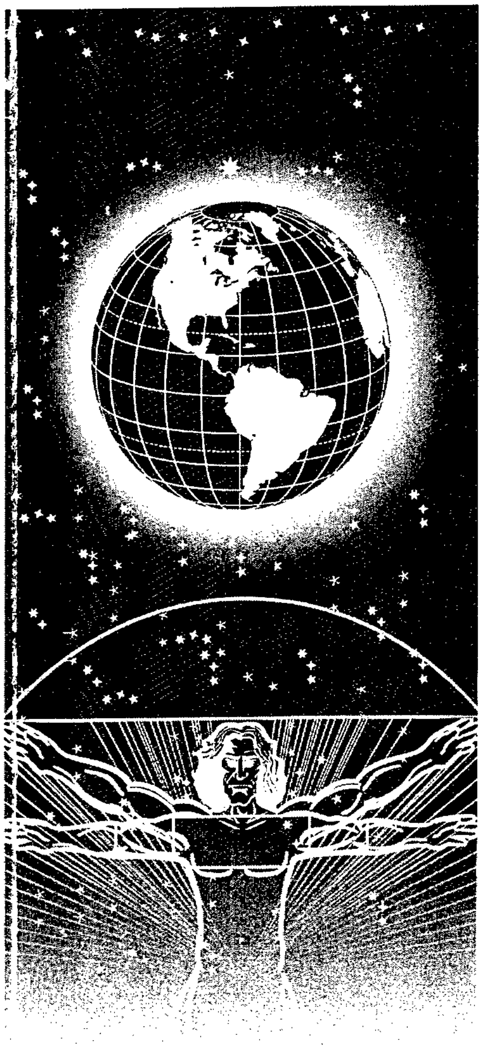

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MULTISENSOR IMAGE INTERPRETATION

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FOR THE COMMANDER

MARIS M. VIKMANIS
Chief, Crew System Interface Division
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13. ABSTRACT *(Maximum 200 words)*
A target acquisition experiment was conducted using simulated synthetic aperture radar (SAR) and forward looking infrared (FLIR) imagery. Ground order of battle provided the target set. Confuser vehicles and decoys were also included in the stimuli.

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PREFACE

The current study explored the operational utility of using synchronized, multi-sensor images for the acquisition of pre-brief ground order of battle targets and specifically for distinguishing real targets from decoys. The rates of target Hits and False Alarms with a synthetic aperture radar (SAR) sensor alone were compared to the corresponding rates when both SAR and forward looking infrared (FLIR) sensors were employed sequentially.

The study was conducted with the joint participation of the Simulators and Human Factors Engineering Branch of the Israel Air Force (IAF) and the Crew System Interface Division of the United States Air Force Research Laboratory's Human Effectiveness Directorate (AFRL/HEC). The research took place in Israel during the years 2000-2001. Mr. Gilbert Kuperman (AFRL/HECA), Lt Col Itzhak Nadler, and Major Michal Chovav (IAF) served as technical project officers.

This study was carried out with the contractual support of Synergy Integration Ltd., Tel Aviv, Israel, who prepared the simulated sensor imagery and did the programming for the experiment.

The authors wish to thank the photo interpreters who volunteered to participate as subject matter experts in the experiment and their commanding staff who helped in organizing the project. Special thanks are due to Major Chovav who coordinated these efforts during the final stages of the study.

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SECTION I

INTRODUCTION

Multi-Sensor Imaging

The combined use of various types of sensor imagery can enhance both speed and accuracy of imagery interpretation. Speed may be improved by combining means that allow fast screening of a large scene with means that enable thorough investigation of individual targets. Accuracy of interpretation may be improved when a combination of sensors provides more information than each of the sensors provides separately. Specifically, such a combination may potentially enhance the distinction between real targets and decoys.

SAR and FLIR Sensors

If, for example, both a SAR (synthetic aperture radar) sensor and an Electro-Optical (EO) sensor (e.g., FLIR, forward looking infrared) can be used in the same area, a user could benefit from the relative advantages of each of them:

SAR may provide images from a long distance (standoff range), which are not affected by lighting and atmospheric conditions. However, SAR has a relatively limited resolution and it provides a non-literal picture in which gray shades are determined by the radar reflectivity of objects in the scene. In comparison, EO sensors may provide higher resolution and a more natural representation of the scene (depending on type of sensor). In addition, some EO systems may be much smaller, lighter and more available then SAR systems. They may, therefore, be installed in larger numbers of smaller platforms such as small UAVs (uninhabited air vehicles), helicopters, small vehicles and even hand held systems. However, all EO sensors are affected by atmospheric conditions and by time of day (lighting or heat emittance) and may therefore be more limited in range.

Clearly, SAR and EO sensors may complement each other and their combined use may provide many advantages. For example, SAR images may be used for detecting suspected objects at long distances while EO sensors may then be used for the recognition stage of information extraction.

In order to take advantage of multiple image sources, it is important to understand the parameters that determine the relative contribution of each of the participating sensors and to understand the circumstances under which they may complement each other. The objective of the present study is to investigate these issues.

SAR and FLIR signatures

The SAR signature (proportionate to the RCS, radar cross section) depends on the geometry of an object and on its material properties. It is not affected by atmospheric conditions, time of day, level of activity (e.g., engine running), etc. In contrast, IR (infrared) images are much less consistent because they are affected by all of the above variables. The IR signature of a typical military target is affected primarily by its heat-producing components (e.g., engine, treads, gun, etc.). However, these components may be hot or cold, depending on whether and when the target has operated its engine, changed its position, fired the gun, etc.

As a result, if an object presents a SAR signature which lacks meaningful detail, it may be decided that the object is "not a target. " The FLIR signature however is much more "tricky" and potentially deceiving because a cold object may be an inactive target.

The Operational Use of Decoys

An observer of a military scene may have difficulty detecting, classifying, recognizing and identifying all the types of military and non-military equipment which may be present in the scene. The task may be even more challenging if the adversary makes effective usage of decoys. Decoys are employed to provide false "targets" against which the enemy will expand its efforts, possibly revealing its position in the process. Decoys also enhance friendly survivability and may deceive the enemy about the number and location of friendly troops and equipment.

A recent case study (Cohen & Shelton, 1999) analyzed the effects of decoys on NATO's war in Kosovo. NATO conducted a 78-day air campaign over Kosovo. The US Army officially claimed that 122 tanks and more than 220 troop carriers and other military vehicles were destroyed. However, when the ground troops (and the media) entered the area there was hardly any evidence of destroyed military targets. At the same time the Serb army was seen to withdraw from Kosovo with hundreds of intact tanks, cannons, and multiple launch rocket systems (MLRS). Apparently, the bombing campaign, which consisted of more than 3,000 sorties and the expenditure of tens of thousands of tons of explosives, including the use of sophisticated precision weapons, succeeded in damaging only about 13 – 30 of the Serb's 300 battle tanks in Kosovo. The exact numbers depend on the source; NATO's official numbers are higher than most media reports (e. g., Norton-Taylor, 2000).

According to some media reports (e.g., Beaver, 1999) these outcomes are a result of two factors: first, the real equipment was hidden in various safe locations and second, the Serbs used large numbers of decoys, smartly located to deceive pilots flying at an altitude above 15,000 feet. The Serbs used pneumatic (i.e., inflatable) rubber "images" of tanks (Figure 1), which included a heat source for decoying thermal imaging systems. (On February 18, 2000, The Herald Tribune wrote that many of the heat sources were domestic microwave ovens looted from Albanian homes.) The decoys were cleverly located next to phony bridges that were constructed on fake roads made of black plastic sheets.

Decoys can be elaborate or simple, pre-constructed or made from field-expedient materials. The fidelity (realism) of decoys depends on whom and what sensors they are meant to deceive. Completely replicating all features of real targets can be very difficult and expensive, especially for moving and mobile targets. Hence, in most cases, decoys may aim at deceiving certain, but not all, aspects of the target's signature (e. g., visible features, size, shape, brightness and color, movement and motion, ground effects, thermal signature, RCS, EM [electro-magnetic] signature). As a result, observing a target by different means, which exploit different phenomenologies, may enhance the ability to distinguish decoys from real targets. For example, had NATO's pilots used SAR, they might not have fallen for the pneumatic rubber tank decoys, for the wooden bridges and for the plastic-sheet roads.

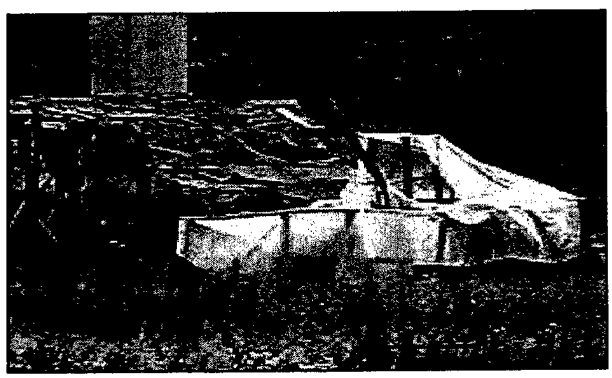

Figure 1 - A destroyed pneumatic tank decoy, next to a decoy bridge in Kosovo (from BBC News Online - June 25, 1999)

The recognition of targets and decoys

Decoys may differ from targets in any of a number of features (e.g., size, shape, texture, motion and movement capabilities, RCS, thermal signature, etc.). In order to distinguish targets from decoys, an observer must be able to recognize some of these differences. The distinction between targets and decoys is a specific case of object recognition that can be examined in view of psychological object recognition theories. Most relevant in the present context are *Feature Theories*. Feature theories postulate that the visual system analyses and represents sensory information in abstract, primitive information units called features or attributes; a "distinctive feature" can be used to make a critical distinction between patterns or classes of objects (e.g., Treisman and Gelade, 1980). The recognition of a pattern involves the analysis of its features (e.g., line direction, size, color, etc.). Feature theories received strong reinforcement from neurological studies, which identified brain cells sensitive to specific features (e.g., lines of a specific orientation, corners and angles - Hubel and Wiesel, 1977). Biederman (1987) postulated a means by which stable, three-dimensional mental representation of objects, can be based on spatial arrangements of simple geometric shapes he called *"geons."* According to Biederman's *Recognition-by-Component theory*, objects are recognized by observing and extracting their edges, and then decomposing them into *geons*, which can then be recomposed into alternative arrangements.

Feature theories seem most relevant to the present context. Decoys are purposely designed to resemble targets. However, they may differ from targets in some of their features. The role of the observer is to detect and recognize these distinguishing features. In the present study, the observers are asked to decide whether an object is a target or "not a target" (rather then positively recognizing the decoys). This decision can be reached in either a positive or a negative approach:

1. The positive approach is to determine that an object has all the necessary (positive) features and only the positive features that characterize a target.

2. The negative approach is to recognize at least one negative feature that precludes the object from being a target.

The positive approach is almost inevitably longer and more tedious than the negative approach since it is serial and exhaustive. Hence, an observer may spontaneously look for negative features rather than try to sum up all positive features. Obviously, the chance of recognizing negative features (that precludes the object from being a target) is higher if there are several such features, and if the features are salient. By potentially revealing a larger variety of features, the multi-sensor approach has two potential advantages: First, there is a better chance for the presence (and recognition) of negative features. Second, a combination of many features may provide better and more conclusive distinction between a target and a decoy.

Objectives

The objectives of the present study are:

1. to investigate working procedures of imagery analysts using SAR and FLIR representations of the same area

and

2. to identify the effects of major image parameters on the imagery interpretation process.

An image library of the same area was represented in simulated SAR and simulated FLIR sensor imagery. The simulated terrain was created from a real, three-dimensional terrain database (extracted from the Ramat Hagolan area). Variations of the background scene were created by adding two and three-dimensional objects and targets (e.g., roads, trees, buildings, military targets and decoys).

During each trial of the experiment, participants were asked to designate all instances of a pre-specified target in the SAR images that contained both targets and decoys. Participants were asked to designate all targets, and to avoid the designation of decoys. After the designation of each object, participants were asked to indicate their level of confidence that the object was a target (on a 1 – 7 scale). After the designation of all suspected targets (or a maximum allowed period of time with the SAR image), participants were able to designate an object in the SAR image and then view a FLIR image of the designated target location. They could then confirm or modify their former target / decoy decision, and update their level of confidence for that object.

It is hypothesized that the use of both SAR and FLIR imagery will increase participants' ability to distinguish targets from decoys, relative to the use of SAR imagery alone.

SECTION II

METHOD

Subjects

Eight Subject Matter Experts (SMEs), seven male and one female imagery analyst of the Israel Air Force, participated in the experiment. The SMEs had 0.5 to 4.5 years of operational experience in image interpretation. The main expertise of all SME was in the interpretation of regular (literal, photographic or electro-optical [television]) imagery. All SMEs had some SAR interpretation experience. Two had some familiarity with FLIR imagery while the other six had no experience with exploiting FLIR. All SMEs had normal or corrected to normal vision.

Test materials

Terrain

Three different areas were created, based on one sampled digital terrain elevation data base (of the Ramat Hagolan area), by inserting different "overlays" of two and three-dimensional objects to the sampled terrain. The added objects included roads, vegetation (trees) and buildings (Figures 2 and 3).

