2006

Cognitively-Engineered Multisensor Data Fusion Systems for Military Applications

Amanda Christine Muller
Wright State University

COGNITIVELY-ENGINEERED MULTISENSOR DATA FUSION SYSTEMS FOR MILITARY APPLICATIONS

A dissertation submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

By

AMANDA CHRISTINE MULLER
B.S., Worcester Polytechnic Institute, 2001
M.S., Worcester Polytechnic Institute, 2002

2006
Wright State University

WRIGHT STATE UNIVERSITY

SCHOOL OF GRADUATE STUDIES

April 20, 2006

I HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER MY SUPERVISION BY Amanda Christine Muller. ENTITLED Cognitively-Engineered Multisensor Data Fusion for Military Applications BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Doctor of Philosophy.

S. Narayanan, Ph.D., P.E.
Dissertation Director

Ramana Grandhi, Ph.D.
Director, Engineering Ph.D. Program

Joseph F. Thomas, Jr., Ph.D.
Dean, School of Graduate Studies

Committee on Final Examination

S. Narayanan, Ph.D., P.E.

Raymond Hill, Ph.D.

Joseph Litko, Ph.D.

Paul McManamon, Ph.D.

Julie Skipper, Ph.D.

ABSTRACT

Muller, Amanda Christine. Ph.D., Department of Biomedical, Industrial, and Human Factors Engineering, Wright State University, 2006. Cognitively-Engineered Multisensor Data Fusion Systems for Military Applications.

The fusion of imagery from multiple sensors is a field of research that has been gaining prominence in the scientific community in recent years. The technical aspects of combining multisensory information have been and are currently being studied extensively. However, the cognitive aspects of multisensor data fusion have not received so much attention. Prior research in the field of cognitive engineering has shown that the cognitive aspects of any human-machine system should be taken into consideration in order to achieve systems that are both safe and useful. The goal of this research was to model how humans interpret multisensory data, and to evaluate the value of a cognitively-engineered multisensory data fusion system as an effective, time-saving means of presenting information in high-stress situations. Specifically, this research used principles from cognitive engineering to design, implement, and evaluate a multisensor data fusion system for pilots in high-stress situations. Two preliminary studies were performed, and concurrent protocol analysis was conducted to determine how humans interpret and mentally fuse information from multiple sensors in both low- and high-stress environments. This information was used to develop a model for human processing of information from multiple data sources. This model was then implemented in the development of algorithms for fusing imagery from several disparate sensors (visible and infrared). The model and the system as a whole were empirically evaluated in an experiment with fighter pilots in a simulated combat environment. The results

show that the model is an accurate depiction of how humans interpret information from multiple disparate sensors, and that the algorithms show promise for assisting fighter pilots in quicker and more accurate target identification.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Funding for this research was provided, in part, by the Dayton Area Graduate Studies Institute (DAGSI) and the Air Force Research Laboratory, Sensors Directorate, Electro-Optics Research Branch (AFRL/SNJM).

I would like to sincerely thank my family, friends, and colleagues at Wright State University for their support throughout my doctoral education. In particular, I would like to acknowledge the following people, without whom this research would not have been possible:

Dr. Narayanan, my advisor, for having tremendous faith in me and encouraging me to stick with it when things got tough;

Drs. Hill, Skipper, Litko, and McManamon, for taking the time to serve on my committee and offering constructive criticism;

Matthew Dierking, Bob Feldmann, Larry Barnes, and **John Schmoll** of AFRL/SNJM, for their sponsorship of this research;

Timothy Meade of AFRL/SNJM, who truly went above and beyond the call to get me what I needed to move my research forward;

Lt. Col. Brian Ewert, and **Capt. Michael Nielsen** for taking time out of their extremely busy schedules to lend me their expertise as pilots;

Bob Esken of AFRL/HEPG for his tireless effort in helping me with the final phases of this project—his work made my results much more valuable than they otherwise would have been;

Richard (Andy) McKinley, Narashima (Seshu) Edala, and **Mike Young** for offering up their modeling expertise to assist in my analysis;

And last, but certainly not least, my husband, **Paul Muller**, for putting up with me throughout my academic career and constantly reassuring me whenever I doubted myself.

1. INTRODUCTION

Warfare is inherently dynamic and chaotic. In wartime situations, human operators are bombarded with substantial amounts of information and are expected to make near-instantaneous decisions. The modern military's information infosphere has the challenge of providing the right information at the right time to warfighters, allowing them to take immediate effective action (2000). However, the large amounts of available data create the potential for information overload, thereby increasing operator stress and the potential for catastrophic error—essentially the converse of the intended function.

Human error alone may not be the reason for such failures. Rather, the lack of adequate interfacing between human operators and automated information systems may be a source contributor (Martel, 1996). Research has indicated that each warfighter must have an effective interface client that focuses information on the immediate task (Eggleston et al., 2000). Furthermore, that information must be presented in such a way to assist the operator in making a decision, rather than making the decision for him (Kuperman, 1997).

In operations involving targeting and reconnaissance, multisensor data fusion[1] has become a prominent mechanism for combining imagery from disparate sensors, thereby decreasing the amount of information processed by the human operator. Fusing the images from the different sensors, while enhancing the supplemental information contained within

[1] While research in multisensor fusion includes numerous types of data, this research considered only imagery. Further references to multisensor data fusion in this document refer solely to image data, unless otherwise indicated.

the images, can serve to decrease the operator's workload and improve overall performance by making targets more visible (Fay et al., 2001).

However, the trend in multisensor data fusion research is toward *automated*, rather than *assisted* target recognition (Brown & Songer, 1989; Byrd et al., 1998; Daniel & Willsky, 1997; Fay et al., 2001; Huttenlocher & Ullman, 1990; Llinas, Acharya, & Ke, 1998; Mitchie, Laganiere, & Henderson, 1993; Peli, Young, Knox, Ellis, & Bennett, 1999; Tong, Rogers, Mills, & Kabrisky, 1987; Umeda, Ikushima, & Arai, 1996). Such methods focus solely on algorithms for fusing data and identifying targets. The human end-user is little more than an afterthought, expected to accept the machine output and act accordingly.

Studies in the fields of cognitive science and cognitive engineering, however, have shown that the human must be an integral part of the design process for any decision aid to ensure enhanced performance (Bisantz & Seong, 2001; Brodie & Hayes, 2002; Cohen, Thompson, & Freeman, 1997; Das, 2000; Guida & Lamperti, 2000; Hollnagel & Woods, 1999; Hutchins, 1996; Kustra, 2000; Martel, 1996; McNeese, Bautsch, & Narayanan, 1999; Muir, 1988; Parasuraman, Sheridan, & Wickens, 2002; Piccini, 2002; Reason, 1988; Roth, Bennett, & Woods, 1988; Ruff, Narayanan, & Draper, 2002; Scott, Lesh, & Klau, 2002; Sheridan, 2002; Woods, 1986). Failure to do so leads to distrust between the human and machine, lack of adequate human preparation in case of machine failure, and ultimate degradation of system performance as a whole.

This research investigated and applied methods for fusing data from visual and infrared sensors using principles from cognitive engineering. It was hypothesized that a system developed using this approach will improve operator performance in high-stress situations.

2. BACKGROUND

This research relates to the bodies of knowledge on multisensor data fusion, cognitive engineering, decision aiding, and user interface design. The following sections present an overview of research on these topics.

2.1. Multisensor Data Fusion

The basic concept of fusing information from multiple sources is not new. For millions of years, animals, including humans, have used multisensor data fusion to combine signals from the five senses with knowledge of their environment to create a dynamic model of their world and to help them interact with their surroundings (Grossman, 1998). This basic mechanism of combining data from different sensors has been extended to such areas as imagery, robotics, signal processing, and surveillance applications.

It has been shown that, in many cases, using multiple sensors improves robustness and reliability, extends coverage (both spatial and temporal), increases the dimensionality of the measurement space, reduces uncertainty, improves resolution, reduces ambiguity, and improves detection performance (Grossman, 1998; Li & Wang, 2002). However, this task which comes naturally to humans and animals in the physiological realm is considerably more complicated from an engineering and system design perspective. In fusing multisensor data, researchers must consider how the sensors and noise are modeled, how information from different sensors is related and how it can be integrated, how the features from different sensors can be verified against each other, and how to select an optimal strategy for a machine vision system to use such information (Aggarwal & Chu, 1993; Basir & Shen, 1996). Prior research has offered numerous methods of addressing these requirements, with differing levels of success. Often, the methods are application-specific, and depend heavily on the unique design requirements of the system. The body of literature on multisensor data fusion is vast. The following sub-sections provide a brief summary, review some of the basic concepts behind data fusion, and glimpse into the diverse array of fusion algorithms and techniques that have been developed over the years.

2.1.1. Sensor Fusion Taxonomies

Developing strategies for multisensor data fusion invariably involves determining the level at which fusion should take place. Several taxonomies for defining the levels of multisensor data fusion exist.

One of the most widely-accepted classifications categorizes the multisensor data fusion into data level, feature level, and decision level (Figure 1) (Li & Wang, 2002). In data level fusion, each individual sensor observes an object, and the raw sensor data are combined (Figure 1a). This method results in minimal information loss, and, since no processing occurs between data collection and fusion, conclusions can be drawn directly from the data (Zhou & Leung, 1998). However, data level fusion has numerous limitations. The large amounts of information involved require large communication bandwidths. Since raw, unfiltered data are used, corruption due to noise is often prohibitive; when Ladar is used, for example, data level fusion cannot be used due to speckle noise (Aggarwal & Chu, 1993). Pixel registration between sensor data must be achieved in order to combine the images, which is often difficult in real-world (non-laboratory) situations. If images are not registered perfectly, the quality of the fused image degrades (Smith & Heather, 2005). Data level fusion cannot be used at all if the sensors involved do not measure the same physical phenomena (Li & Wang, 2002).

Feature level fusion involves an image processing step before fusion takes place. Feature vectors are extracted from the raw data, and are then combined into a single feature vector (Figure 1b). Feature level fusion requires less communication bandwidth than does data level fusion, but some information is lost when the feature vector is created.