Objects: targets and decoys

Targets

Six ground order of battle vehicles were used as *targets* in the experiment: M-1 main battle tank, T-72 main battle tank, MLRS, air defense radar, SCUD transporter/erector/launcher, and SA-6 surface-to-air missile launcher (Appendix 1). The number of targets of each type in each trial was between 1 and 6, depending on type of target (1 or 2 SCUD; 3 SA-6; 4 MLRS; 2 or 3 Radar; 5 or 6 Tanks). These numbers were selected in order to create realistic operational scenarios. All targets were entered as computer-aided design (CAD) models in the sensor simulation applications (see below).

Decoys

Four types of *decoy objects* were defined. Three of them were derivatives of the "real" target and the fourth was one of the "other" targets:

A *Similar-decoy* (i.e., derived from the corresponding target CAD model) was created for each target by introducing small variations in the target's physical appearance (Appendix

1). These were briefed to the SMEs as "real objects" that are decoys for the purpose of the experimental task (e. g., low priority targets, high fidelity decoys, etc.).
A *SAR-decoy* was created for each target, by introducing small structural modifications to the CAD model (e. g., by removing small parts such as antennas, etc.). In order to create a realistic decoy against the SAR sensor, the SAR-decoy had a similar material definition to that of the actual targets. The thermal (FLIR) signature of SAR-decoys was similar to that of a cold target.

A *FLIR-decoy* object was created for each target by introducing small structural changes (e. g., removing small parts such as antennas, etc.). In order to provide a realistic decoy against the FLIR sensor, the FLIR-decoy had a thermal signature that was similar to the signature of an actual, hot target. The FLIR-decoys were described as being fabricated from "soft" materials (e. g., wood or plastic), and were therefore only barely visible by the SAR.

During each trial, a single target was pre-briefed to the SME as the designated target for that trial. Thus, other target objects could be used as decoys. These objects are called *Target-decoys*. In practice, only one type of target and one Target-decoy (and the other types of decoys) were presented during one trial. Each of the targets was assigned a counterpart target that served as its Target-decoy. The pairs were:

- M-1 tank and T-72 tank
- Radar and MLRS
- SCUD launcher and SA-6 launcher

These pairs were formed on the basis of relative physical similarity. In reality, however, the degree of physical similarity differed between the three pairs: the two tanks were highly similar, the Radar and MLRS were moderately similar, while the two launchers were least similar.
All decoys were entered as computer-aided design models in the sensor simulation applications (see below).
In addition to the above, *Terrain-objects* (e.g., buildings) could also be confused with targets.
Relevant parts of targets and decoys (i. e., engines, wheels, thread, guns) could be hot or cold. FLIR-decoys always had a hot part. SAR-decoys' parts were always cold.

SAR imagery

MultiGen-Paradigm (http://www.multigen.com/) SensorVision™, SensorWorks™, and RadarWorks™ applications were used to create the SAR imagery. The resolution of the SAR was 1 m per pixel. Each SAR image (i.e., one experimental trial) represented an area of approximately 1000 x 1000 m., displayed at a high grazing angle of 30 degrees. The image was displayed with the shadows facing upwards (Figure 2).

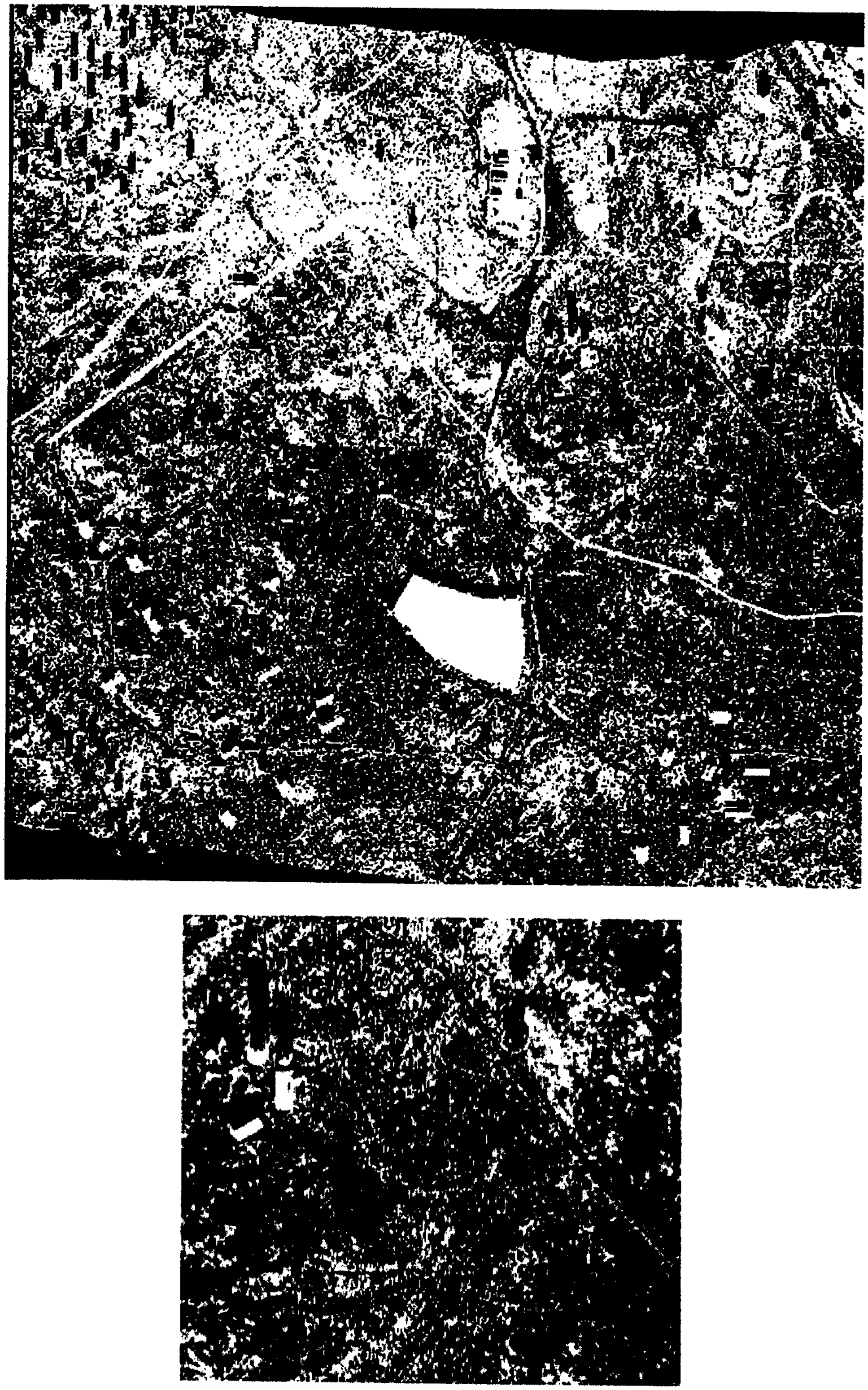

Figure 2 – Simulated SAR imagery: TOP: overall scene at reduced resolution; BOTTOM: scene extract at full resolution.

FLIR Imagery

Simulated FLIR imagery (Figure 3) was generated from the same terrain and target (or decoy) data bases using MultiGen-Paradigm SensorWorks and SensorVision applications to create and display the images. The resolution of the simulated FLIR was approximately twice the resolution of the SAR, i.e., approximately 2 pixels per 1 meter. The simulated FLIR field of view (FOV) was approximately 1.4 degrees, covering an area of approximately 125 x 125 meters from a slant range distance of 10,000 meters. Depression angle of the sensor was -45 degrees. The magnification of the FLIR was approximately twice the magnification of the SAR.

Figure 3 - Simulated FLIR imagery

Apparatus

A graphics workstation equipped with a 17" diagonal, 1280 X 1024 pixel resolution, color monitor and standard keyboard and mouse were used for stimulus presentation and data collection.

Experimental Design and Procedure

Training phase

Each experiment started with a training phase, in which the participants were familiarized with the targets, with the various types of decoy objects, and with the experimental procedure. In addition, since most of the SMEs had no FLIR experience, they were briefed about major FLIR imagery attributes (see Appendix 2 for the written instructions). The SMEs were shown images that displayed each object from five different viewing angles (top, front, back, left, and right) (Appendix 1). They then performed two procedural practice trials in which all the targets and all the decoys were arrayed on the terrain in sorted rows. This enabled the SME to view and compare all objects in their simulated setting and to practice the experimental procedure (Figure 4). Following the procedural trials, two additional trials (with the targets appearing as they would in the data collection images) were performed for additional practice (Table 1). The training phase was self-paced, and lasted from 45 to 75 minutes.

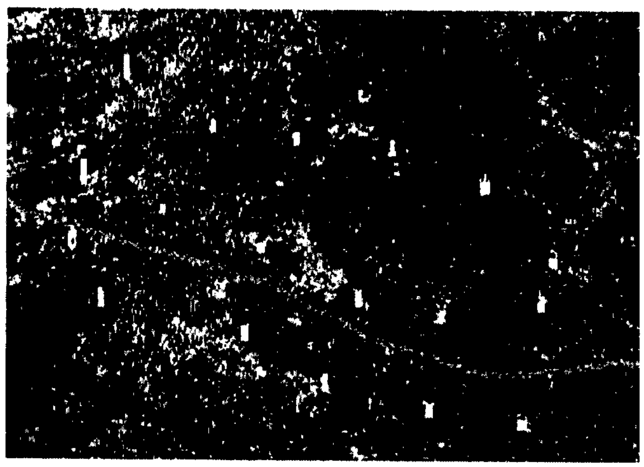

Figure 4 – SAR Imagery of all targets and decoys (ordered in columns from left to right are: SCUD, SA-6, Radar, MLRS, M-1, and T-72; ordered in rows from bottom to top are: Targets, Similar-decoys, FLIR-decoys, and SAR-decoys)

Experimental phase

The experimental phase included 10 trials. A within-subject design was used in which each participating SME performed the same set of trials. The order of the experimental trials was reversed between participants to counterbalance order effects. Table 1 presents the experimental design.

Table 1 - Experimental design

	Target type	Number of targets	Number of Decoys				
			Similar	Different	FLIR-decoy	SAR-decoy	Total
Procedural trials							
1	All	6	6	6	6	6	24

2	All	6	6	6	6	6	24
Practice trials							
1	Scud	2	1	1	2	2	6
2	Radar	2	3	1	4	4	12
Experimental trials							
1	Radar	2	3	2	2	2	9
2	SA-6	3	3	2	2	2	9
3	Scud	1	4	3	4	4	15
4	Radar	2	4	4	4	4	16
5	AV	4	2	2	3	3	10
6	M-1	6	3	2	3	3	11
7	AV	4	4	4	4	4	16
8	T-72	5	4	3	4	4	15
9	M-1	6	4	4	4	4	16
10	Radar	3	3	2	2	2	9

Procedure

Each experimental trial presented one of the terrain backgrounds with a set of targets and decoys distributed across it. A pre-brief was provided for each trial during which the set of objects was presented. Each set contained the pre-defined target, its Similar, SAR and FLIR-decoys and its Target-decoy. (See Table 1 for the number of objects in each category represented in each trial.) SMEs were asked to detect and recognize the pre-defined target and ignore decoys.

The target was designated by placing the mouse-driven cursor over the target and then depressing the left mouse-button. A square red frame appeared around the designated object (target, decoy or terrain object). Each trial consisted of two Phases: the *SAR-only Phase* and the *SAR&FLIR Phase*. The SAR-only Phase had to be completed before the SME could move to the SAR&FLIR Phase. (See below for more details).

(Note: the rigid one-way process that starts with the SAR-only and then moves to the SAR&FLIR phase, was selected for experimental purposes. This process enabled us to separately measure the contribution of SAR-only and of SAR&FLIR. Operationally, however, it would make more sense to allow for more flexibility, e.g., command the FLIR imagery at any desired stage [assuming that the target was in range].)

After the designation of an object (in either Phase), the SME was asked to specify his/her *level of confidence* on a 1 – 7 scale, by pressing one of the F(unction) keys on the keyboard as indicated below. The red box then changed color to blue.

The level of confidence scale

The level of confidence measure represents the SME's subjective evaluation of the attained level of information extraction. It was defined as follows:

F1 - Detection: The object may be some type of target.
F2 - Recognition: The object is possibly a target of the specified category (e.g., a tank)
F3 - Recognition: The object is probably a target of the specified category
F4 - Recognition: The object is definitely a target of the specified category
F5 - Identification: The object is possibly the designated target (e.g., T-72 tank)
F6 - Identification: The object is probably the designated target
F7 - Identification: The object is definitely the designated target
F8 - Not a Target: This key was used only during the SAR&FLIR Phase. It canceled the former selection of a target.

The SAR-only Phase

Each trial started with the SAR-only Phase in which the SME viewed only the SAR image and was given time to designate any candidate object. The bounding square red frame indicated each designated object. Following each designation, the SME rated his/her confidence level in that designation by selecting an associated level of confidence.