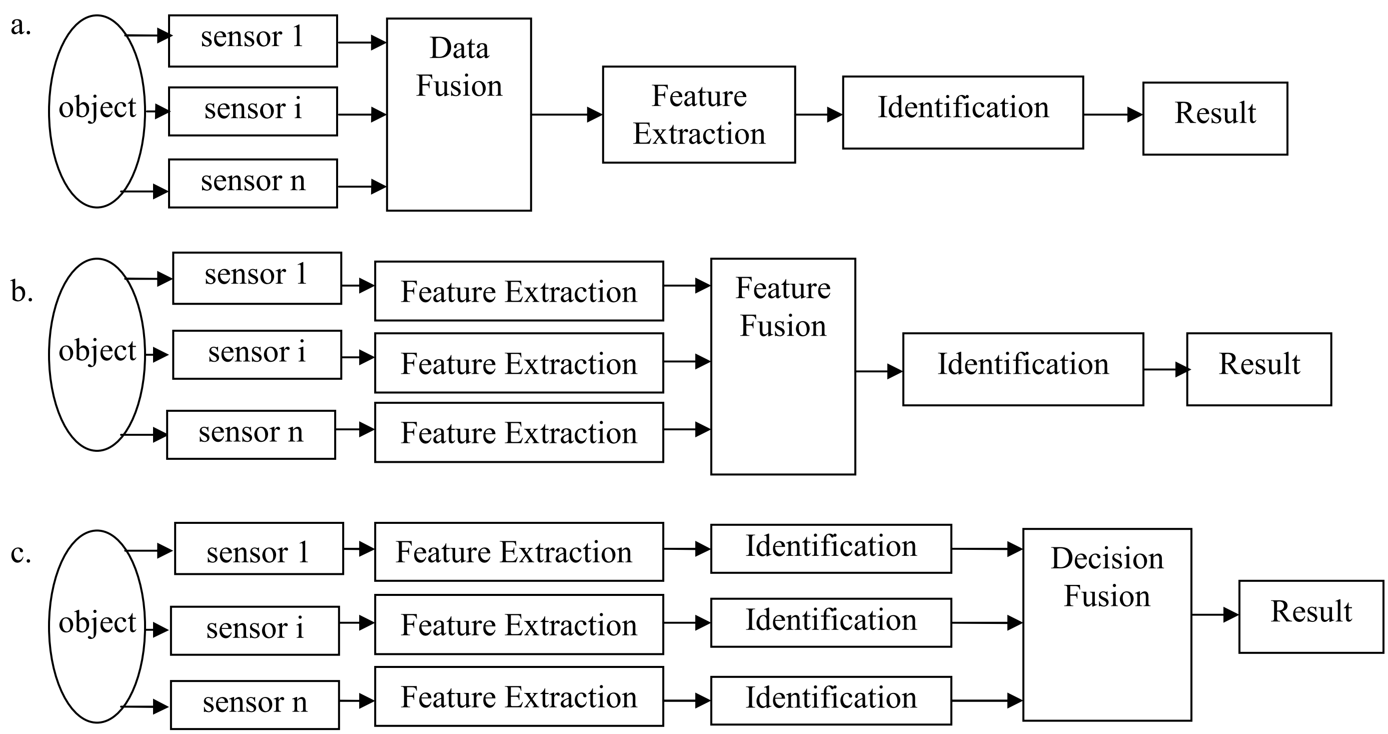


Figure 1: Li and Wang's (2002) diagram of the levels of multisensor data fusion. In data level fusion (a), the raw data from each sensor are directly fused, and interpretation of the fused image follows. Feature level fusion (b) requires extraction of feature vectors from the raw data. The features are then fused, followed by object identification. Decision level fusion (c) allows object identification by each sensor, and the final decisions are fused. Reproduced with permission from *Advances in Modelling and Analysis B: Signals, Information, Patterns, Data Acquisition, Transmission Processing, Classification,* Vol. 45, No. 2, (2002).

Decision level is the highest plane of multisensor data fusion. In this method, each sensor collects data, extracts features, and provides a decision based on those features

(Figure 1c). The final decisions are then fused, usually using a majority voting or weighted averaging approach. This method requires the least communication bandwidth, but also suffers the most data loss.

Dasarathy (2004) proposes a more specific taxonomy based on fusion inputs and outputs. His modes of sensor fusion are:

- data in-data out,
- data in-feature out,
- feature in-feature out,
- feature in-decision out, and
- decision in-decision out.

The methods behind the categories where the input and output are the same (data in-data out, feature in-feature out, and decision in-decision out) are identical to those outlined by Li and Wang (2002). The categories where the input and output differ are application-specific. For example, temperature (a feature) can be derived from two-band image pixels (data) in data in-feature out fusion. It can be argued, however, that the pixel values achieved in this type of fusion are still at the data level, and the information must be interpreted subsequently to obtain the temperature values. Therefore, these categories are essentially the same as Li and Wang's definitions, with a few application-specific distinctions.

The most popular taxonomy for fusion in military contexts is the Joint Directors of Laboratories (JDL) Data Fusion Model. The model consists of five levels—preprocessing, object refinement, situation assessment, threat assessment, and process assessment. Despite its wide use and its numerous appropriate applications, the JDL model is not appropriate for describing the concept of multisensor fusion (The Data Fusion Server, 2004). The model is intended to be functional rather than data-driven. It is also not generally applicable outside the military domain. Thus, in the interest of keeping this research generalizable, it will be referred to minimally.

2.1.2. Sensor Fusion Methods

Within these levels, numerous methods for fusing sensor information exist. The simplest method is weighted averaging, where data are combined mathematically. The challenge in this method lies in finding the appropriate weights for each sensor, feature, or decision to be combined. Weights may be based on confidence in the information, prior probabilities, or other application-specific criteria.

Bayesian statistics is one method used to determine weights for combining sensor data when the information to be fused is mutually independent. The Bayes formula in the context of sensor fusion is:

$$P(H_j \mid E_i) = \frac{\prod_i P(E_i \mid H_j) P(H_j)}{\sum_j \left\{ \left[\prod_i P(E_i \mid H_j) \right] P(H_j) \right\}}$$

where $P(H_j|E)$ is the *a posteriori* probability of hypothesis H_j being true given sensor evidence E_i, $P(H_j)$ is the *a priori* probability of hypothesis H_j being true, and $P(E_i|H_j)$ is the conditional probability of observing sensor evidence E_i given that hypothesis H_j is true (Grossman, 1998). If training data are available, a linear discriminant classifier may be obtained and applied using decision-level fusion.

A disadvantage of using Bayes' rule for sensor fusion is that the *a priori* probabilities must be known (Zhou & Leung, 1998). In some cases, these probabilities can be estimated using training data; however, in military situations, acquiring training data may be difficult or impossible. Maximum likelihood estimation may be used to obtain a priori probabilities in such cases, but the result is often computationally costly (Mitchie et al., 1993).

When sufficient training data are not available, the Dempster-Shafer theory of evidence may be used to obtain weights for combining sensor data (Llinas et al., 1998). Dempster-Shafer theory uses a number between zero and one, inclusive, to indicate the degree to which the available evidence supports a given hypothesis (Buchanan & Shortliffe, 1984). These belief functions sum to one for all hypotheses in the experiment, creating a complete domain.

Fuzzy logic methods can be used when mutual sensor dependence or unknown *a priori* probabilities make the use of Bayesian statistics impossible. The relationship between a physical quantity and the pixel values in an image can be represented by a membership function (Figure 2). Measurement functions can also be used to represent noise and other uncertainties (Nejatali & Ciric, 1998). A possibility function, computed as the maximum of the product of the class membership function and the uncertainty membership function for each class and imaging system, can then be processed for all coordinates corresponding to a given class to produce a reconstructed image.

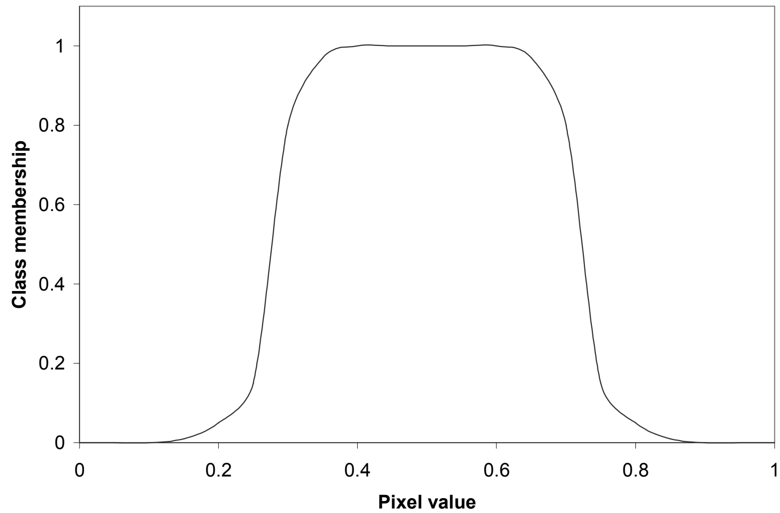


Figure 2: Example of a membership function. Modified from Nejatali & Ciric (1998).

The same principle can be applied at the feature level. Membership functions can be defined with decisions on the y-axis, and feature values on the x-axis. An advantage of using fuzzy logic is that no *a priori* probabilities are required; however, knowledge of these values can yield even better results (Nejatali & Ciric, 1998).

Neural networks can also be applied to multisensor data fusion problems. Neural networks consist of a large number of nodes, or neurons, with weighted interconnections. The weights are learned from inputs to the network (Mitchie et al., 1993). The networks can consist of multiple layers, called "perceptrons," which further their functionality. Such networks can be used to identify features in images and cluster them together, resulting in an effective means of feature-level fusion (Mitchie et al., 1993). However, while neural networks are good at solving one type of problem, they fail spectacularly outside their problem space, making them impractical for broad-reaching applications.

In 1996, Toet and Walraven developed what is now known as the TNO fusion scheme (Toet & Walraven, 1996). This data-level fusion methodology first involves registering images from two different sensors (thermal and visual, in the case cited in the article). The common components of the two images are determined. This common component is then subtracted from each image, leaving only the unique aspects of each image. The unique component of the thermal image is then subtracted from the original visual image, and vice versa. These final images are then displayed through red and green channels, resulting in a false color display. This fusion algorithm is subject to the pitfalls of pixel-level fusion, as discussed above. However, subsequent studies have shown that this method does perform well in conditions of low contrast (i.e., around sunrise), and in tests of overall scene recognition (Toet & Franken, 2003; Toet, IJspeert, Waxman, & Aguilar, 1997).

At about the same time, the MIT fusion scheme was developed (Waxman et al., 1997). This fusion methodology is similar to the TNO scheme in that false color is used to display fused imagery from visual and infrared sensors. However, it differs in that the mechanism for assigning color to the images is based on processes of the human visual system. Neurons in the optic tectum "display interaction in which one sensing modality (e.g., IR) can enhance or depress the response to the other sensing modality (e.g., visible) in a strongly linear fashion…Moreover, these visible/IR fusion cells are suggestive of ON and OFF channels feeding single-opponent color-contrast cells" (Waxman et al., 1997). Following pre-processing (including image registration and preliminary fusion carried out according to the aforementioned optical model), an enhanced visual image is assigned to the green color channel, a visual/negative-polarity IR fused image is assigned to the blue color channel, and a visual/positive-polarity IR fused image is assigned to the red color channel. Evaluation of this fusion methodology showed that it enhanced contrast inherent in visual imagery (Waxman et al., 1997). Tests with target detection tasks showed that the MIT fusion scheme yielded similar performance to the TNO scheme (Fay et al., 2000; Toet et al., 1997).

Gaussian and Laplacian pyramids have also been used extensively (Sims & Phillips, 1997; Smith & Heather, 2005). These methods entail convoloving an image with a Gaussian or Laplacian kernel, then subsampling the image at each convolution to produce a new, reduced-size image. The process is repeated until a pyramid of successively small images is produced. In Smith and Heather's (2005) method, the smaller images are then re-expanded through an inverse transform, and the differences between the expanded images are calculated. This calculation results in a new image containing only the salient features (edges and textures) of the original. These processed images from different sensors can then be combined (Sims & Phillips, 1997; Smith & Heather, 2005). In Sims and Phillips's method, the reduced images are fused using either weighted averaging or some method of feature selection, and the fused image is then re-expanded through an inverse transform. Similar operations have also been performed with wavelet transforms (Smith & Heather, 2005).

2.2. Cognitive Engineering and Decision Aiding

Naïve human-machine systems operate under that assumption that the whole is merely the sum of the parts; however, when humans are included in the arrangement, this is never the case (Hollnagel & Woods, 1999). The human element adds an inherent complexity that is often ignored or misunderstood in machine design.

The concept of replacing human actions with automation is certainly not new. Even before the industrial revolution, machines were built to assist humans in myriad activities.

However, the design of such early systems considered the human and the machine in isolation. When these systems were brought into practice to replace human functions, it was found that human error was not eradicated, as expected. Rather, the nature of the human error changed (Billings, 1997). The automation process invariably changes the behavior of the human operator, often placing new demands on him that were not present before the automation was introduced, thereby altering the structure of the system (Billings, 1997; Parasuraman et al., 2002). Human-machine systems must therefore be designed with consideration of both the human and the machine elements and their interaction with each other (Billings, 1997).

2.2.1. Levels of Automation

Automation may take place at varying levels of complexity. Parasuraman and Sheridan (2000) developed a model for the continuum of levels of automation for decision aiding and action selection (Table 1). Automated systems may operate at specific levels within this range, or may adapt to different levels depending on the application.

Decision support systems are developed to assist human decision makers in complex situations without actually making the decision, placing them low on this continuum (Brodie & Hayes, 2002). If information overload occurs, the decision aid should remove redundant information, making it easier for the human operator to analyze the available data (Hollnagel, 1988). In time-critical situations, higher levels of automation may seem appropriate, particularly if the operator does not have time to respond and take action (Parasuraman et al., 2002). However, the danger exists that, if the operator ever has to take complete control and act without the help of the decision aid (due to a system failure or some other unexpected event), he will not have the benefit of experience. In such cases, it is evident that high levels of automation should not be used (Parasuraman et al., 2002).

Table 1: Parasuraman & Sheridan's (2000) Levels of Automation of Decision and Action Selection

Level	**Description**
10	The computer decides everything with no input from the human
9	The computer informs the human only in particular cases
8	The computer informs the human only if asked
7	The computer executes automatically, then informs the human
6	The computer allows the human a restricted time to veto before automatic execution
5	The computer executes its decision only when the human approves it
4	The computer suggests one alternative, and the human may accept or reject it
3	The computer narrows the selection down to a few alternatives, and the human chooses between them
2	The computer offers a complete set of decision/action alternatives, and the human chooses between them
1	The computer offers no assistance. The human makes all decisions

If the human is not actively involved in the decision making process, and is merely asked to accept or reject a machine's solution (as suggested in levels 4 and higher on Parasuraman's chart), one of two things usually happens—the user either always accepts the solution because he feels the cost of overriding it is too high (due to time constraints or other issues), or he always rejects it because he feels the machine is unreliable (Woods, 1986). Hollnagel (1988) states that, "as long as decision making is not fully automated…, the responsibility must be on the human decision maker." This ultimate responsibility makes the human operator extremely wary of any process in which he is not directly involved. Billings (1997) has ascertained that pilots in particular will resent decision aids which provide them with menial tasks and do not involve them in relevant decision-making procedures. Sarter and Schroeder (2001) have shown that pilots who are given status-only displays (which provide information, but do not suggest a course of action) to assist in decision aiding for a life-threatening situation make fewer errors than those who are given a command display that tells them what to do.

2.2.2. Cognitive Engineering

Studies in cognitive engineering have found ways to bridge the gap between humans and machines, and to determine the appropriate level of automation for a human-computer decision aid. The difficulty in cognitive engineering lies in the inherent differences between cognition and computation. Cognition is the utilization of experience, intuition, and opinion (inherently human qualities) to arrive at conclusions. Conversely, computation utilizes precise, consistent, algorithmic processes (Das, 2000). In cognitively-engineered systems, computation is guided by cognitive insight, and cognition is encouraged by computational results (Das, 2000).

In order to achieve these goals, a human-computer system must be conceived, designed, analyzed, and evaluated with a focus on the cognitive tasks (Hollnagel & Woods, 1999). Such a system must be goal-directed, using knowledge about itself and its situation to modify and execute is actions to reach them (Woods, 1986). Thus, when the primary purpose of the system is decision aiding, the system must improve the accuracy, relevance, and overall quality of information available to the decision maker (Hollnagel, 1988).

If a human-computer system is not engineered according to cognitive engineering principles, the act of automation can actually increase operator workload rather than relieve it (Parasuraman et al., 2002). In many existing systems, the human functions as a passive data gatherer for the machine, and is not actively involved in the decision making process. It has been shown that joint system performance is degraded in these situations (Roth et al., 1988). The reason for this degradation is that active human participation is necessary to achieve expedited decisions and solutions. This fact has been recognized specifically in military research. Ardey (1998) states that it is essential that the intuition and cognitive processes of the user be taken into account when designing new, complex technologies for the warfighter.

Often, human operators have difficulty accepting a machine's decision, particularly if the system is not cognitively-engineered (Muir, 1988). These problems are frequently indicative of an underlying deficiency in cognitive coupling between the user and the computer (Woods, 1986). Achieving a balance between the human and the computer can be difficult. Neither cognition nor computation should consistently dominate (Das, 2000).

Successful coupling comes from assigning tasks to the human and the computer based on their differing, yet overlapping expertise (Brodie & Hayes, 2002). This process of task/function allocation has been identified as the key step in the design process for solving problems related to operator error, system unreliability, and human-machine mismatch (Malone & Heasly, 2003). The Fitts list (Fitts, 1951) is the seminal catalog on what humans and machines can do better than one another, and serves as a guide for function allocation. This list, also known as the MABA-MABA (men are better at/machines are better at) list, appears in Table 2.

While the Fitts list is somewhat outdated, the basic principles behind it remain valid—there are areas in which humans are generally more adept than machines, and vice versa. Humans are highly adaptive, and can respond to unknown situations (Martel, 1996). They can make do with incomplete information (Reason, 1988). They are good at recognizing patterns, making classifications, detecting novel situations, associating with previous experience, detecting similarities, and making generalizations (Hollnagel, 1988).

It is these abstract qualities that make the whole of a human-machine system greater than the sum of its parts (Hollnagel & Woods, 1999).

Table 2: The original Fitts list (Fitts, 1951).

What Can Men do Better than Machines?	**What Can Machines do Better than Men?**
1. Sensory functions	1. Speed and power
2. Perceptual abilities	2. Routine work
3. Flexibility	3. Computation
4. Judgment and selective recall	4. Short-term storage
5. Reasoning	5. Simultaneous activites

Humans have limitations in other areas. They are comparatively poor at formal logical reasoning and integration of information over time. They tend to stay at the same level of performance, and are ineffective at recognizing their own biases (Hollnagel, 1988). It is in these domains that the machine element of a human-machine system is more effective, and should be allowed to dominate.

2.2.3. McNeese's Framework

McNeese et al. (1999) developed a framework for cognitive engineering to act as a guide for the design and analysis of cognitive systems. This framework can be clearly applied to the problem of human-centered multisensor data fusion. Specifically, the authors address the decisions regarding the study of cognitive systems in context. The purpose of this framework is to allow researchers to develop specific approaches for modeling such systems. Their framework consists of a work domain with six elements: goals, experimental world, knowledge acquisition, representation, evaluation, and analysis of results (Figure 3).

The framework specifies three types of goals: strategic, theory and modeling, and application. Strategic goals involve a specific, limited zone of activity. They are not intended to be generalized to other, unrelated applications. Theoretical and modeling goals involve gaining an understanding of how humans interact with their environment, each other, and their work. Application goals go one step further to involve applying the results of theory and modeling to design tasks such as function allocation, user interface and display design, and decision aid design (McNeese et al., 1999).

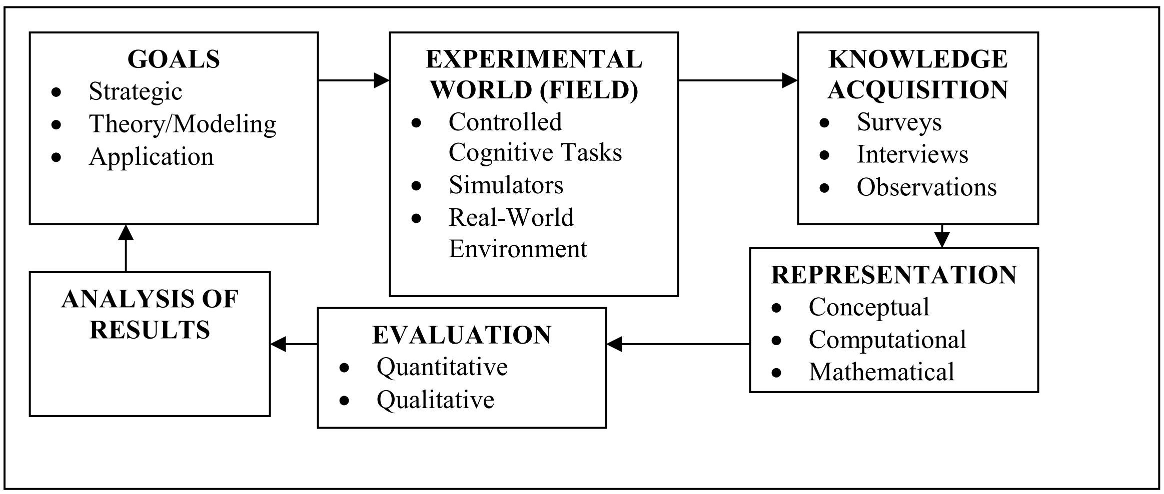


Figure 3: Components in the study of cognitive systems in context. Reproduced from McNeese et al (1999).

The experimental world is the setting in which contextual data are collected. The authors identify three types of experimental worlds: controlled cognitive tasks, simulators, and real-world environments. Controlled cognitive tasks are conducted in a laboratory environment. Symbolic representations of real-world systems may be used to study the strategies humans use to perform cognitively complex tasks.

Simulators replicate the real-world situations in which humans interact with systems in particular tasks. High-fidelity simulators, such as virtual reality systems, closely replicate the real-world environment. They are usually very expensive. Low-fidelity systems were typically used before the development of more sophisticated computer technology. Most simulators used today fall under the classification of medium-fidelity.

Real-world environments involve the study of cognition in the actual work setting. In many situations, such as studies of wartime performance of fighter pilots, real-world environments are simply not feasible. In such cases, simulators must be used to replicate the environment as closely as possible. No matter which type of simulator is preferred, the experimental world should be chosen in such a way that the results are generalizable and scalable (McNeese et al., 1999).

Knowledge acquisition involves collecting data from domain experts. McNeese et al. (1999) list surveys, interviews, and observation (including behavioral traces, concurrent protocol, and recall) as methods for data collection. Surveys are useful for studies involving a large number of subjects and broad-based problems. Interviews are effective in acquiring information from specific experts; however, the interviewer must be knowledgeable in domain jargon and interviewing techniques to extract useful information from the subject. Observation techniques include passive study, thinking-out-loud exercises (also known as concurrent protocol), and recall questioning. In all cases, the goal of knowledge acquisition is to observe natural patterns of cognition and behavior without contamination by the observer (McNeese et al., 1999).

The representation phase involves the development of the actual model of human cognition. McNeese et al. (1999) identify conceptual, computational, and mathematical types of representations. Conceptual representations include descriptive statements, flow charts, and tree structures. Computational representations use frames, finite state machines, or procedures. Mathematical representations include quantitative means such as differential equations and control theory. The choice of representation should be based on the goals of the study (McNeese et al., 1999).