The SAR-only Phase lasted until the SME completed the designation of all suspected targets or until 15 minutes elapsed (whichever happened first). During the SAR-only Phase the SME could revise previous confidence levels. The SME could also "de-designate" an object by assigning it to the "Not a Target" category (F8).

The SAR&FLIR Phase

After designating all suspected targets from the SAR image (or after 15 minutes had elapsed), the SME moved to the SAR&FLIR Phase. The SME could now select each of the previously designated SAR objects, thereby opening a FLIR image for the area containing that object. On the SAR image, the frame surrounding the target turned green, indicating that a FLIR image had been commanded. The FLIR image was displayed next to the designated SAR target, without concealing it, thereby enabling the SME to compare the SAR and FLIR representations of each object (Figure 5). The designated object appeared randomly within a radius of 80 meters from the center of the FLIR image (reflecting a certain level of possible misalignment between SAR and FLIR images). Therefore, the SME had to locate the previously designated target, select it on the FLIR and then confirm or change the former target / decoy decision and update the confidence level for that object. On the displayed FLIR image, the SME could designate any object, even one not previously designated on SAR. After the completion of the rating procedure the FLIR window was closed by the SME. On the SAR image, the frame surrounding the target now turned white indicating that the object had been rated using a FLIR image. A new FLIR window was displayed when the SME selected another designated object on the SAR. The SME could not return to previously displayed FLIR windows. Time for the SAR&FLIR Phase was unlimited. The trial ended when the SME decided that the process was completed, usually after going through all objects that had been designated on the SAR image.

All events of each trial were recorded in a log file.

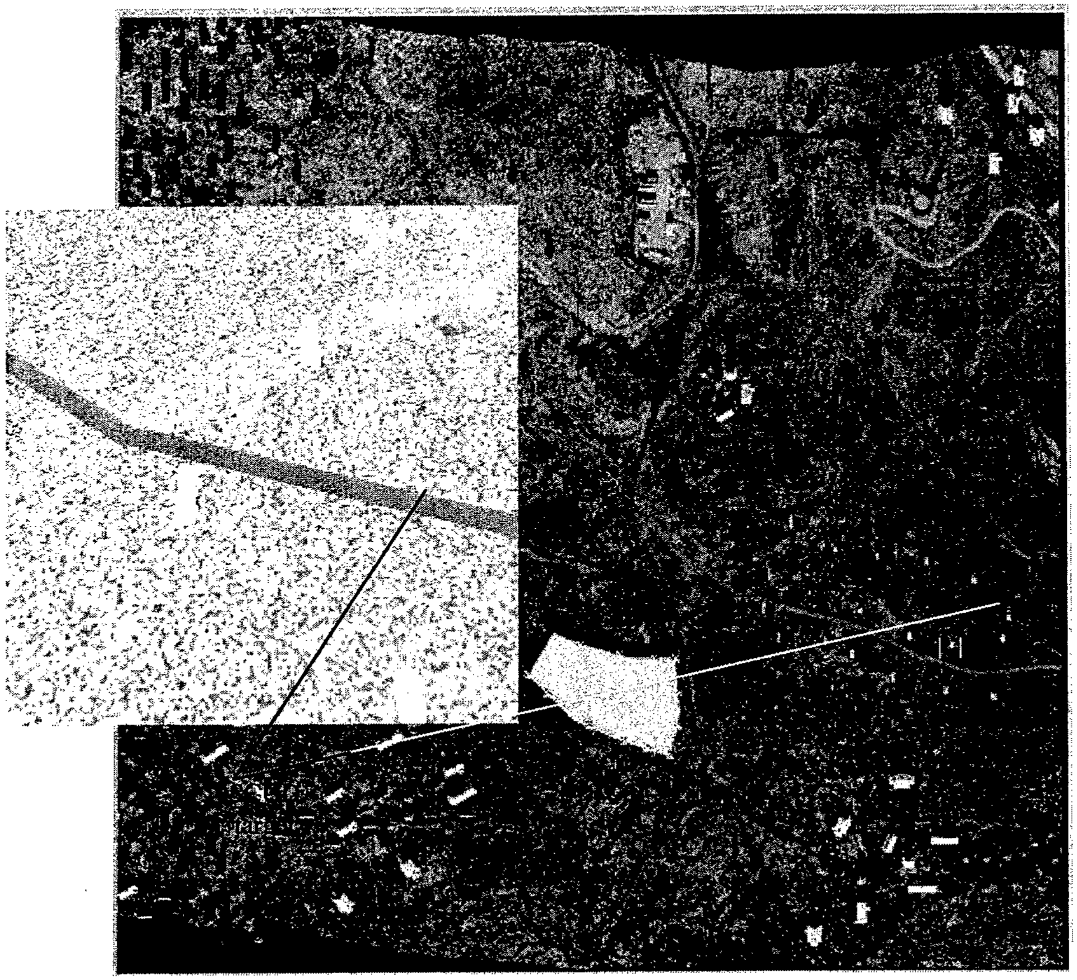

Figure 5 – FLIR imagery displayed above the SAR imagery (the selected object is a SCUD target)

Dependent variables

During the experiment, the following dependant variables were recorded:

1. Hits: the number of correct designations (designation of targets).
2. False alarms (FAs): the number of false designations (designation of decoys and terrain-objects).
3. Level of confidence: The level of confidence as expressed by the SME during each Phase.

Throughout the experiment, accuracy was emphasized over speed.

Section III

Results and Discussion

General

The major hypothesis was that the overall levels of information extraction/target designation performance would be better in the SAR&FLIR Phase than they were in the SAR-only Phase. Based on the dependent measures, the following combined scores were calculated.

Hits and False Alarms

- Hit and FA Scores: Four basic scores were calculated by summing up the Hits and the False Alarms (FA) of every trial of each SME for each Phase (i.e., SAR-only and SAR&FLIR Phases).

- Mean Hit and FA Rates: The Hit and FA Scores were transformed into rates by dividing the actual scores by the maximum scores, where maximum Hits is the total number of targets, and maximum FA is the total number of decoy objects (not including terrain-objects). The rates were then averaged across SME and across trials, for each Phase (i.e., SAR-only and SAR&FLIR Phases).

- Difference Scores: *Difference Scores* were calculated for each SME by subtracting the mean Hit and FA Rates in the SAR&FLIR Phase from the mean Hit and FA Rates (respectively) in the SAR-only Phase.

- Productivity Scores: *Productivity Scores* were calculated for each participant at each Phase by dividing mean Hit Rates by the mean FA Rates, for the SAR-only and SAR&FLIR Phases.

An additional calculation was preformed to compute a Designation Rate. It was the sum of Hits and FAs divided by the total number objects present in each trail. It was pooled over trials and SMEs.

Table 2 summarizes the resulting data:

Table 2 – Mean Hit and FA Rates, Productivity Scores and Difference Scores

	SAR-only Phase Mean (Standard Error)	SAR&FLIR Phase Mean (Standard Error)	Difference Mean (Standard Error)
Mean Hit Rate	80.08 (4.48)	65.46 (7.30)	14.63 (3.90)
Mean False Alarm Rate	70.66 (5.68)	37.72 (4.61)	32.94 (4.60)
Productivity Score (Hit Rate/FA Rate)	1.20 (0.05)	2.31 (0.18)	

Both the mean Hit and FA Rates were higher during the SAR-only Phase (M_{Hit}=80.08, Se_{Hit}=4.48; M_{FA}=70.66, Se_{FA}=5.68) than during the SAR&FLIR Phase (M_{Hit}=65.46, Se_{Hit}=7.30; M_{FA}=37.72, Se_{FA}=4.61) (Figure 6). An analysis of variance, in which one factor was Phase (SAR-only or SAR&FLIR) and the other was Designation Status (Hit or FA), revealed a significant main effect for Phase ($F(1,28)=17.84$, $p<0.001$). Overall Designation Rates were higher in the SAR-only Phase (M=75.37, Se=3.70) than in the SAR&FLIR Phase (M=51.59, Se=5.50). A main effect was also found for Designation Status ($F(1,28)=10.89$, $p<0.005$). Averaging across the two Phases, Hit Rates (M=72.77, Se=4.55) were higher than FA Rates (M=54.19, Se=5.53). The interaction between Phase and Designation Status was nearly significant ($F(1,28)=2.65$, $p=0.058$, one-tailed). When shifting from the SAR-only Phase to the SAR&FLIR Phase, the FA Rate decreased more rapidly than did the Hit Rate.

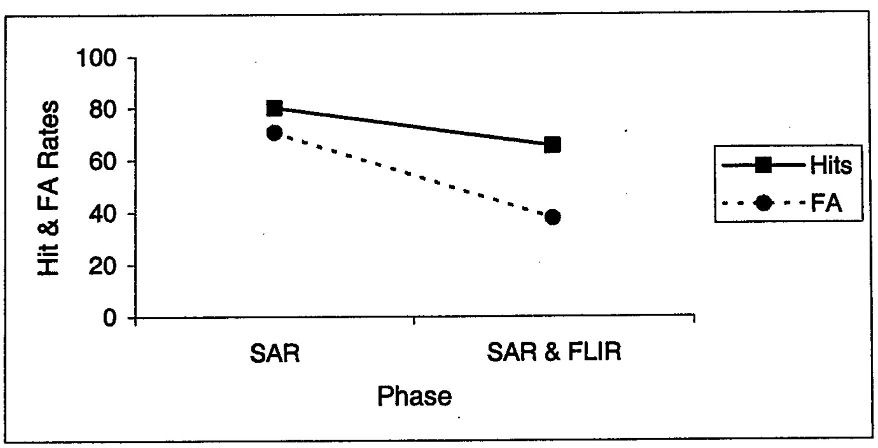

Figure 6 - Hit and False Alarm Rates, by Phase

The Difference Score for Hits (M=14.63, Se=3.90) was lower than the Difference Score for FA (M=32.94, Se=4.60) ($t(7)=4.52$, $p<0.005$) (Figure 7).

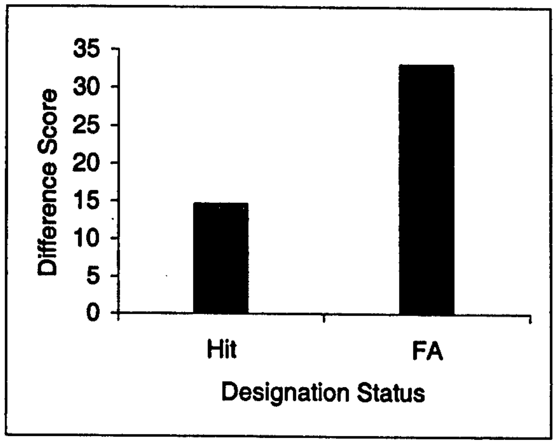

Figure 7 – Difference Scores for Hits and False Alarms

The Productivity Score was higher in the SAR&FLIR Phase (M=2.31, Se=0.18) than in the SAR-only Phase (M=1.20, Se=0.05) ($t(7)=5.62$, $p<0.001$) (Figure 8)

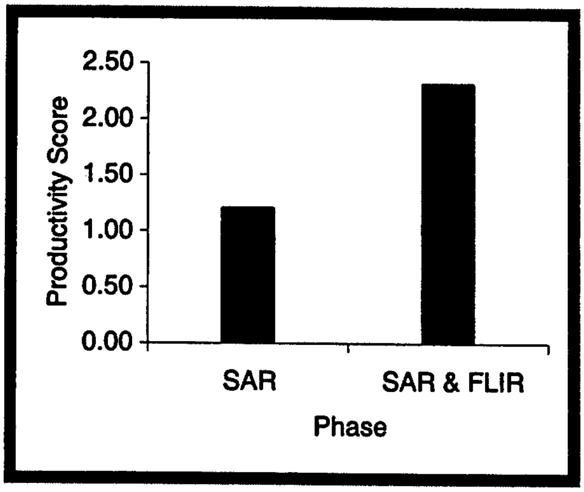

Figure 8 - Productivity Scores by Phase

During the SAR-only Phase, the SMEs produced high levels of both Hits and FAs. Approximately 80 percent of the targets and 70 percent of decoys were designated (**Table 2** and Figure 6). This was not surprising given that the SMEs understood that it was beneficial to their overall performance to make low-confidence selections during the first Phase (see Confidence Ratings below). They realized that during the second Phase (SAR&FLIR) they could eliminate FAs but had no way to compensate for misses (because only those objects that were designated during the SAR-only Phase could be examined during the SAR&FLIR Phase). In other words, during the SAR-only Phase the SME employed a "liberal" criterion and designated almost every suspected object. Nonetheless, approximately 20 percent of the targets were missed, this may be due to inability to detect the targets (even though SME had almost unlimited time to scan each scene) or due to incorrect object rejection decisions. The fact that FA Rate was only moderately smaller than the Hit Rate provides some indication to the difficulty of the task. Only around 30 percent of the decoys were rejected with full confidence during the SAR-only Phase.