Evaluation is the process of ensuring the model developed in the previous steps is an accurate representation of human cognition and behavior. Evaluation can be quantitative or qualitative. When application goals are involved, the evaluation phase involves analyzing the effectiveness of the application (McNeese et al., 1999).

The final phase, analysis of results, involves the interpretation of the evaluation from the previous phase. In this phase, the level of attainment of the original goals is assessed and new research questions are posed (McNeese et al., 1999).

The framework presented by McNeese et al. (1999) is intended as a loose outline to guide research in cognitive modeling. As such, it does not provide safeguards against improper application of the techniques, or methods to evaluate the choices of specific components. It does, however, simplify research and experimental design by limiting the choices that must be made and guiding the progression of the research process.

2.2.4. Modeling Human Decision Making

As suggested by McNeese's framework, the design of any human-machine system must involve identification of the operator's characteristics (Piccini, 2002). The cognitive engineering process should provide the designer with a realistic model of how the human functions cognitively (Hollnagel & Woods, 1999). The goals of this modeling process are to determine the type and style of information to be presented to the human user, and to establish the technical demands of the system in the context of the user's needs (Hollnagel & Woods, 1999; Narayanan et al., 2000).

Extensive research has been done on modeling human decision making, and numerous schools of thought have emerged. Archer, Warwick, and Oster (2000) state that the most common approach for modeling human decision making is the utility function, an algorithm that computes weighted summations of the factors that influence a decision (similar to the weighted averaging method of multisensor data fusion). The problem with these utility functions is that they do not represent the way humans make decisions in the real world, particularly in time-critical situations (Archer et al., 2000). As previously stated, human decision making is not based on logic or rationality (Hollnagel & Woods, 1999; Sokolowski, 2003). Rather, it has been theorized thathumans make decisions according to a process called *naturalistic decision making*; recognize cues from their environment and use prior knowledge about a scenario to select a course of action (Archer et al., 2000).

Naturalistic decision making theory specifically describes the role of experts in a particular domain for establishing decision models. Domain experts are decision makers who compare their current situation to their past experiences, and use that information to understand the significance of the current problem, derive the intention, model the situation, select the action, evaluate the choice, and anticipate the consequences (Hutchins, 1996; Sokolowski, 2003).

Human decision-making is often goal-oriented. Decision makers evaluate the progression of a decision by checking the plan of action against the overall goal. Any plans that do not meet the goal are eliminated from consideration (Kustra, 2000). Thus, the decision maker does not necessarily look for the optimal solution, but rather the one that meets his objectives (Sokolowski, 2003). In this vein, the decision maker will often postulate how a given alternative will meet his goals, and will make a decision based on the likelihood that alternative will result in a favorable outcome; he will rarely systematically evaluate all possible courses of action (Sokolowski, 2003).

Beach's (1993) image theory gives a similar picture of how humans make decisions. He suggests that, when a human makes a decision, he first screens his options to determine if they are compatible with his personal standards. If no options endure this screening, he then searches for other options or rescreens the original options. In time-critical situations, screening may not take place at all, and the decision maker may rely solely on his intuition and experience (Beach, 1993).

In 1994, Rasmussen, Pejtersen, and Goodstein developed a similarly-veined outline of the decision processes involved in actual work domains. Like Beach's image theory (1993), their "decision ladder" model emphasizes the decision maker's states of knowledge about the work environment and the goals of the task at hand (Rasmussen, Pejtersen, & Goodstein, 1994). The decision ladder is not a model *per se*, but rather a general framework that can be modified to represent various decision-making situations (Figure 4). The decision ladder has been used to represent decision making for applications such as in-flight error management (Naikar & Saunders, 2003), medical diagnostics (Rasmussen et al., 1994), in-flight retargeting of a missile (Cummings & Guerlain, 2005), and nuclear power plant accidents (Yoshida, Yokobayashi, Kawase, & Tanabe, 1995).

Cohen, Freeman, and Wolf (1996) also expand on Beach's image theory to develop a recognition/metacognition (R/M) model of how humans make decisions under time stress, particularly in military domains (Figure 5). In this model, the human uses evidence-conclusion relationships to identify his plan, then critiques problems with these

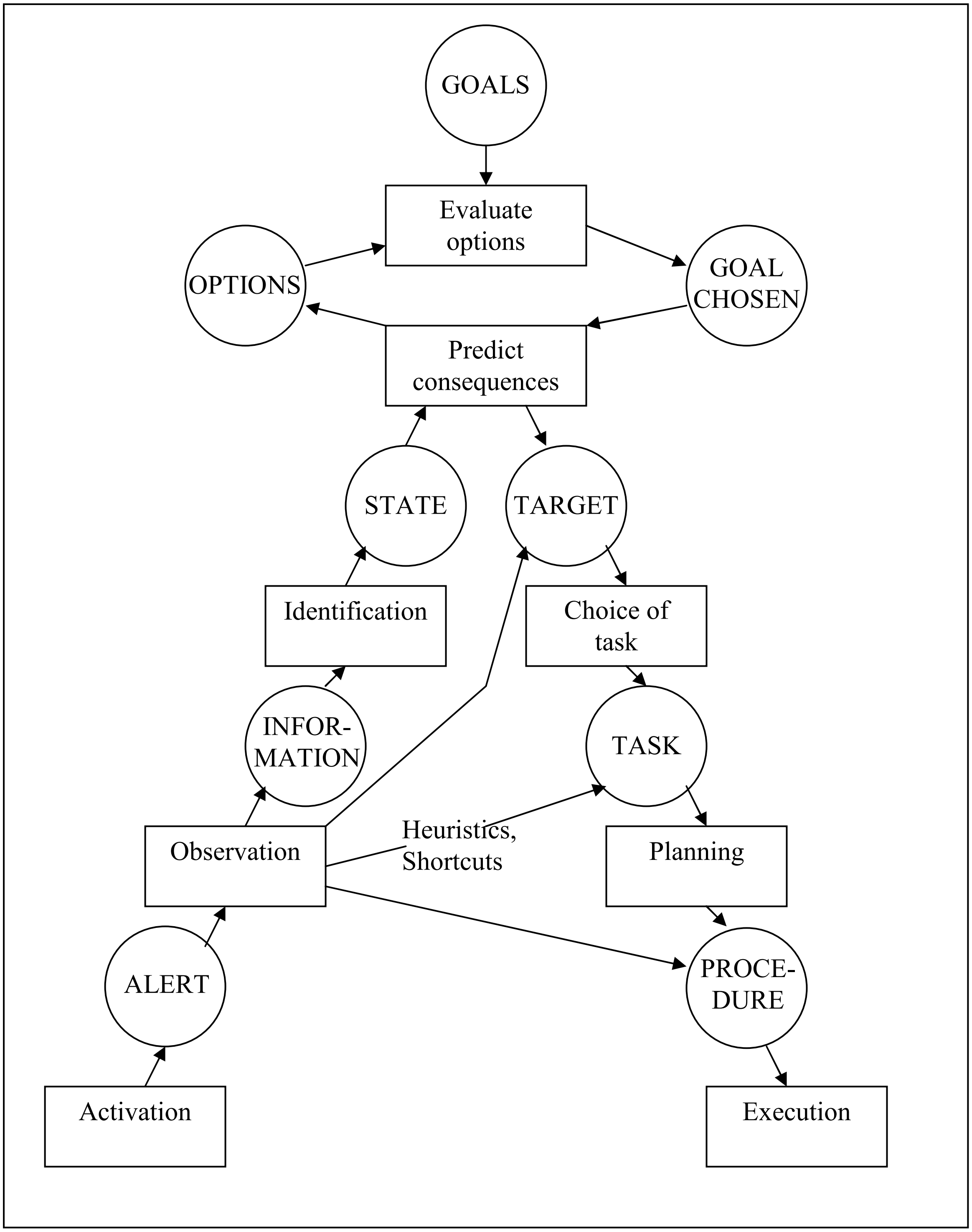


Figure 4: The decision ladder. Reproduced with permission from *Cognitive Systems Engineering,* 1994.

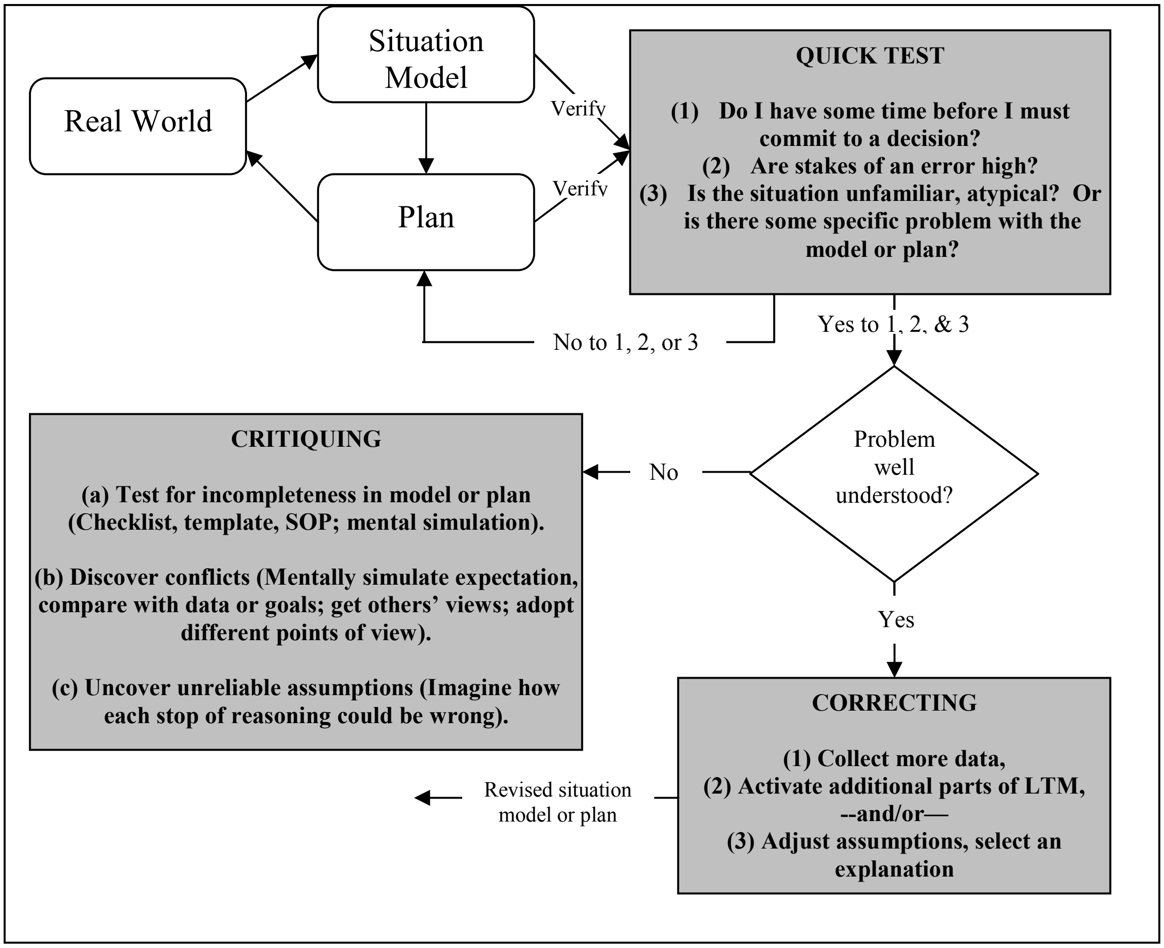


Figure 5: Recognition/metacognition model of time-stressed decision making. Reproduced with permission from *Human Factors,* Vol. 38, No. 2, (1996). Copyright 1996 by the Human Factors and Ergonomics Society. All rights reserved.

relationships. He corrects his plan to respond to these problems, and acts accordingly (Cohen et al., 1996). This dynamic view of decision making shows how experienced decision makers use both that experience and new information to solve problems.

Mitchell's operator function model (OFM) is a modeling tool designed specifically to assist in cognitive engineering of human-computer systems (Mitchell, 1987). The OFM is organized hierarchically, structurally accounting for where the human operator focuses his or her attention during a complex task (Mitchell, 1987). It consists of nodes, representing operator tasks and functions, and arcs, representing triggering events that cause the operator to change to another task or function. Operator function models have been used in the design of decision aids for search-and-rescue missions (Dave, Ganapathy, Fendley, & Narayanan, 2004), ship navigation (Lee & Sanquist, 2000), ground control of orbiting satellites (Mitchell, 1987), and information retrieval in a corporate environment (Narayanan et al., 2002; Narayanan et al., 1999) (Figure 6).

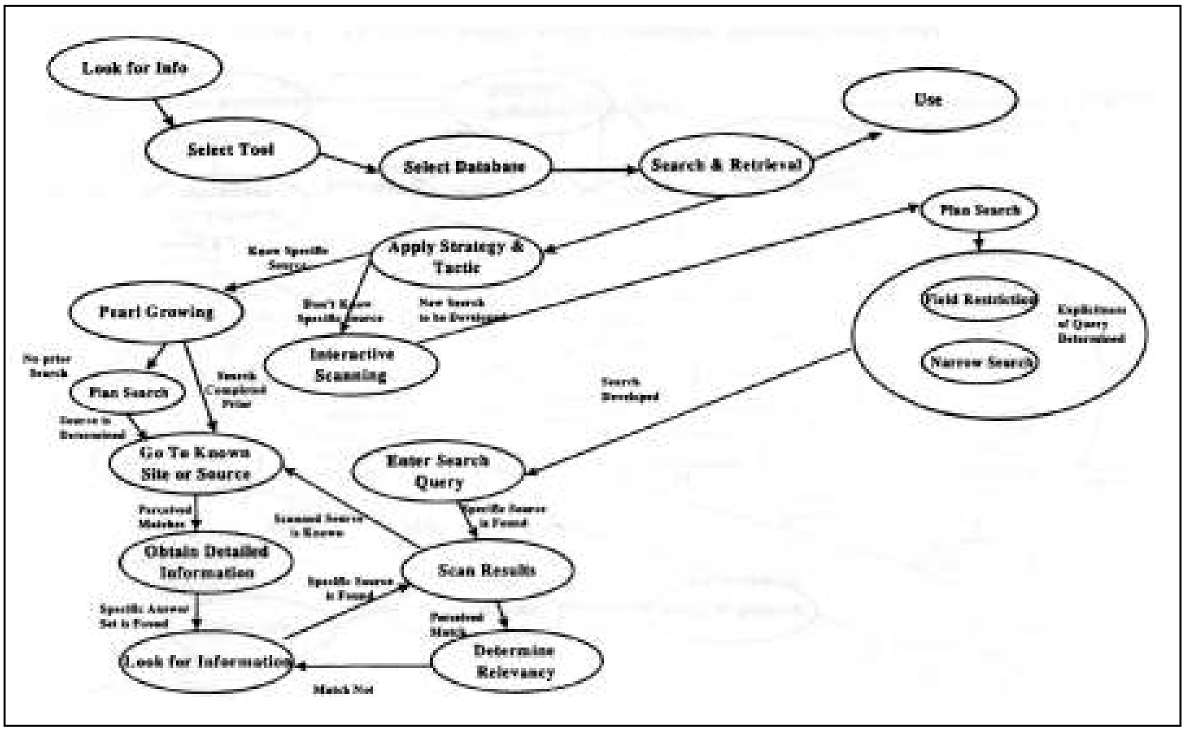


Figure 6: Operator function model. Reproduced with permission from *Human Factors and Ergonomics in Manufacturing,* Volume 9, No. 2 (Narayanan et al., 1999).

The most notable decision-making model relating to the military is John Boyd's OODA loop. Though never officially published in its original form, the OODA model (Observe, Orient, Decide, Act) has been widely used as a descriptor of how fighter pilots function in military situations. The very specifica OODA loop does not disagree with the aforementioned, more general models of human decision making, and therefore will be referred to minimally here.

There has been some limited research on modeling how humans interpret imagery. In 1987, Irving Biederman published an in-depth theory on human recognition of objects in two-dimensional images (Biederman, 1987). He postulated that humans distinguish objects by first recognizing the edges of the object in the image. The object is then parsed, while simultaneously being evaluated in terms of non-accidental relations which translate into three-dimensional space (i.e., points that are collinear on a two-dimensional image will also be collinear in three-dimensional space). The core shapes which make up the image, including "block, cylinders, wedges, and cones," are then identified. Finally, the perception of the object is matched with the human's memory, and subsequently identified (Biederman, 1987). This model of image interpretation provides a comprehensive evaluation of how humans recognize objects in images, and has been empirically evaluated. However, the concept of multiple disparate images was not addressed, nor were images which display non-visual information (such as infrared).

In the past decade, some effort has been made toward alternate models of how humans interpret images (Isberg, Thorstensen, & Jorulf, 2004; B. J. Jones, 1995; Rasche & Koch, 2002). Jones (1995) created a model in outline form that shows how humans view images from a cultural and emotional perspective. Isberg et. al. (2004) investigated how doctors interpret diagnostic images from repeat examinations of small lesions using magnetic resonance imaging and computed tomography. Rasche and Koch (2002) modeled the specific neurobiological processes involved in human processing of a visual scene. Each of these models is useful in its own right, but each is extremely application-specific and cannot be applied directly to other types of human image processing (such as multisensor data fusion).

As is evident from this previous research, modeling human decision making is not an exact science. Narayanan et al. (2000) recommend consulting with domain experts to determine what information content is necessary for making good decisions. Sokolowski (2000) recommends using neural networks to model the decision making process. He also developed an agent-based theory based on Klein's (1998) theory of *recognition-primed decision making* (RPD) that models human decision making in military situations, where it is assumed that the human makes decisions based on past experiences, (Sokolowski, 2003).

The general purpose of modeling human decision making in the context of cognitive engineering of decision aids is to match the machine's image of the user to the cognitive nature of the user, and to adapt to the user's changing needs (Hollnagel & Woods, 1999). In other words, "by accurately considering and combining system functional features and human cognitive characteristics, it is possible to estimate the weight of the human element in the design process, perform an identification process of specific cognitive activities of reference and related categorization in classes, perform an identification process of specific error modes and related categorization in classes, and obtain a set of specific human-related problems that may be used as a reference for subsequent design phases" (Piccini, 2002, p. 260).

2.2.5. Trust in Decision Aids

In order for a decision aid to be reliable and effective, the human user must be able to trust the system (Bisantz & Seong, 2001; Muir, 1988). The way in which the operator uses the system throughout its life may be affected by his trust in that system (Bisantz &

Seong, 2001). Therefore, it is essential that trust between the human and the decision aid be established early and maintained throughout the operating life of the system.

However, trust is difficult to quantify, and therefore difficult to engineer. The concept is based on *perceived* qualities rather than actual characteristics, and is therefore subject to individual biases (Muir, 1988) Trust has been found to depend on system performance (both current and past), the presence of system faults, prior levels of trust, operator faults, and the consequences of error (Bisantz & Seong, 2001). In military situations, where errors can mean loss of human life and property, trust can therefore be difficult to establish and to maintain.

The level of automation in a decision aid can be linked directly to trust. As automation increases and errors become more difficult to detect, trust either decreases significantly (creating a situation of *distrust*) or increases disproportionately (creating a situation of *overtrust*) (Ruff et al., 2002). The level of trust must be manipulated such that the user neither overestimates nor underestimates the capabilities of the decision aid (Muir, 1988). If the user is well-calibrated, he will then be able to maximize the capabilities of the system (Muir, 1988).

Muir (1988) has discovered numerous ways to improve a user's trust in a decision aid. Trust can be increased by constraining the machine's behaviors, creating greater predictability. Making the machine's behaviors observable, and enhancing its ability to communicate its intentions to the user allows for trust to grow. Ultimately, the easiest way to improve trust is to train the user in how the system works.

2.2.6. Evaluation

In a cognitively-engineered system, it is the actual function of the system, rather than the theoretical or ideal function, that is important (Hollnagel & Woods, 1999). Therefore, it is essential that cognitive systems be evaluated empirically. This evaluation phase must be carried out while the system is being implemented, as the results of the evaluation may dictate further changes in the system design (Piccini, 2002).

Every aspect of the system, from the original model of decision making to the final functionality, must be evaluated (Carolan & Scott-Nash, 2000). Piccini (2002, p. 261) identifies three main phases of assessment of cognitive systems:

- "a top-down assessment, performed following the information flux 'from tasks to displays/command';
- a bottom-up assessment performed following the information flux 'from displays/command to tasks';
- a human reliability assessment, both of qualitative and quantitative nature, with last generation techniques, able to take into account cognitive aspects of human performance and their links and dependencies with the control system and human-machine interfaces."

Hollnagel (1988) sets forth several criteria for a properly-functioning cognitively-engineered system which may be evaluated using Piccini's methods. They include correctness of the user's final decisions, accuracy of the final decision, sensitivity of the system (the minimum variation in input needed to change the decision), robustness of the system (the ability to absorb and compensate for non-standard input such as noise, disturbances, incompleteness, or contradictions), and correctness of the reasoning.

Regardless of the manner in which it is done, the cognitively-engineered system must be evaluated to determine its efficacy. Martel (1996) stresses the importance of simulation and testing to provide the data necessary for understanding the multiple failure mechanisms to which cognitive systems are susceptible. Reason (1988) states that small failures are always present in cognitive systems. The more complex, centralized, and interactive the system is, the more it is liable to succumb to more regular failures. Thus, thorough evaluation of the system is necessary to recognize these shortcomings.

3. RESEARCH FRAMEWORK FOR COGNITIVELY-ENGINEERED MULTISENSOR DATA FUSION

3.1. Overview

Examination of the preceding background research shows that there are numerous areas in the fields of cognitive engineering and multisensor data fusion which beg further study. Little has been done in the area of cognitive engineering as it relates to multisensor data fusion. However, in recent years, there has been some recognition of the need for human factors research in the fusion domain. According to Krebs and Sinai (Krebs & Sinai, 2002), the results of these studies vary—some show improved human performance with fused imagery, while some do not. Fay et al (2001) have performed some human factors experiments indicating that color fused images allow easier identification of targets than grayscale images. Another study showed improved target detection capabilities with fused imagery (Toet et al., 1997). Yet another study showed that subjects favored fused imagery over individual images (Smith, Ball, & Hooper, 2002). Krebs and Sinai (2002) found that certain types of fused imagery did not improve performance on some tasks (including target detection), but did improve performance on tasks such as object recognition, spatial orientation analysis, and scene identification.