During the SAR&FLIR Phase, both Hits and FAs decreased significantly. However, Hit Rates decreased by approximately 14.6 percent whereas the FA Rate decreased by approximately 33 percent (**Table 2** and Figure 7) producing significant Difference Scores. These changes indicate that the SAR&FLIR provided SME with higher *sensitivity* to differences between targets and decoys than the SAR-only. However, it also indicates a change in their *decision criterion*. During the SAR&FLIR Phase, the SMEs were more conservative than during the SAR-only Phase and while decreasing their FA Rate they also had to sacrifice some Hits. The overall task remained difficult and in order to produce approximately 65 percent Hits, the SMEs also produced approximately 37 percent FAs.

The Productivity Score (Figure 8) provides an additional view of the data, showing that overall productivity was significantly higher during the SAR&FLIR Phase than during the SAR-only Phase.

Confidence Ratings

Four basic Confidence Scores were calculated for each SME by averaging the Confidence Ratings for Hits and FA in each trial within Phase (SAR-only and SAR&FLIR).

Two Difference Scores were calculated for each participant by subtracting the mean Hit and mean FA Confidence Scores in the SAR-Only Phase from the Hit and FA Confidence Scores in the SAR&FLIR Phase (Table 3).

Table 3 - Mean Confidence Ratings

	SAR-only Phase Mean (Standard Error)	SAR&FLIR Phase Mean (Standard Error)	Difference Mean (Standard Error)
Hits	3.11 (0.55)	5.57 (0.31)	2.46 (0.31)
False Alarms	2.94 (0.50)	4.95 (0.32)	2.01 (0.30)

Both mean Hit and mean FA Confidence Scores were higher in the SAR&FLIR Phase (M_{Hit}=5.57, Se_{Hit}=0.31; M_{FA}=4.95, Se_{FA}=0.32) than in the SAR-only Phase (M_{Hit}=3.11, Se_{Hit}=0.55; M_{FA}=2.94, Se_{FA}=0.50) for both Hits and FAs. (Figure 9). In an analysis of variance, in which one factor was Phase and the other was Designation Status, a main effect was found for Phase ($F(1,28)=26.80$, $p<0.001$). Overall Confidence Scores were higher in the SAR&FLIR Phase (M=5.26, Se=0.27) than in the SAR-only Phase (M=3.03, Se=0.36). No other effects were significant in this analysis.

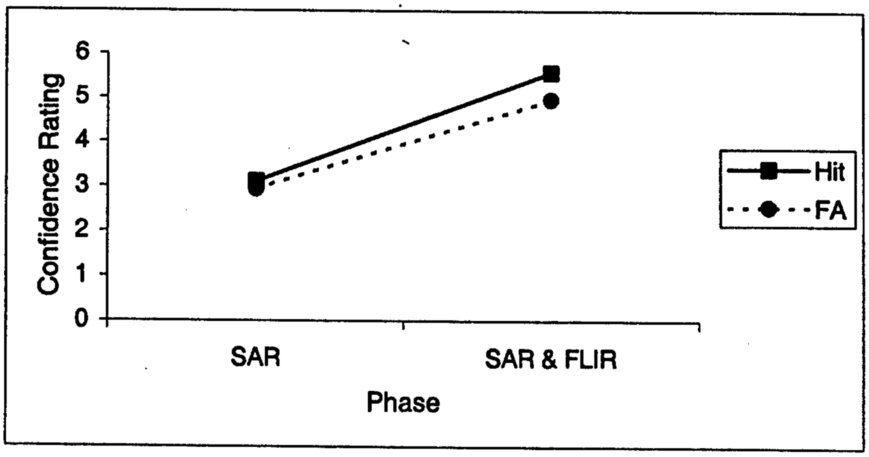

Figure 9 - Confidence Ratings for Hits and FA by Phase

The Difference Score for Confidence in Hits (M=2.46, Se=0.31) was higher than the Difference Score for FAs (M=2.01, Se=0.30) ($t(7)=2.01$, $p<0.05$, one-tailed) (Figure 10).

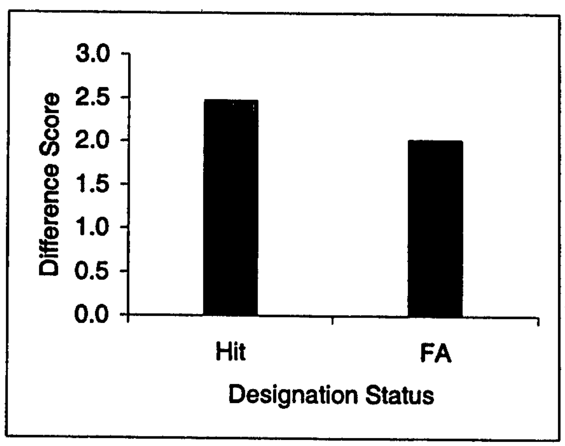

Figure 10 - Confidence Ratings Difference Scores for Hits and FA (pooled across Phase and SME)

The Confidence Ratings during the SAR&FLIR Phase were significantly higher than during the SAR-only Phase. This was anticipated because during the SAR-only phase, the SMEs were expected to designate objects even if their confidence level was very low, whereas during the SAR&FLIR Phase they were expected to make a final decision, based on reasonably high confidence levels. As expected, the Confidence Ratings for Hits were significantly higher than for FAs. Similarly and as had been found for the Difference Scores, the Confidence Ratings for targets during the SAR&FLIR Phase increased more than the Confidence Ratings produced for designated decoys. However, the differences between them were rather small during both Phases (Table 3 and Figure 10). This may be an additional indication to the difficulties that SME encountered in distinguishing between targets and decoys. It is also possible that the SMEs decided that if they repeated the same decision (in both the SAR-only and in the SAR&FLIR phases), it must reflect a higher level of confidence, even if there was no real ground for such confidence.

False Alarms for various decoys

During each trial, one target was identified as the designated target for that trial and the other objects were the various decoys of that target. Each target had four types of decoys, three of which were derivatives of the target. The fourth decoy (the "Target-decoy") was its counterpart among the other targets.

Corrected False Alarm Scores

To calculate the distribution of FAs per type of decoy, Corrected FA Scores were calculated. The rate of FA per type of decoy was corrected by the frequency of occurrence of that decoy. The calculation was performed as follows:

The number of FAs, per type of decoy, per trial of each SME, and for each Phase, was divided by the total number of objects of that type. For example, if SME #1 designated 2 SAR-decoys as targets and the total number of SAR-decoys in that trial was 3, then the score was 2/3=0.66. These scores were then averaged across trials and SME. Figure 11 and Table 4 present the distributions of mean Corrected FA Scores, by Phase.

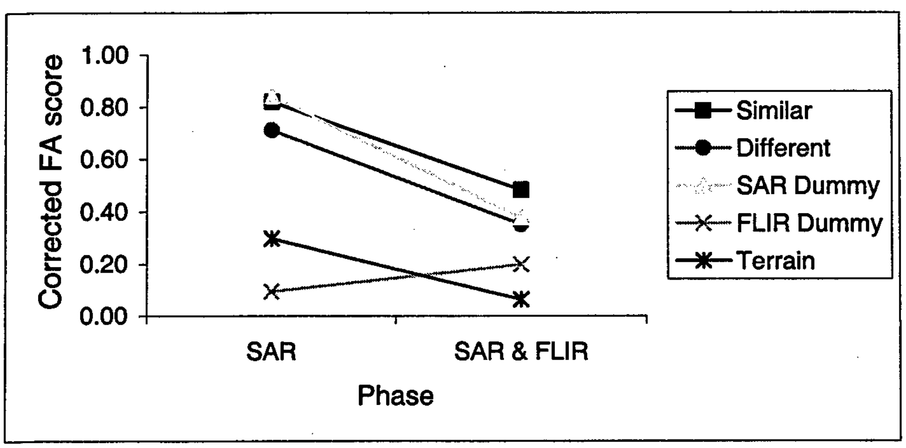

Figure 11 – Corrected False Alarm Scores per decoy type, by Phase

Table 4 - Corrected False Alarm Scores per decoy type, by Phase

	SAR-only Phase Mean (Standard Error)	SAR&FLIR Phase Mean (Standard Error)
Similar-decoy	0.82 (0.04)	0.48 (0.06)
Target-decoy	0.71 (0.07)	0.35 (0.07)
SAR-decoy	0.84 (0.04)	0.38 (0.07)
FLIR-decoy	0.09 (0.02)	0.20 (0.04)
Terrain-objects	0.30 (0.11)	0.06 (0.03)

In an analysis of variance, in which one factor was Phase and the other was Decoy Type (Similar / Target / SAR / FLIR / Terrain-object), a main effect was found for Phase ($F(1,70)=45.96$, $p<0.001$). Averaging across Decoy Types, Corrected FA Scores during the SAR-only Phase (M=0.55, Se=0.05) were higher than Corrected FA Scores during SAR&FLIR Phase (M=0.30, Se=0.04). A main effect was found for Decoy Type ($F(4,70)=32.21$, $p<0.001$). Averaging across the two Phases, Similar-decoy Corrected FA Scores (M=0.65, Se=0.05) were higher than Target-decoy Corrected FA Scores (M=0.53, Se=0.07) ($t(7)=3.12$, $p<0.05$). Similar, Target and SAR-decoy Corrected FA Scores (M=0.65, Se=0.05; M=0.53, Se=0.07; M=0.61, Se=0.04, respectively) were higher than FLIR and Terrain-object decoy Corrected FA Scores (M=0.15, Se=0.03; M=0.18, Se=0.06, respectively) (($t_{Similar,FLIR}(7)=13.9$, $p<0.001$); ($t_{Target,FLIR}(7)=8.18$, $p<0.001$); ($t_{SAR,FLIR}(7)=14.00$, $p<0.001$); ($t_{Similar,Terrain}(7)=6.77$, $p<0.001$); ($t_{Target,Terrain}(7)=4.67$, $p<0.005$); ($t_{SAR,Terrain}(7)=8.05$, $p<0.001$)).

An interaction was found between Phase and Decoy Type ($F(4,70)=6.54$, $p<0.001$). Similar, Target, SAR, and Terrain-object decoy Corrected FA Scores were lower in the SAR&FLIR Phase (M=0.48, Se=0.06; M=0.35, Se=0.07; M=0.38, Se=0.07; M=0.06, Se=0.03, respectively) than in the SAR-only Phase (M=0.82, Se=0.04; M=0.71, Se=0.07; M=0.84, Se=0.04; M=0.30, Se=0.11, respectively). In contrast, the FLIR-decoy Corrected FA Scores were higher in the SAR&FLIR Phase (M=0.20, Se=0.04) than in the SAR-only Phase (M=0.09, Se=0.02).

Overall, the different types of decoys behaved as expected. All decoys except the FLIR-decoy produced higher FA Rates during the SAR-only Phase then during the SAR&FLIR Phase. This is in line with the previously observed general shift in criterion between the two Phases. The FLIR-decoys produced fewer FA during the SAR-only Phase because they were barely visible in the SAR imagery. As a result, they were not designated during this Phase and could not be investigated during the SAR&FLIR Phase. Some FLIR-decoys were visible and could be designated on the FLIR when they were next to other

SAR objects that were designated by the SME. As a result, the FA Rate for these decoys increased during the SAR&FLIR Phase, but remained relatively low, even though they were designed to deceive the FLIR. FA Rates of SAR-decoys dropped to less than half during the SAR&FLIR Phase. Apparently, SAR-decoys succeeded in deceiving the SME in the SAR-only Phase but many of them were correctly rejected during the SAR&FLIR Phase. Nonetheless, the absolute level of FA Rates remained high during the SAR&FLIR Phase. This may be attributed to the inconsistent nature of FLIR images, i. e., SAR-decoys were always cold; Targets, however, could also be cold.

Similar-decoys' FA Rates decreased less between the Phases than did all other decoys (except FLIR-decoys). In addition, Similar-decoys created the highest rates of FA, indicating that, on the average, they were most similar to the targets in both sensor modalities (SAR and FLIR). Target-decoys may have been similar, in this respect. However, some of the target pairs were quite different from eachother and created low FA Rates, thereby reducing the mean FA Rates of Target-decoys (see Table 7 below).

In general, it is apparent that the SMEs benefited from all the differentiating aspects of SAR and FLIR imaging. The differences in signature (and RCS) enabled them to distinguish the SAR and FLIR decoys from the real targets. The distinction between targets, Similar-decoys and Target-decoys could not be based solely on the signature (because all these objects had similar signatures) and should be attributed to other features, e.g., the larger target display size and higher ground resolution of the FLIR.

Confidence Ratings

Confidence Ratings were calculated for each type of decoy object, per SME per Phase (Table 5 and Figure 12). In some cases, an SME did not designate any decoy of a specific group. As a result, there were no Confidence Ratings for that type of decoy (e.g., one SME did not designate any FLIR-decoys in the SAR-only Phase, three subjects did not designate Terrain-objects in the SAR&FLIR Phase). In these cases the mean Confidence Score for the specific decoy was assigned to the empty cell.

Table 5 - Confidence Rating Confidence Ratings per decoy type, by Phase

	SAR-only Phase Mean (Standard Error)	SAR&FLIR Phase Mean (Standard Error)
Confidence Ratings		
Similar-decoy Rates	2.97 (0.51)	5.28 (0.25)
Target-decoy Rates	2.99 (0.48)	4.35 (0.50)
SAR-decoy Rates	3.14 (0.51)	4.71 (0.34)
FLIR-decoy Rates	2.70 (0.45)	5.12 (0.42)

Terrain-objects Rates	1.92 (0.39)	2.00 (0.38)

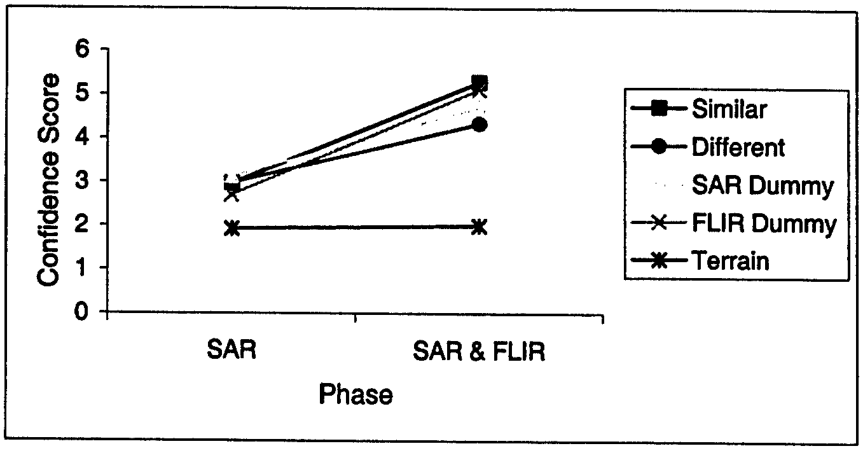

Figure 12 - Confidence Ratings per decoy type, by Phase

In an analysis of variance, in which one factor was Phase and the other Decoy Type, a main effect was found for Phase ($F(4,70)=32.17$, $p<0.001$). Averaged across Decoy type, the FA Confidence Score was higher in the SAR&FLIR Phase ($M=4.29$, $Se=0.30$) than in the SAR-only Phase ($M=2.74$, $Se=0.43$). There was also a main effect for Decoy Type ($F(4,70)=8.441$, $p<0.001$). Averaged across the two Phases, the Confidence Score for Similar-decoys ($M=4.13$, $Se=0.35$) was higher than the Confidence Score for Target-decoys ($M=3.67$, $Se=0.47$) ($t(7)=2.32$, $p<0.05$, one-tailed). The Confidence Score for Terrain-objects ($M=1.96$, $Se=0.37$) was lower than the Confidence Scores for all other decoys ($M_{Similar}=4.13$, $Se_{Similar}=0.35$ ($t(7)=10.23$, $p<0.001$); $M_{Different}=3.67$, $Se_{Different}=0.47$ ($t(7)=6.28$, $p<0.001$); $M_{SD}=3.92$, $Se_{SD}=0.41$ ($t(7)=9.60$, $p<0.001$); $M_{FD}=3.91$, $Se_{FD}=0.35$ ($t(7)=9.55$, $p<0.001$)).

Confidence Ratings for all types of decoys (except terrain-objects) were significantly higher after the SAR&FLIR Phase than after the SAR-only Phase. Apparently the SMEs decided that if they selected an object for the second time (first on SAR and then on FLIR), it should have a higher probability of being a target. The Confidence Ratings seem to have some correlation with FA Rates, i. e., decoys that produced high FA Rates tended to have high Confidence Ratings. In particular, the Similar-decoy that was the most difficult decoy, was also associated with the highest Confidence Scores. Apparently, these decoys were so similar to the targets that the SMEs felt very confident that they had selected a real target and not a decoy.

Overall, the Phase effect seems much larger than the decoy effect. The differences between the Confidence Ratings of the various decoys were fairly small, except for terrain-objects which received much lower ratings.

Individual Targets

Because of the relatively low incidence of each target, the data in this independent variable are descriptive and were not analyzed statistically.

Hit and FA Rates for different targets

Table 6, Figure 13 and Figure 14 present Hit and FA Rates of each target during the SAR-only and the SAR&FLIR Phases. Corrected FA Scores by decoy and Phase were calculated separately for each target, as described above and in Table 4. These results are presented in Table 7.

The Productivity Scores of each of the targets were higher during the SAR&FLIR Phase (M=2.31, Se=0.18) than during the SAR-only Phase (M=1.20, Se=0.05) (Table 2). In the SAR-only Phase, the Productivity Scores were fairly similar across all targets (between 1.01 and 1.44). In the SAR&FLIR Phase, however, the difference between scores is much larger (between 1.23 and 6.78). This is an additional exemplification of the crude performance-strategy of the first Phase opposite the more specific and target-dependent performance strategy apparently employed by the SMEs during the second Phase of the experiment.

The SCUD was much easier to recognize than all other targets. It had a 100% Hit Rate during both Phases. Its final FA Rate was the lowest and its Productivity Scores were much higher than those of all other targets. The SCUD was easy to distinguish from other targets (and specifically from its SA-6 Target-decoy) because it was significantly bigger than all other targets, whereas the other targets had generally comparable sizes.

The SA-6 target produced the second highest Hit Rates and the second highest final Productivity Score. The reason for that is that the SA-6 and the SCUD served as each other's Target-decoy and, as such, produced negligible FA Rates (Table 7), thereby reducing overall FA Rates and increasing the Productivity Scores.

Table 6 – Hits Rates, FA Rates and Productivity Scores per target, by Phase

	SAR-only			**SAR&FLIR**		
	Hit Rates	FA Rates	Productivity	Hit Rates	FA Rates	Productivity
Target						
M-1	66.7	65.2	1.01	61.5	45.3	1.75
T-72	80.0	75.0	1.15	65.0	59.2	1.30
MLRS	67.7	54.1	1.28	58.3	43.4	1.36
Radar	77.1	76.6	1.09	47.2	37.4	1.23
SA-6	87.5	80.6	1.12	75.0	25.0	3.56
Scud	100.0	73.3	1.44	100.0	18.3	6.78

Table 7 - Corrected FA Scores per target, by decoys and by Phase

	SAR-only					SAR&FLIR				
Decoy	Similar	Target	SAR	FLIR	Terrain	Similar	Target	SAR	FLIR	Terrain
Target										
M-1	0.91	0.58	0.78	0.02	0.26	0.63	0.38	0.44	0.31	0.04
T-72	0.81	0.88	0.97	0.16	0.28	0.69	0.79	0.41	0.50	0.04
MLRS	0.66	0.56	0.95	0.02	0.18	0.39	0.41	0.54	0.07	0.02
Radar	0.80	0.86	0.70	0.23	0.37	0.53	0.38	0.20	0.21	0.11
SA-6	1.00	0.50	0.94	0.00	0.44	0.21	0.00	0.50	0.06	0.16
Scud	0.88	0.88	0.97	0.03	0.28	0.31	0.04	0.31	0.03	0.00

The MLRS had the lowest final Productivity Scores. It can be seen that its Hit Rates as well as FA Rates decreased very little between Phases. The reasons for that are not quite clear.

The M-1 had a high final Productivity Score but the T-72 had a low score. These two tanks served as each other's Target-decoy. An interesting asymmetry can be observed in Table 7. In the SAR&FLIR Phase, the T-72 had a very high rate of Target-decoy FA, i. e., the M-1 was easily mistaken for a T-72. However, the Target-decoy FA Rate of the M-1 were less than half as large, i. e., the T-72 was not mistaken for a M-1. At present we have no explanation for this phenomenon.

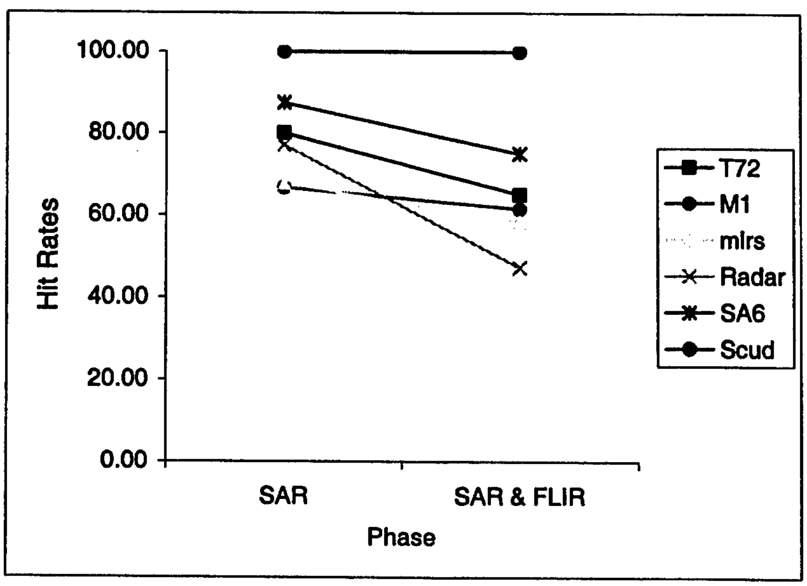

Figure 13 – Hit Rates per decoy type, by Phase

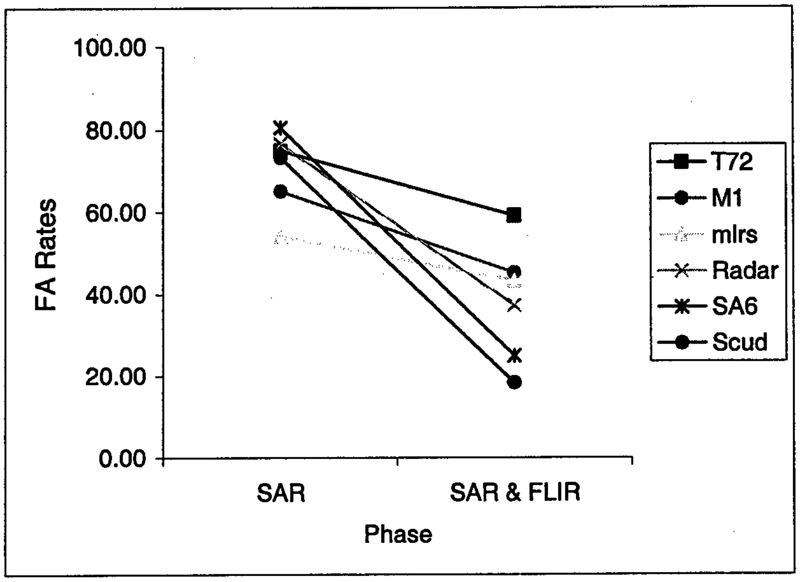

Figure 14 – False Alarm Rates per Decoy Type, by Phase

Individual Difference Case Explorations

The SMEs who participated in the present study were assigned to it by their superior officers. They varied in experience, skill and, perhaps, personal interest and motivation to participate in the experiment. Even though all the4 SMEs had professional experience as imagery interpreters, the experimental setup was new and unfamiliar. Some SMEs had only limited SAR experience and most of them had little or no FLIR experience. In addition, the fidelity of the simulated SAR and FLIR images was limited and their nature was unfamiliar. The experimental procedure had only partial resemblance to the SME's familiar working routine: the background terrain area was completely unfamiliar and changed between trials; recognition was based solely on the appearance and signature of the objects and could not benefit from additional information such as deployments of objects, environmental effects (e.g., track scarring), etc. Although briefing and practice times were not limited, it is quite clear, however, that within the 45 to 75 minutes taken for preparation the SME could not reach a very high professional level.

It is therefore argued that the results of the present study represent a low end of operational fidelity and that the potential benefits of the dual-sensor procedure may be much larger than those indicated by the current results. To explore some aspects of this argument, the performance of individual SMEs was examined in greater detail. The rationale is that if any one SME did much better than average, then it is potentially possible (through specific selection criteria, additional training, etc.) for others to perform at least as well.

SME #6

SME #6 had no apparent outstanding characteristics. She had one year of operational experience in image interpretation, little SAR-interpretation experience, and no FLIR experience. Nonetheless, she performed considerably better than average, and succeeded in markedly reducing her FA Rate during the SAR&FLIR Phase without reducing the Hit Rate (Figure 15, Figure 16, Figure 17). This kind of performance indicates high sensitivity to the differences between targets and decoys during the SAR&FLIR Phase. Interestingly, the level-of-confidence of SME #6 increased for both Hits and FA to the same extent from the SAR-only to the SAR&FLIR Phase. Apparently, the SME exhausted her ability to distinguish decoys from targets, and on the average she made all her decisions at the same level of confidence (Figure 18, Figure 19).