However, despite the recognition of the need for empirical evaluation of sensor fusion systems, none of these studies involved the human in the design process. All human factors experiments were done post-hoc, with existing fusion algorithms that were designed from an strictly algorithmic perspective. The MIT fusion scheme, described above, is one exception. It was designed from a biological perspective. However, it has long been recognized in the field of cognitive science that the relationship between biology and cognition is not always easily understood (Winograd & Flores, 1986). While it was recognized that “careful and elaborate psychophysical testing must precede the deployment of any sensor fusion system” (Krebs & Sinai, 2002), and that “a sensor fusion system should be carefully tailored to the circumstances under which it will be employed” (Krebs & Sinai, 2002), no instances were found in the literature of top-down cognitive engineering in the design process. Eggleston et al (2000) identify the constant struggle in the design of decision aids between reducing cognitive burden by automating certain tasks, and increasing cognitive burden by operating behind the scenes and degrading the decision making ability of the user. A balance between these elements was attempted in this research project.

3.2. Research Objectives, Questions, and Hypotheses

The objective of this research was to design, implement, and evaluate a multisensor data fusion system for visual and infrared sensor data using cognitive engineering principles. The research questions and the related hypotheses used to reach this goal appear in Table 3. McNeese’s (1999) framework (Figure 3) was loosely followed, as this was a study of a cognitive system in context. The goal was both theory/modeling *and* application: a conceptual model of human task information processing from multiple data sources was developed and used to design algorithms for multisensor data fusion. The algorithms were implemented in a user interface designed to assist pilots in high-stress situations. Since a real-world environment could not feasibly be tested, the experimental world was a medium-fidelity simulator. Knowledge acquisition was done through concurrent protocol observations and interviews. The system was empirically evaluated both quantitatively and qualitatively to ensure accuracy of the model and cognitive coupling between the user and the computer system.

Table 3: Research questions and hypotheses

	Research Question	**Related Hypothesis**
Qualitative	How do humans interpret and combine information from two-and three-dimensional active and passive sensor images to identify objects?	Humans use previous experience, knowledge of sensor capabilities and limitations, and any other available information to make decisions based on sensor data.
	Can human methods of multiple-image interpretation be converted into software-based algorithms for multisensor data fusion?	Some methods humans use to interpret multisensory data may be converted into software algorithms. However, some aspects may be lost.
	What components should be present in the user interface of a multisensor data fusion system to allow the user to trust the system?	The user will want to be aware of the fusion process and how it is done. The original images should be visible.
Quantitative	Is there a significant difference in operator trust of a solution obtained using raw images or fused images?	H_0: There will be no significant difference in trust between the raw image interpretation and the fused image interpretation. H_1: Operators will trust the raw image interpretation more than the fused image interpretation.
	Is there a significant difference in time to obtain a solution using raw images or fused images?	H_0: There will be no difference in time to obtain a solution using raw images or fused images. H_1: It will take significantly more time to obtain a solution using raw images than with fused images.
	Is there a significant difference in accuracy of solutions obtained using raw images or fused images?	H_0: There will be no difference in accuracy of solutions using raw images or fused images. H_1: Solutions will be less accurate with raw images than with fused images.

4. METHODS

This research used cognitive engineering principles to develop a multisensor data fusion system for pilots and battlefield commanders in high-stress situations. Several studies were necessary to establish a model of the typical user's decision making process, to evaluate the sensor fusion algorithms, and to assess the effectiveness of the user interface.

4.1. Imaging Systems

Two passive (naturally illuminated) forward-looking infrared (FLIR) imaging systems were used to acquire image data. The Phoenix InSb FLIR is a 12-bit digital mid-wave infrared (MWIR) camera system with a bandwidth of 3-5 µm and a 640 x 512 array. The Jade MCT FLIR is a 14 bit digital, long-wave infrared (LWIR) camera which operates at 8-12 µm, and has a 320 x 256 array.

The test plan for data collection using these imaging systems appears in Appendix A. The sensors were positioned on the 11th floor of a tower at Wright-Patterson Air Force Base. Images were acquired through an open window. The Phoenix acquisition rate was 1 Hz, and the Jade rate was 60 Hz.

4.2. Preliminary Study Number One

An initial study was performed to assess user needs and create a model of the decision-making process involved in interpreting images from multisensor data. Images of several different targets (a military vehicle, a woodchipper, a pickup truck, and people) were used to assess how human subjects view and interpret different types of images.

4.2.1. Experimental Design and Procedure

A concurrent protocol procedure was used. This mechanism of data collection, where subjects were asked to think out loud and verbalize their thought processes in real time, was utilized for several reasons. First, since fighter pilots are required to communicate with their colleagues and their mission commander almost continuously during flight, concurrent protocol is a realistic scenario in this problem domain. Second, if the alternate method of post-hoc or recall analysis were used, where subjects would describe their task performance *after* the task is completed, the subjects may have suffered from memory issues or post-analysis of behavior . Concurrent protocol allowed immediate, unprocessed collection of the cognitive processes of the subjects to the greatest extent possible.

Images of a target obtained using the two FLIR sensors and a visual sensor were displayed on a laptop computer. Subjects were asked to identify the object in the images and to explain what features in each image they used to come to that conclusion. Subjects were encouraged to think out loud while evaluating the images. The full testing protocol appears in Appendix B.

4.2.2. Participants

Twelve subjects were recruited from Wright-Patterson Air Force Base. All subjects were military scientists currently serving either in the Sensors Directorate of the Air Force

Research Laboratory or at the Air Force Institute of Technology. All subjects viewed the same images. The order of presentation was randomized based on a Latin Square design.

4.3. Preliminary Study Number Two

A second preliminary study was conducted to analyze how humans view and interpret imagery from multiple sensors while under stress. Images of a military vehicle in different orientations simulating an aircraft fly-by were used.

4.3.1. Experimental Design and Procedure

The entire procedure was pilot-tested with active-duty military pilots and adjusted accordingly prior to implementation. As in the previous study, a concurrent protocol procedure was used. The imaging modalities were also the same as those used in the previous study: two passive FLIR sensors and a visual sensor. The main target in all images was some type of military vehicle, but other parameters were varied (see Appendix C). The orientation was reversed on one of the image sets to simulate the conditions that would be experienced if a pilot were to fly by the same target area several times, reversing direction in between passes.

Subjects were again asked to identify the object in the images and to explain their thought processes in coming to that conclusion. The images were displayed for a fixed amount of time before being replaced by a blank screen. To incorporate the inherent variability of these types of missions, the length of display time for each image was determined using MatLab’s random number generator function for a standard Normal distribution with a mean of 30 seconds and a standard deviation of 20 seconds. These parameters were suggested during an interview with Lt. Col. Brian Ewert, a flight test navigator with the US Air Force (Ewert, 2005). The time between images was also generated with MatLab's random number generator function, with a mean of 60 seconds and a standard deviation of 15 seconds. These times were deemed an accurate approximation of the time it would take for a fighter jet to turn around and fly by the target area a second time. Subjects were informed that the images would be displayed for a fixed amount of time, but were not told exactly what that time would be.

In addition to analyzing the images in this study, subjects were asked to perform other tasks in parallel (Figure 7). The cognitive task program SynWin© was used to simulate the mental demands of flying an airplane. Subjects were told to attempt to obtain as high a score as possible by performing a memory task, an arithmetic task, a visual monitoring task, and an auditory monitoring task. Scoring was used only to add stress to the situation—scores were recorded, but not analyzed. The full testing protocol appears in Appendix C. During the pilot study, the subjects agreed that the SynWin© program coupled with the concurrent protocol accurately simulated the mental demands of flying.

Figure 7: Subject performing in Preliminary Study Number Two

4.3.2. Participants

For the pilot study, two active-duty flight officers were recruited. At the time of the study, one was serving as a 2nd Lieutenant in the Air National Guard. He was a fighter pilot, and had one and a half years of military fight experience and nine years of civilian flight experience. The other subject was a Major in the U.S. Air Force. He had logged over 3000 hours as a navigator, mainly on cargo aircraft. For the main study, the same participants who participated in the first preliminary study were recruited. Three subjects were unable to participate, leaving a total of nine (six male, three female).

4.4. Preliminary Analysis

The subjects' responses were recorded (see Appendices D and E for full results, Figures 8-9 for sample results), and their individual statements were separated. Each subject's responses were then compared between the two conditions. Statements which indicated similarities between the two conditions were clustered with similar statements from other subjects. For example, the statement, "This looks like the flightline down by the museum," given by Subject 1 in the low-stress condition, and the statement "We have two images, one is of something in the treeline back in the [WPAFB Building] 620 area," given by the same subject in the high-stress condition were considered similar and were grouped under the heading "Compares image to prior knowledge." These results appear in Table 4. Statements that appeared in one condition but did not appear in the other are shown in Table 5.

Subject 1 (1Lt., Male)

Condition 1 (Hot woodchipper)

- ☐ Starts with visual image—does it full screen. Uses color of trees and grass to discern the season. Says scene is of "the flightline down by the museum."
- ☐ Says the only new info in IR is the dirt—hot—otherwise, compares all features to the visual image
- ☐ Was able to determine that the cars are moving due to the heat signature
- ☐ Compares woodchipper to the dirt, and concludes that it is hot due to solar energy
- ☐ Uses context, color, and shape to ID highway cone

Condition 2 (Cold woodchipper)

- ☐ Thinks tree colors are different [mistake]
- ☐ Uses phx to ID the haze
- ☐ Uses phx to ID vehicle tracks
- ☐ Finds the other equipment behind woodchipper

Condition 3 (Dayton skyline)

- ☐ Visual first, again
- ☐ Compares to previous image
- ☐ Uses prior knowledge of the area to discern viability
- ☐ Zooms in on image to get more detail
- ☐ Uses context—since road is wet, finds standing water
- ☐ Picks out similar features to get FOV

Condition 4 (Men behind trees)

- ☐ Without visual, flips back and forth between IR images
- ☐ IDs trees
- ☐ IDs MMO—road/line/pipe
- ☐ Can't ID people (says the more he looks, the more they look like blobs)

Condition 4—movie (Men behind trees)

- ☐ Can ID 2 people in phx movie
- ☐ Uses the fact that they're moving together, bending down, and walking away separately to discern that they're dropping something off

Figure 8: Sample subject responses for low-stress scenario. Exact quotes were unavailable due to a sound system malfunction. Complete results appear in Appendix D.

Subject 1 (1Lt., Male)

Condition 1 (Wide-angle hot Humvee with flame-sprayed aluminum target)

- □ "OK, we have two images, one is of something in the treeline back in the 620 area, you have fresh tire tracks in both, maybe there's some snow or something causing that, the big temperature difference. The upper image is black, I can't see anything in that at all. It's square, I don't know what's giving those—target panels, maybe? It's something at the ground that's causing this, you can see clearly, maybe there's some sort of sign in front of the road, that's propped up. Something's been driving around back there, there's two black panels…almost like a black panel, it's not very reflective, or cold or hot relative to these images. It's right beside the main target, a spot. We have some sort of symmetry that's going down, right to left."
- □ [Image disappears]
- □ "It's like a stair-step type function"

Condition 2 (Wide-angle hot Humvee rotated 180°)

- □ "OK, top image is blank, they're inverted, I can see some sort of target with varying contrast, parked behind the trees. I can still see what looks like a sign post in this. I don't think that's what it is, but I've got no clue otherwise. I can see tire tracks leading from what's probably the road, inverted heading in towards the target site. I think maybe it's maybe it's a target of one general reflectance"
- □ [Image disappears]
- □ "with something reflective in front of it, that's in a square shape."