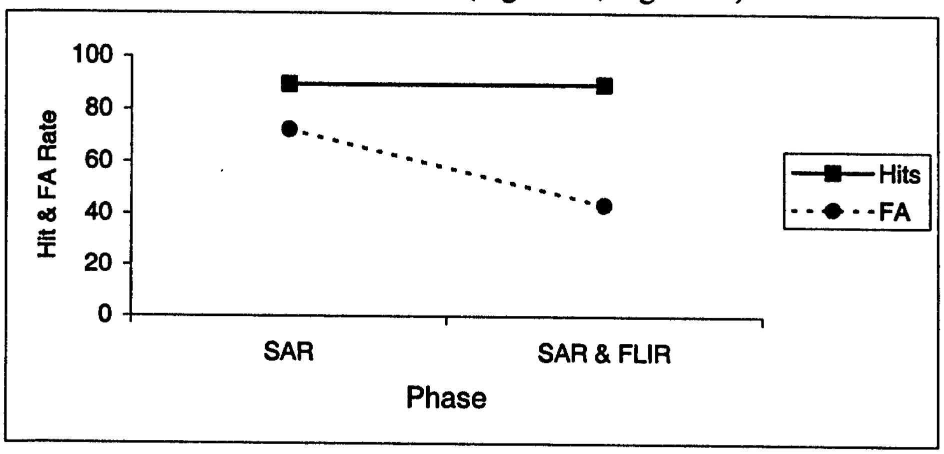

Figure 15 - SME #6: Hits and FA Rates by Phase

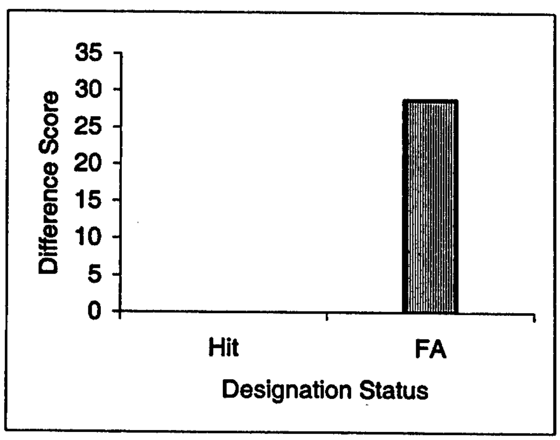

Figure 16 - SME #6: The Difference between SAR-only and SAR&FLIR designation rates for Hits and False Alarms

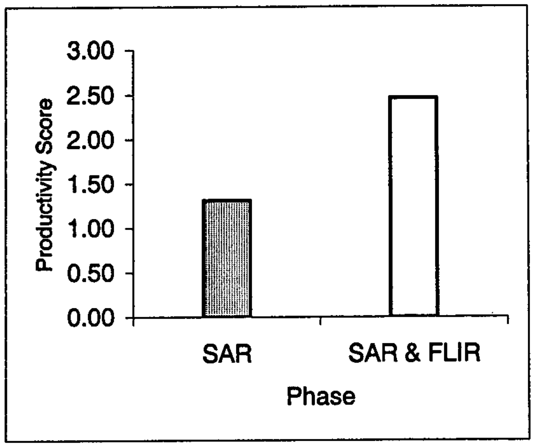

Figure 17 - SME #6: Productivity Score by Phase

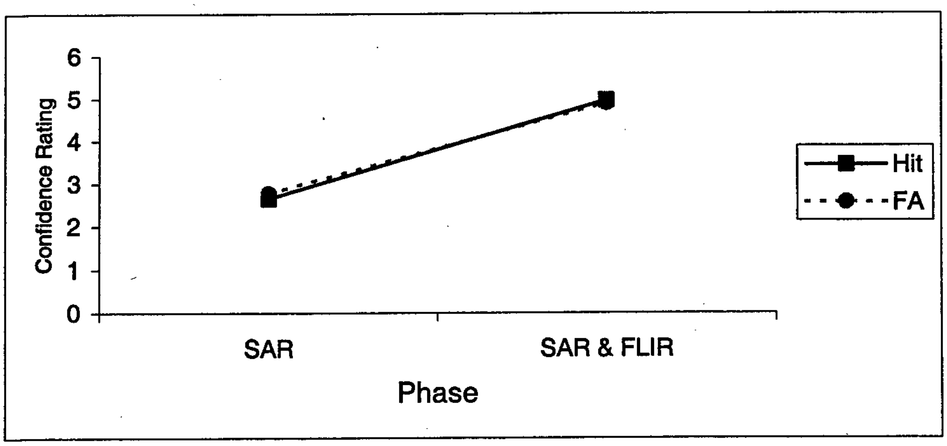

Figure 18 - SME #6: Confidence Ratings for Hits and FA, by Phase

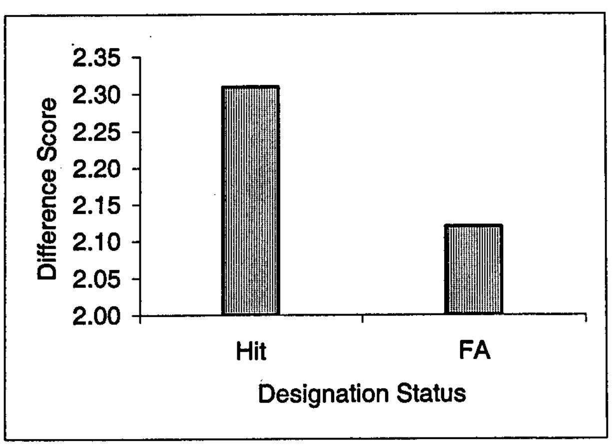

Figure 19 - SME #6: The Difference between SAR-only and SAR&FLIR Confidence Ratings for Hits and False Alarms

SME #8

SME #8 had three years of image interpretation experience, approximately two years of SAR interpretation experience, and some FLIR experience. Nevertheless, he performed rather poorly. During the SAR-only Phase his Hit and FA Rates were nearly identical. During the SAR&FLIR Phase, both Hits and FA reduced nearly to the same extent (Figure 20, Figure 21, Figure 22). This SME changed his criterion between the first and the second Phases. However, his sensitivity to the differences between targets and decoys was very low during both Phases. This did not prevent the considerable increase in Confidence Scores between the first and the second Phase (Figure 23, Figure 24). Clearly, this kind of performance has negative effects on overall average achievements.

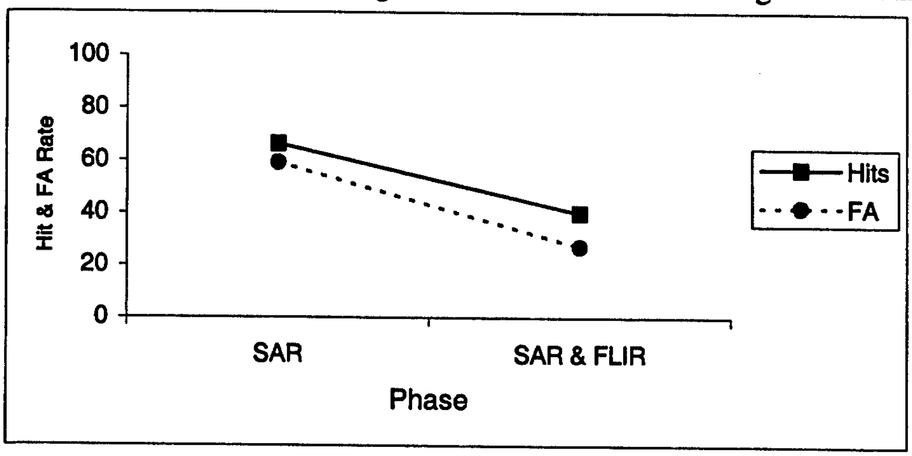

Figure 20 – SME #8: Hits and FA Rates by Phase

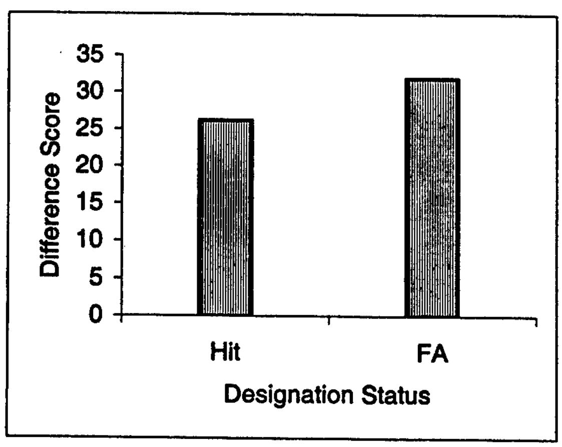

Figure 21 - SME #8: The Difference between SAR-only and SAR&FLIR designation rates for Hits and False Alarms

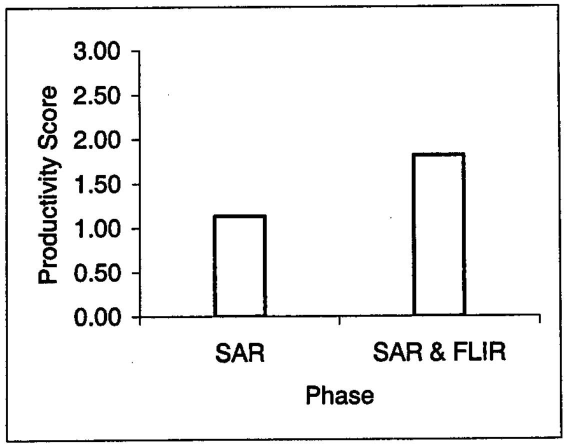

Figure 22 - SME #8: Productivity Score by Phase

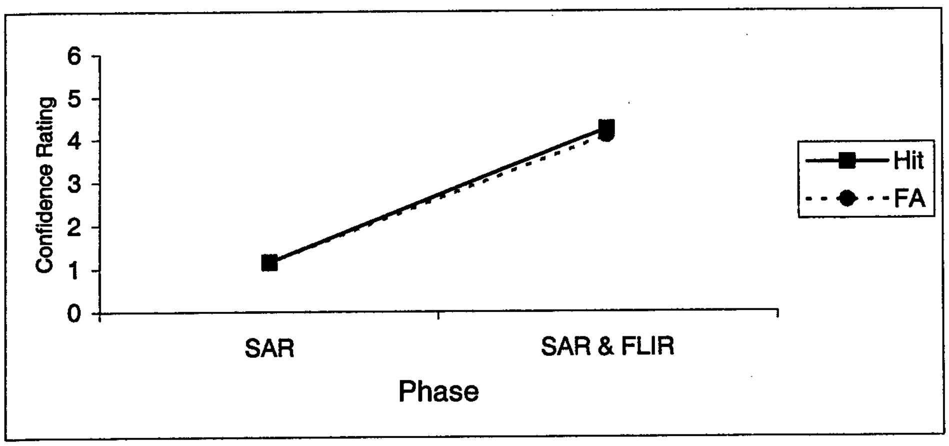

Figure 23 - SME #8: Confidence Ratings by Phases

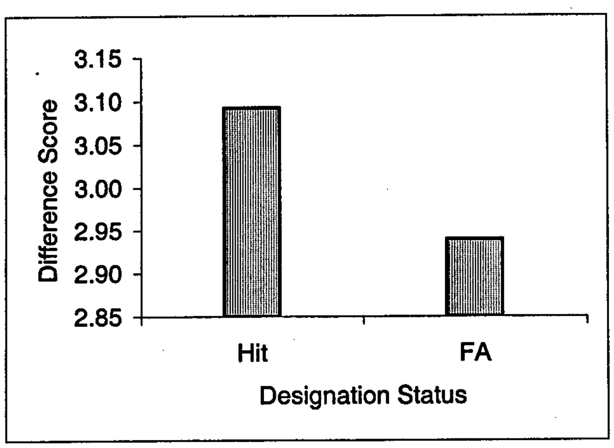

Figure 24 - SME #8: The Difference between SAR-only and SAR&FLIR Confidence Ratings for Hits and False Alarms

Criterion and Sensitivity

According to Signal Detection Theory, SDT (Tanner and Swets, 1954), differences in recognition performance can be related to criterion as well as to sensitivity changes. In the present research the data suggest that the change in performance between Phases results from both criterion and sensitivity shifts. The changes in criterion are towards more cautious and conservative decisions, which cause the average drop in both Hits and FA. Sensitivity in the SAR&FLIR Phase is higher then in the SAR-only Phase, enabling improved overall Difference Scores and Productivity Scores.

SDT was designed to analyze detection of signals with a known (or assumed) distribution against a background of noise with a known (or assumed) distribution. Similar methods have been developed to deal with non-parametric stimuli. (Schacter, Israel and Racine, 1999; Snodgrass and Corwin, 1988). The descriptive aspects of these tools can be employed to present an overall picture of criterion changes, sensitivity and individual differences. **Figure 25** presents mean Hit Rates as a function of mean FA Rates for each SME in each Phase. The straight lines delineate non-parametric equivalents of SDT Receiver Operating Characteristic curves, for the SAR-only Phase. The full square in the center represents the overall mean for that Phase. This point is connected to the (0,0) corner (bottom left - "designate nothing" point) and to the (1,1) corner (top right – "designate all"). Each of these two lines is extrapolated to its full length. These lines depict the assumption that the Hit / FA Rates that are delineated by them could be reached by adapting a more conservative criterion (lower left section) or a more liberal criterion (upper right section). However, performance above these areas (upper left) could only be reached through improved sensitivity.

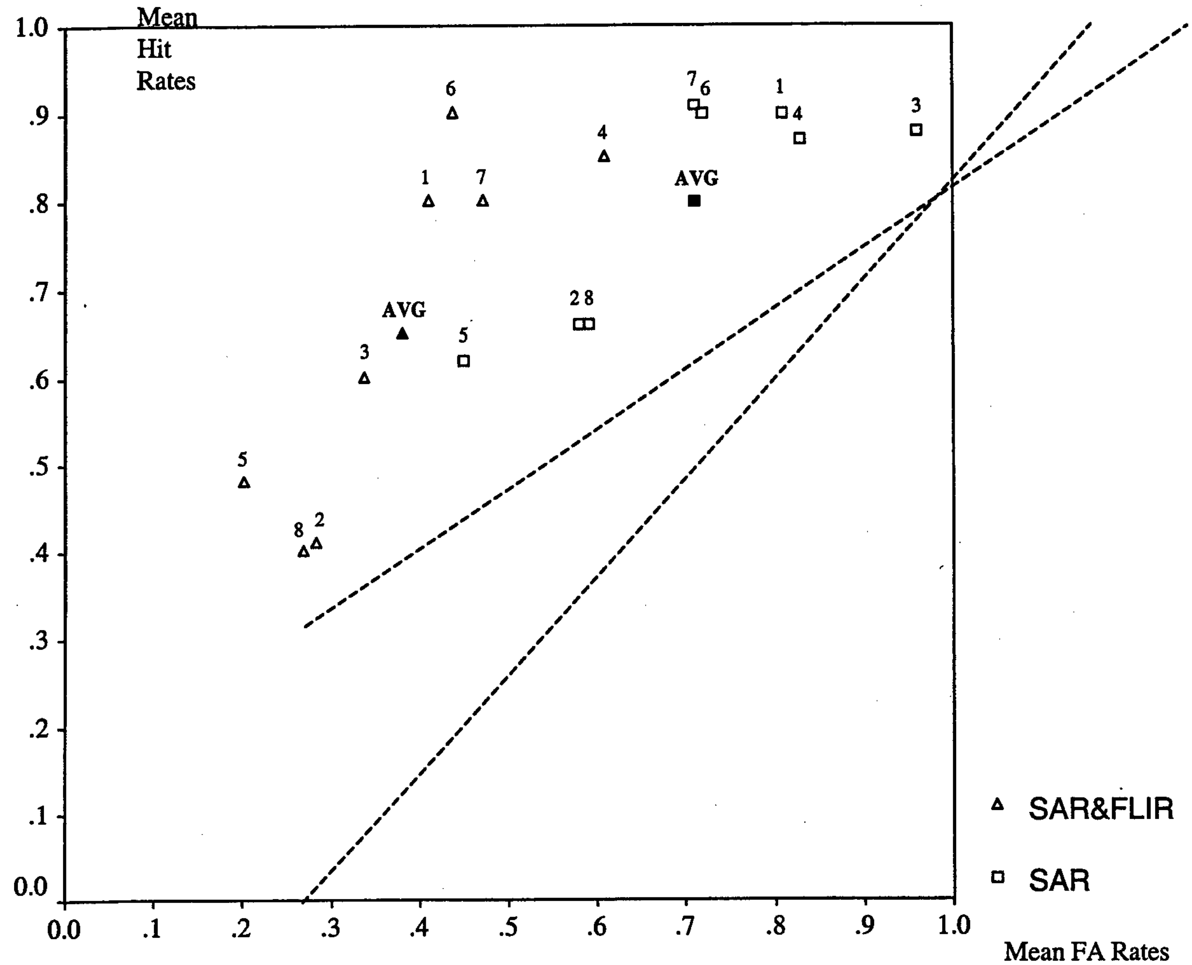

Figure 25 –Hit Rates as a function of FA Rates for each SME in each Phase

Figure 25 depicts the mean changes in criterion between the SAR-only and the SAR&FLIR Phases. It can be seen that the triangles, (representing the SAR&FLIR Phase) are, on the average, much further to the left and somewhat below the squares (representing the SAR-only Phase). This indicates a large decrease in FA along with a moderate decrease in Hits.

Figure 25 also reveals some interesting individual differences. Only SME #6 was capable of reducing FA without reducing Hits as well, indicating the improvement in her performance was due to improved sensitivity only. SME #4 showed a similar pattern of performance although he did not do as well as SME #6.

SME #2's and SME #8's mean performance was almost identical in both Phases. They adapted a fairly conservative criterion during the SAR-only Phase (producing relatively few hits and FAs) and became very conservative during the SAR&FLIR Phase. Their location inside the delineated area, in the SAR&FLIR Phase, indicates that they changed their criteria but hardly improved their sensitivity. In other words, they benefited very little from the FLIR imagery.

SME #5 shows a somewhat similar trend: he was the most conservative SME during the SAR-only Phase and remained the most conservative during the SAR&FLIR Phase. However, a substantial drop in FA, indicating some improvement of sensitivity, accompanied his relatively modest drop in Hits. In contrast, SME #3 adopted a very liberal criterion during the SAR-only Phase and was close to the maximal possible number of Hits and FAs. During the SAR&FLIR Phase, however, his strategy changed drastically, with a large decrease in Hits and a huge decrease in FA. Overall, he revealed a strong change of strategy with modest sensitivity improvement.

Section IV

Summary and Recommendations

The growing availability of sensor imagery in digital form allows the pictorial data to be stored, processed and transformed in various ways that were not possible in the past. One possibility is to synchronize and combine information from various sources, thereby gaining from the benefits of each of them, separately and in combination.

The present study explored some potential benefit of the combined usage of SAR and FLIR sensor imagery. SAR images provided wide area coverage in which the targets' RCS determined their displayed representation in relatively low-resolution. The simulated FLIR sensor provided an IR image of twofold magnification and twice the resolution of the SAR in a much smaller immediate field of view (1/16 that of the SAR image). The experimental task posed a difficult problem: to distinguish between highly similar objects, some of which were defined as targets, others were "real" objects that were defined as non-targets (e. g., friendly forces) and still others that were various types of decoys. In this challenging task, performance with the SAR&FLIR combination was better, over all, than performance with SAR-only. During the SAR-only Phase, the SMEs were expected to adapt a "liberal" performance strategy in which they designated all suspected objects, even at low confidence levels (i.e., low probability that the object was a target). This enabled them to later reexamine the object during the SAR&FLIR Phase. In the SAR&FLIR Phase, the SMEs changed their performance criterion, became more "conservative" and performed their selections on the basis of much higher confidence levels. As a result, both their Hit rates and FA rates were lower during this phase. However, their *sensitivity* to differences between targets and decoy also increased, resulting in a significantly smaller decrease in Hit rates than in FA rates. Overall, the productivity scores increased significantly between phases for all the targets.

The SMEs benefited from all sensor imaging aspects that differentiate between the SAR and the FLIR phenomenologies. Their ability to reject FLIR-decoys during the SAR-only Phase and to reject SAR-decoys during the SAR&FLIR Phase was based on the SAR RCS and FLIR signatures respectively. Their ability to distinguish between the targets, the Similar-decoys and the Target-decoys, however, could not be based on these signature differences because the latter were also target-object that had similar signature. Hence, they must have been based on other aspects such as the larger size of the target image on the display and the inherently higher resolution of the FLIR image (supporting an enhanced ability to exploit target-internal detail).

In general, confidence ratings (which were given after each target designation in both phases) were low during the SAR-only Phase and high during the SAR&FLIR Phase. This is another indication of the SMEs' liberal performance criterion during the SAR-only Phase as compared to the much more conservative criterion adopted during the SAR&FLIR Phase (in which the final target designation decisions were made). The confidence ratings for correct targets (Hits) were higher than for decoys (FA). The effect was not very large but produced significant difference scores. Interestingly (but not surprisingly), decoys that were very hard to distinguish from targets and produced high FA rates also produced high confidence ratings.

Large individual differences between SMEs were observed in terms of both the apparent decision criteria and overall performance levels. Some SMEs adapted a fairly conservative criterion during the SAR-only Phase. This limited their ability to improve performance during the SAR&FLIR Phase and resulted in poor final performance. Even though all SMEs were imagery ianalysts with various degrees of experience, they had only moderate SAR experience (and that with much lower resolution imagery) and practically no FLIR experience. In addition, the SMEs were assigned to participate in the experiment during a working day and some of them may not have been as highly motivated as desired.

The rigid procedure in the experiment, in which all objects were first scanned on SAR-only and then with FLIR, was designed for experimental purposes. This enabled us to measure the relative contributions of the SAR and of the FLIR. In operational practice, a more flexible procedure would allow the SME to move back and forth between multiple sensor images.

In summary, the present results reveal some of the benefits of multiple-sensor imagery interpretation. In view of the various research limitations, we believe that the results manifest only the most basic levels of potential benefits and that appropriate usage by trained experts may yield much higher performance improvements. Research in this area has just begun and should be continued and extended.

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Glossary

CAD	Computer aided design
EM	Electro-magnetic
EO	Electro-optical
FA	False alarm
FLIR	Forward looking infrared
FOV	Field of view
IR	Infrared
M	Meter
M	Mean
MLRS	Multiple launch rocket system
NATO	North Atlantic Treaty Organization
RCS	Radar cross section
SAR	Synthetic aperture radar
SDT	Signal detection theory
Se	Standard error of the mean
SME	Subject matter experts
UAV	Uninhabited air vehicle

Appendix 1: Target and Decoy Images

Displayed in the following pages are images of the targets and decoys that were used in the experiment. These images were shown to the SME in the training phase. Each image depicts the target in the top panel, the Similar-decoy in the middle panel, and the SAR and FLIR-decoys in the bottom panel. Objects are displayed from five different viewing angles (top, front, back, right, and left).