Condition 3 (Wide-angle hot Humvee in new target area)

- □ "OK, three images, two infrared, one visible. On the top, it's slightly overcast there, looking towards the corner out onto the flightline area. There might…ah, it's too hard to see…there are things out on the flightline, but I *know* that, I can just barely see some blips that might or might not be actual information. In the infrared, I see a real hot spot, I think…yeah, it's just the road that comes between the trees, so the road's reflecting very brightly as compared to the rest of the imagery. On the Dayton skyline, there's something dark on the middle image, on the left, it's maybe just out of frame"
- □ [Image disappears]
- □ "because of this different field of view on the bottom image"

Condition 4 (Narrow-angle hot Humvee obscured by foliage)

- □ "OK, new image, it's clearly our Humvee, it's hot, its engine compartment is still hot, as well as the wheel well, you can see a temperature gradient along the...probably from water or soil turnover where it went into the covered area. It's in the patch of trees over across from the building, see, I know that—that's clearly where it's at. I can see some spots where it might have been that people stood for a little while, you can see where there are some different colors from the ground, and there's no other obvious reason why they would"
- □ [Image disappears]
- □ "change, maybe where some other targets *had* been placed in a previous part of the experiment. But there definitely is a vehicle that had been stopped…either been running for a while then been stopped, or just recently been turned on then stopped, because the wheel wells were hot from crap being thrown around in them, as well as the engine compartment still showing heat."

Condition 5 (Narrow-angle Humvee with flame-sprayed aluminum target)

- □ "OK, regular image of the Humvee in the target area, now you can see there's snow on the ground, there's a flame sprayed aluminum target leaning against the rear of the vehicle, the nose of the vehicle is switched from some of the previous images, facing to the right. So it's been pulled in, you can see where the snow's been disturbed, it was pulled in and then pulled back, to get to its current position in the field of view."
- □ [Image disappears]
- □ "Can't tell if there's anything else inside the vehicle."

Condition 6 (Wide-angle Humvee and 10-wide)

- □ "OK, single image on the flight line, it's the trailers and something else looks like it may be the air conditioning vent showing up kind of hot, there's a darkened spot, a dark spot, it's just short of one of the crossovers on the…you can see the taxiway and also the other part of the runway, taxiway's darker than the primary runway. You can see the crossover, actually it's very near one of the other crossovers, and that's what that is here. There's been a moving vehicle, I think that's what this is, the windscreen's showing up as cold, or dark, maybe due to some air conditioning or heating inside it. There's this extra little hot spot that I think is probably the engine compartment of the vehicle. I think this is a hot air conditioner, where it's"
- □ [Image disappears]
- □ "been exchanging heat to the outside, so it's why there's one little globule on the trailer facing towards us."

Figure 9: Sample subject responses for high-stress scenario. Complete results appear in Appendix E.

Table 4: Subject responses similar between low-stress and high-stress conditions

Percentage of Subjects	Response Category
100%	Focuses on similarities between current image and previous images
89%	Uses visual image to establish the scene
78%	Uses individual features in images to analyze context of scene
78%	Compares all IR features to visible (if available)
78%	Compares image to prior knowledge
56%	Finds common points to register images

Table 5: Subject responses differing between low-stress and high-stress conditions

Percentage of Subjects	Response Category
100%	Able to discern small details in low stress, but misses them in high stress
100%	Focuses on details in low stress, takes a general "snapshot" of the images in high stress
89%	Uses individual features in images to analyze the context of the scene in low stress, but misses connections between objects and their context in high stress
67%	Able to see small changes between similar image sets in low stress, but misses differences between image sets in high stress
67%	Identifies all man-made objects in low stress, but misses man-made objects completely in high stress
56%	Focuses heavily on high-contrast areas in high stress
56%	Does not notice noise, resolution, and other hardware anomalies in high stress
44%	Uses context and shape to identify object in low stress, but is unable to identify similar objects
33%	Stops looking at image before it disappears in high stress
33%	Wants more background information or a specific objective in high stress
33%	Wants images and other tasks on the same screen in high stress
33%	Prioritizes the multiple tasks in high stress
22%	Wants sound cues to indicate when images are there in high stress
11%	Can't tell is image is unavailable or just dark in high stress
11%	Wants all images to be right-side up in high stress
11%	Wants a scale to help identify sizes in high stress

4.5. Model Development

The information gleaned from the concurrent protocol experiment was used to create a model of human information processing for integrating multisensor data under time critical situations. All types of models were considered in the development. Naturalistic decision and image theory types of models were too descriptive in nature—

their structure did not allow for the prescriptive analysis necessary to establish related algorithms. The decision ladder and recognition/metacognition models were too constrictive, and did not allow for representation of the different paths the human subjects used in reaching their decisions. In the end, an operator function model was created, because this type of model was able to capture both the cognitive events that occurred when the subjects viewed the imagery, and the transitions between those events. The low-stress model appears in Figure 10, and the high-stress model appears in Figure 11.

4.6. Algorithm Development

The preceding operator function models were used to create algorithms for fusing the images from the visual and infrared sensors. The models indicate that humans use the visual image as a base and compare the infrared images to it. Therefore, the algorithms used this same idea. In both models, man-made objects were identified by finding areas of high contrast in the infrared. However, smaller man-made objects were missed in the high-stress scenario. Therefore, the algorithms had to use contrast (which the human operator utilized well) to highlight the smaller objects that the operator would miss otherwise.

Image registration was also a problem for the human subjects in high stress, so the images were registered. For the purposes of this study, the registration was done by hand using the transparency function in the GNU Image Manipulation Program (GIMP) software package. For practical purposes, images may be registered optically by using lenses and fields of view that correspond between cameras.

Other aspects of fusion had to be left to the human operator. Establishing context was a problem for the subjects in high stress, but this function would be difficult, if not impossible to perform by machine, as indicated by the Fitts list (Table 2) (Fitts, 1951).

Differences from previous images would also be difficult to perform by machine due to the large variation in extraneous factors such as time of day, weather, object orientation, etc., that

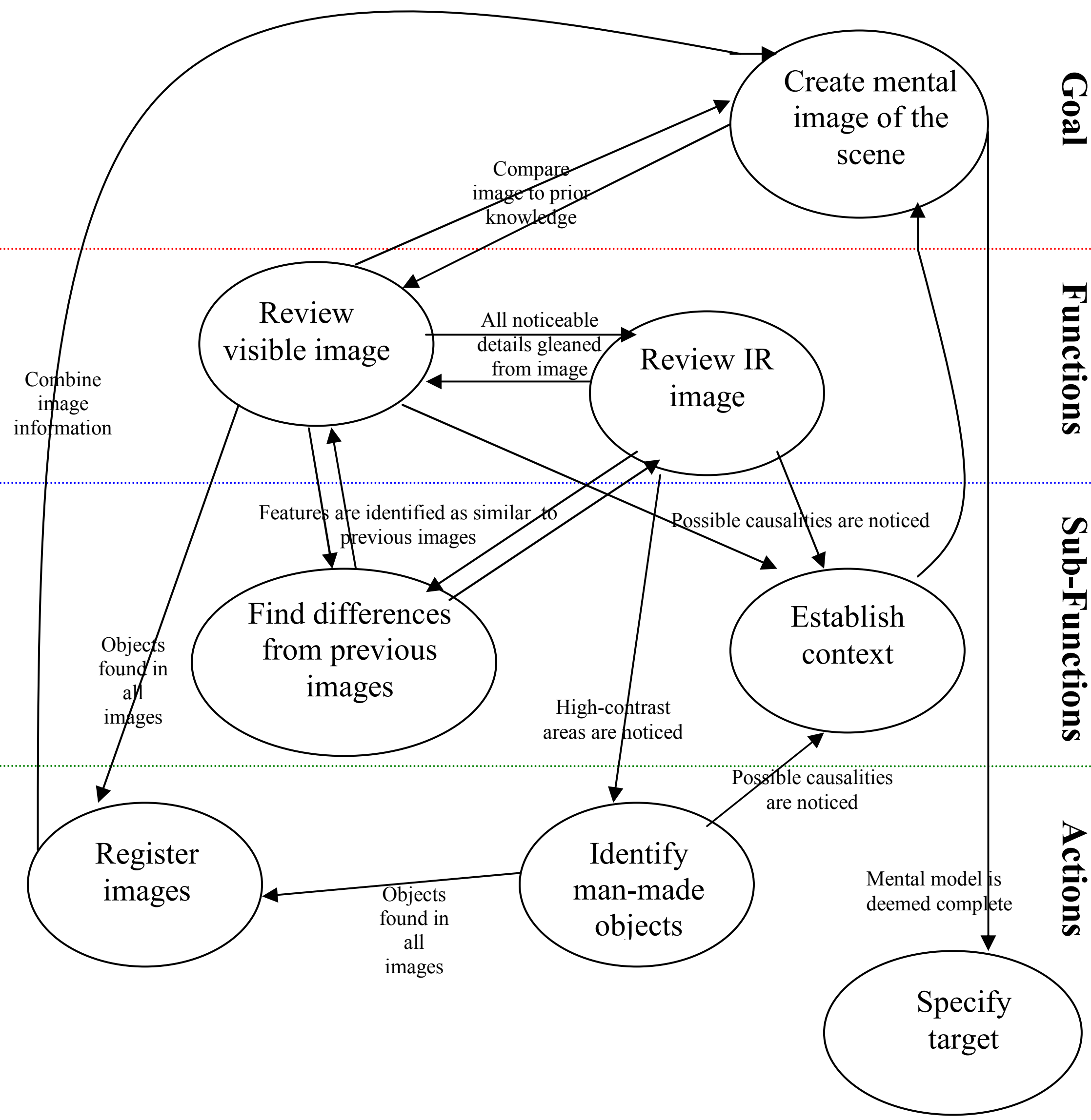


Figure 10: Low-stress operator function model for human interpretation of multisensory images.

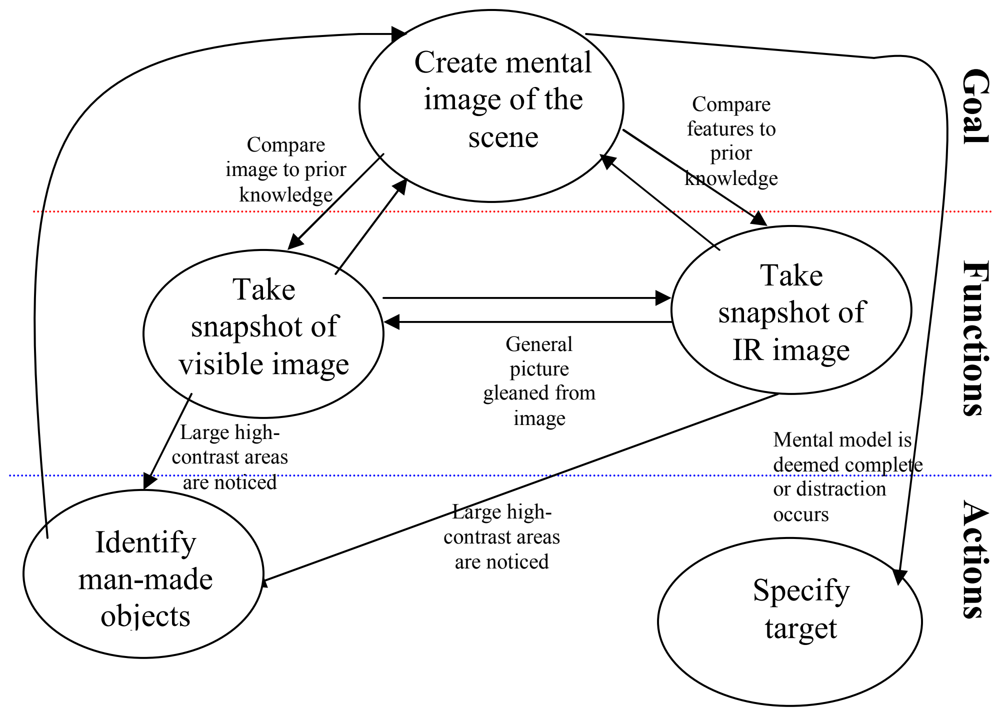


Figure 11: High-stress operator function model for human interpretation of multisensory images.

would have an impact on the comparison. According to Fitts (1951), these factors may be easily accounted for by the human operator, but would be significantly more difficult to perform by computer.