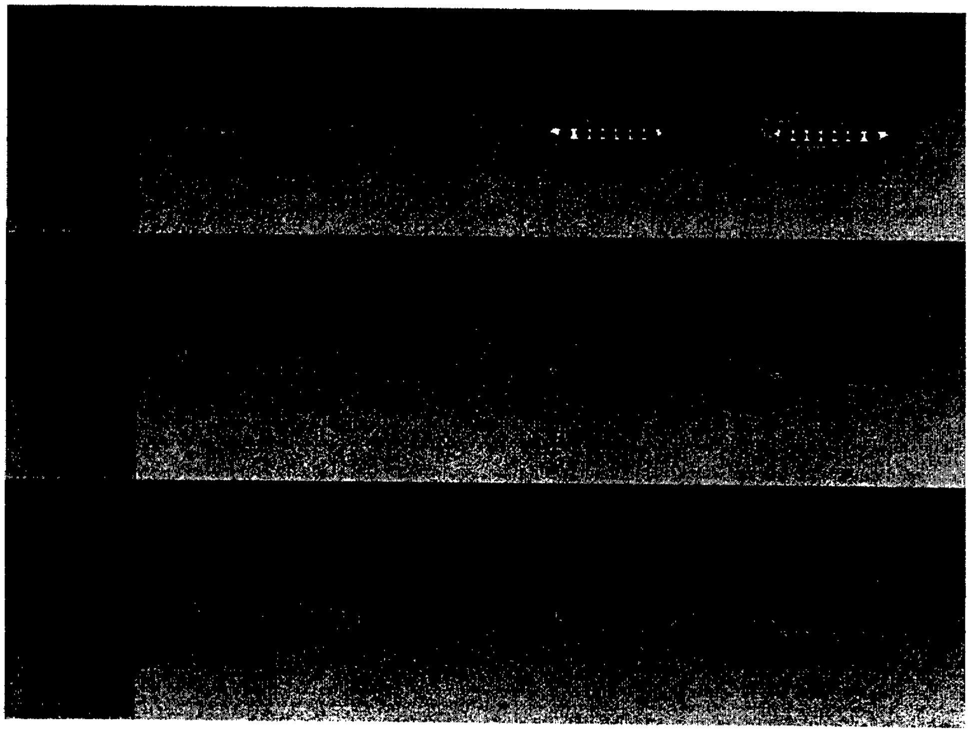

Figure 26 – M-1 tank

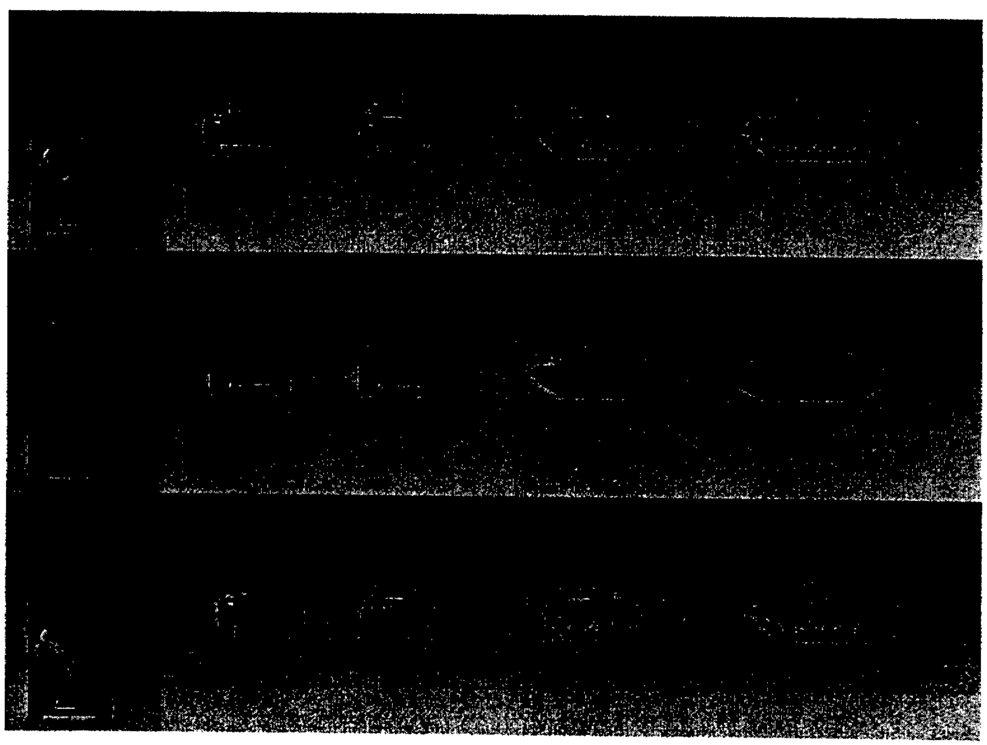

Figure 27 – T-72 tank

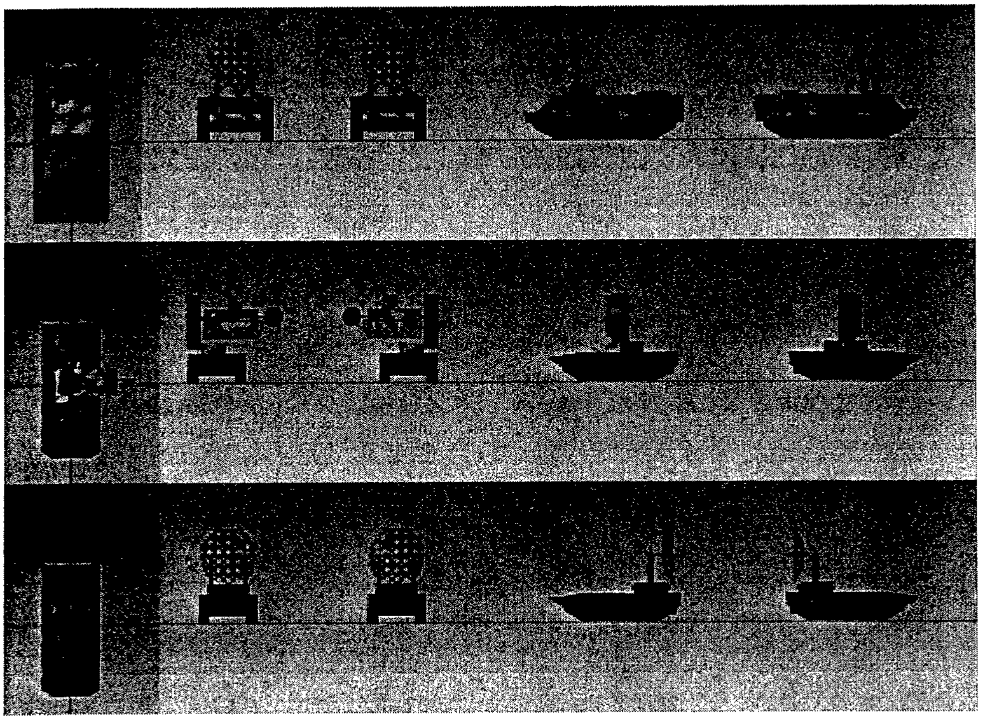

Figure 28 – Radar

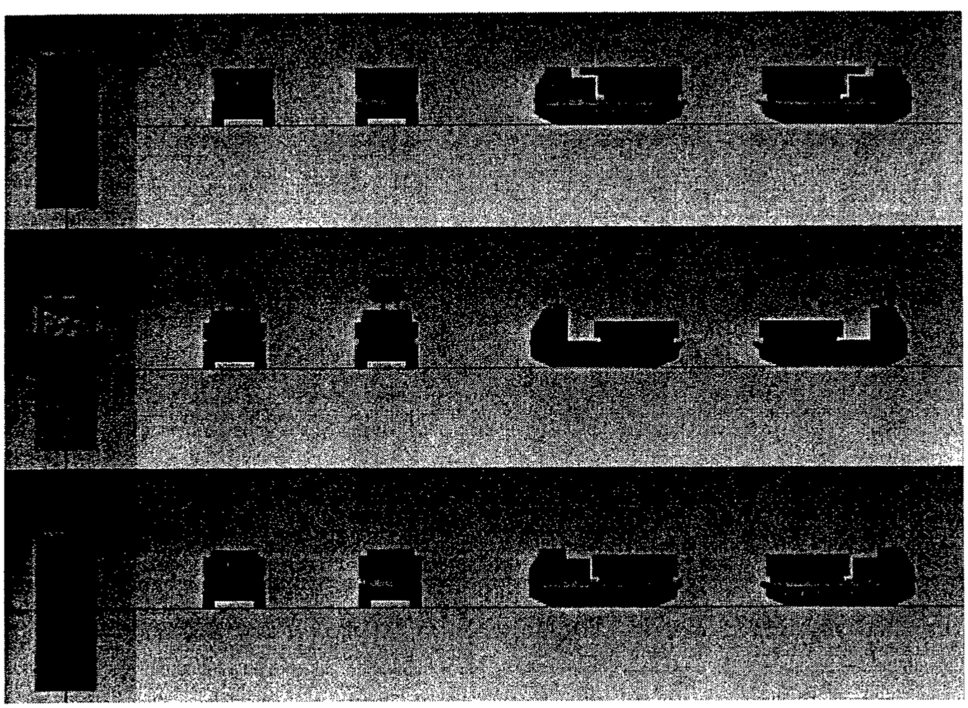

Figure 29 – MLRS

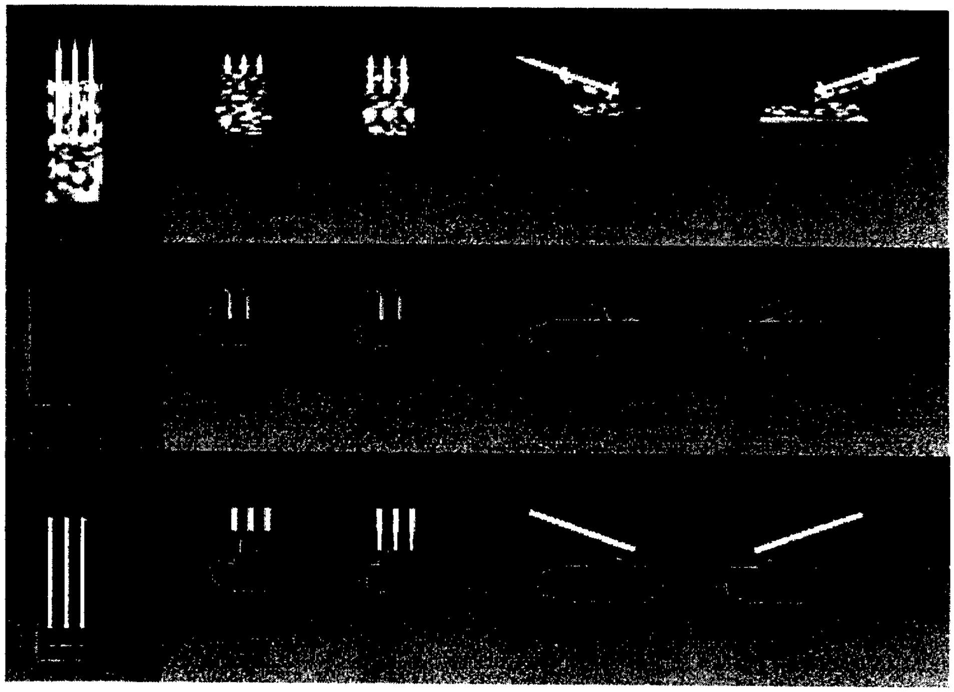

Figure 30 – SA-6 launcher

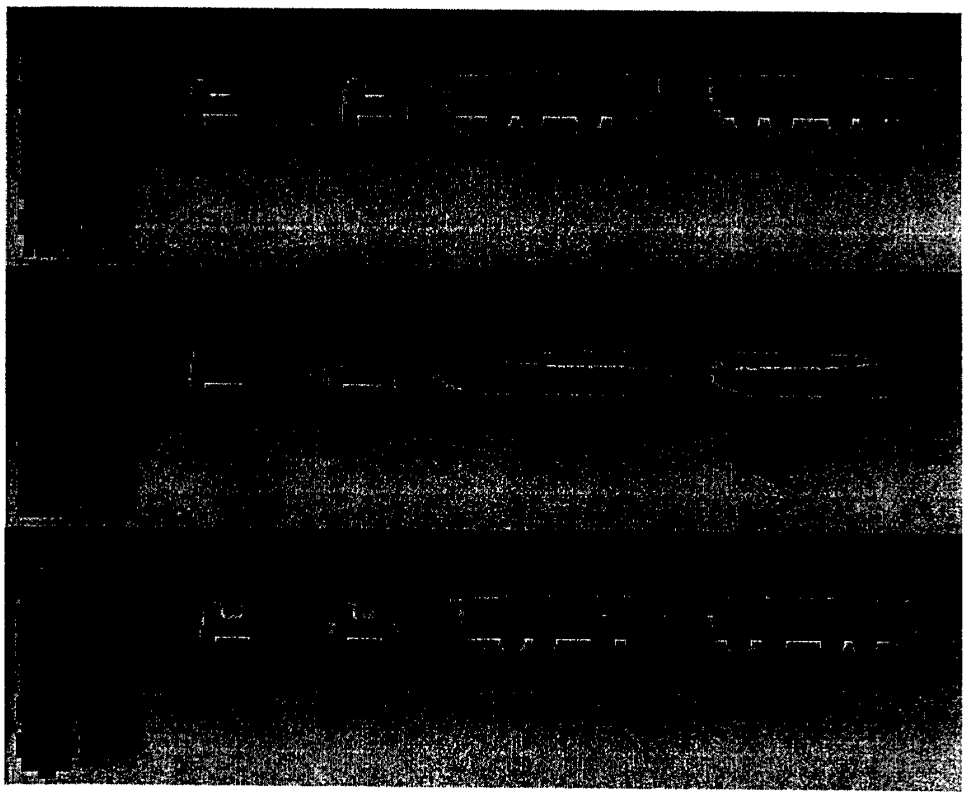

Figure 31 – SCUD launcher

Appendix 2: SME Instructions

In the present experiment you will be asked to identify targets in SAR and FLIR imagery. For each trial one of the following objects will be pre-briefed as a target:

- T-72 tank
- M-1 tank
- SCUD launcher (type a)
- SA-6 launcher (type a)
- MLRS (type a)
- Radar (type a)

The targets will be located in an area of 1000x1000 m. During each trial, several targets (1-6) of the pre-briefed type may be present. You will be asked to designate all of them. In addition, various other objects, including targets (other then the pre-briefed one) and various types of decoys, may be present.

During the first phase of each trial, the whole area will be presented in a SAR image. After the completion of designation of all targets (or after a specified period of time), you will be able to view a FLIR image of the designated targets and their area. Each FLIR image covers an area of approximately 250x250 m. Following each target designation (on SAR or FLIR) you will be asked to indicate your level of confidence on a scale of 7 grades:

1 – Detection: The object may be some type of target.
2 – Recognition: The object is possibly a target of the specified category (e.g., a tank)
3 – Recognition: The object is probably a target of the specified category
4 – Recognition: The object is definitely a target of the specified category
5 – Identification: The object is possibly the designated target (e.g., T-72 tank)
6 - Identification: The object is probably the designated target
7 - Identification: The object is definitely the designated target

0 – Not a target: In addition, on FLIR, you may cancel your previous decision (on SAR) and determine that an object was not a target.

During the first phase of the experiment (SAR) you should designate targets even if your confidence level is low, in order to reexamine them in the FLIR image. **Your final goal is to end each trial with as many correctly designated targets as possible and as few false alarms as possible.**

Putting the cursor on the target and pressing the left mouse key designates the target. A red box will appear around the designated target. After designation you will be asked to indicate your level of confidence by pressing one of the F1 – F7 keyboard keys. The red box will then change to blue. After the designation of all targets on SAR press F9 to view the FLIR (this will also happen automatically at the end of elapsed time). Now the SAR image will become inactive and you may not designate additional targets on SAR. Put the cursor on a designated SAR target and press the left mouse key to view the FLIR imagery of that target (Note that you may only select previously designated SAR targets). On the SAR image, the box surrounding the target will turn green. Now, designate the target on the FLIR image with the left mouse button and specify your level of confidence between 1 - 7 (F1-F7). Note that now you may also select F8 to change your previous decision and indicate that an object was not a target. To complete working on a FLIR image press F9. Note that you may not return twice to the FLIR image of the same SAR target (on the SAR image, the box surrounding a target that was already seen in FLIR will turn white). Also note that the designated SAR object may not be displayed in the exact center of the FLIR image.

You should try and work as fast as possible, but, more importantly, try to be as accurate as possible. Remember that the final goal is to correctly designate as many targets as possible while designating as few false alarms as possible.

Now you will perform a few learning and practice trials followed by 10 experimental trials.