With these requirements established, a k-means fusion algorithm was developed. The k-means method of pattern recognition is a well-known algorithm that clusters pixels into k different groups based on value, and replaces the pixel value with the cluster value. This algorithm is able to highlight differences in the infrared, and enhance the contrast. It also decreases the amount of data that the human operator has to process, thereby making it easier for them to identify the objects of interest. The k-means algorithm was programmed in Matlab, and appears in Appendix H. A flow chart of the algorithm appears in Figure 12. The clustering algorithm was applied to the available image data using a wide range of values for k. The resulting images were compared, and it was found that four clusters were sufficient to highlight all man-made objects in the images (Figure 13c). Fewer clusters also means less time and computational workload, so using this low number of clusters was ideal.

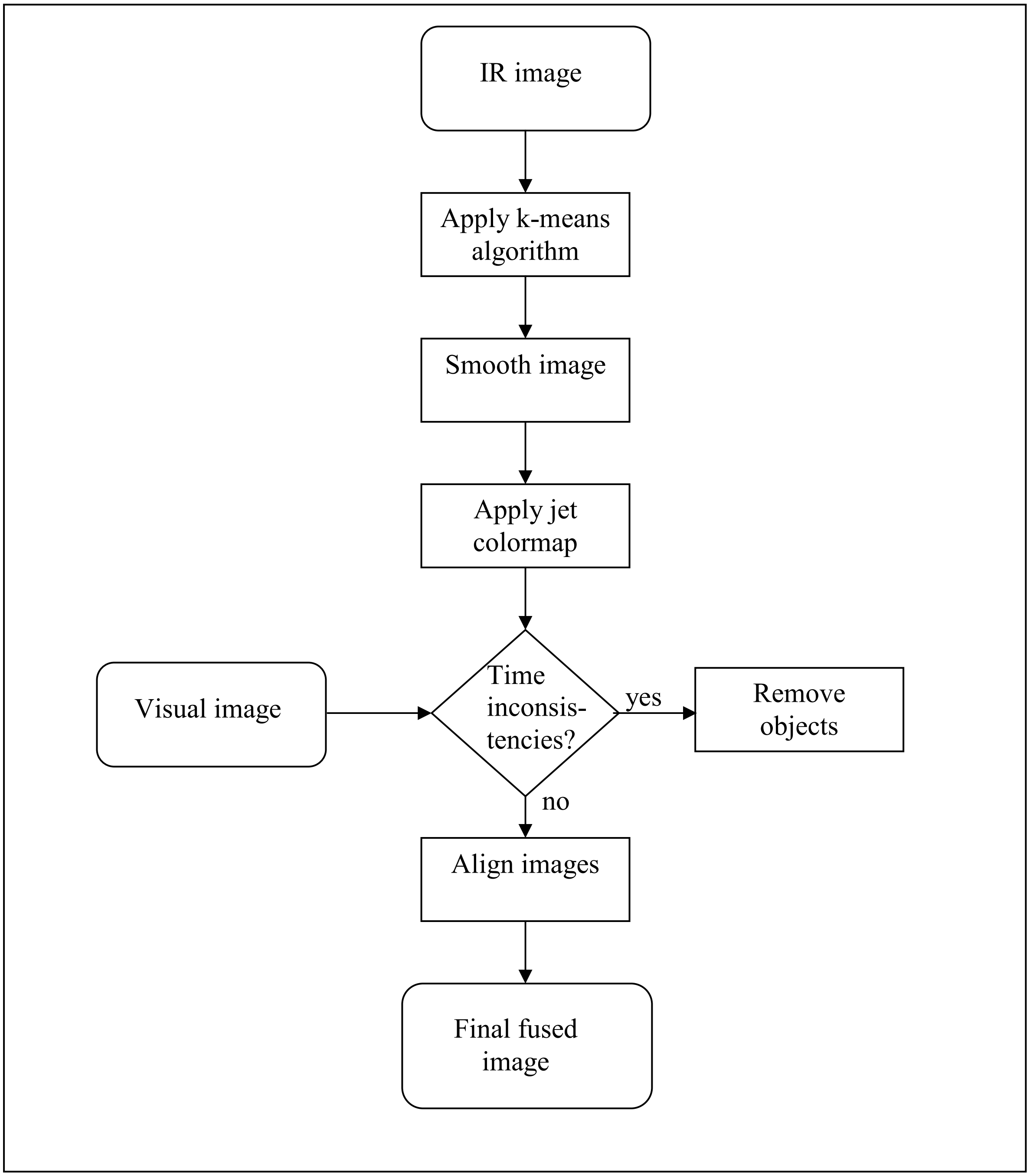


Figure 12: Fusion algorithm flowchart.

Since noise was a problem in some of the images, a 2x2 median filter was then applied to the masks using the Matlab function medfilt2. This small filter was able to smooth out the noise without affecting the rest of the image to any perceivable extent (Figure 13d). A jet colormap was then applied to the mask images to add further contrast for the human operator (Figure 13e). This particular colormap was selected because it mimics the colors of a jet engine, with which the human operators in the context of this experiment would be familiar.

Image registration required some additional processing due to the way in which the image data were collected. In some cases, vehicles appeared in the infrared that did not appear in the visual, and vice-versa, because the images were collected at different times. In these cases, the images were temporally registered by copying and pasting the surrounding areas over the anomalies using GIMP (Figure 13f). Additionally, the field of view and image angle were often different. Registration was again accomplished using GIMP by overlaying the infrared mask as a 60% transparency, and resizing and moving the image until the features lined up (Figure 13g). In cases where image features did not register even after using these methods, sections of the infrared mask were cut and pasted to allow the images to align. In real-world situations, these procedures would not be necessary, so long as the sensors are optically aligned. However, as is evident from the procedures used in this research, precise alignment is not necessary; application of the k-means algorithm and smoothing filter result in an approximation of the original infrared image that does not need to line up perfectly with the visual image to be effective.

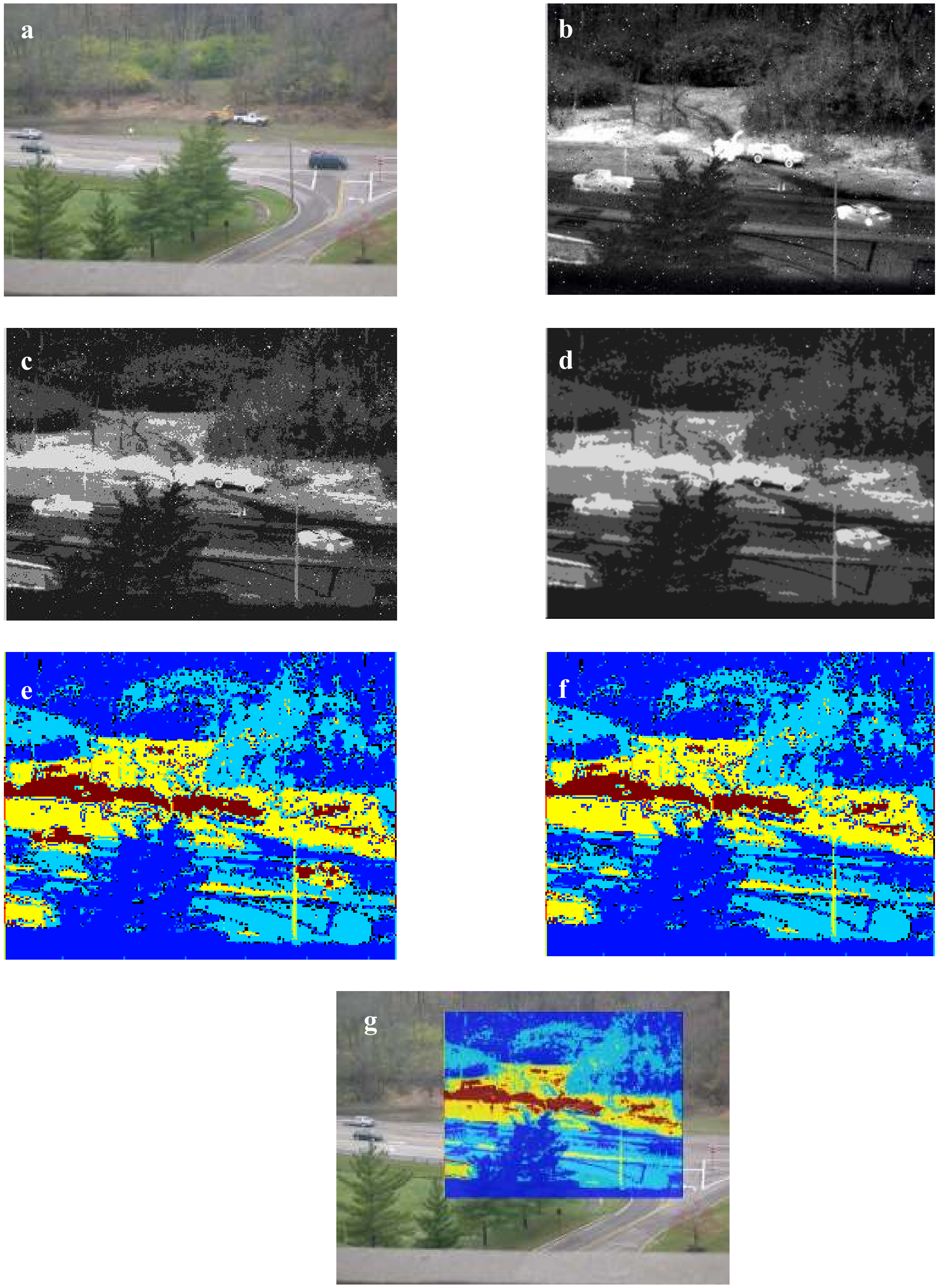


Figure 13: Steps of the fusion process between the visual image and the Jade image for the hot woodchipper data set. Start with the visual image (a) and the infrared image (b). Apply the k-means algorithm to the infrared image with k = 4 (c). Smooth the mask with a 2 x 2 median filter (d). Apply the jet colormap (e). Remove vehicles that were not in the visual image (f). Align the two images using GIMP (g).

4.7. Empirical Evaluation

Following implementation of the results of the pilot study in the form of algorithms for multisensor data fusion, the entire system was evaluated. Since the overall goal of the proposed project was a decision aid for pilots and battlefield commanders in high-stress situations, these conditions were approximated as closely as possible. Hollnagel's (1988) criteria of correctness and accuracy of the final decisions and correctness of reasoning were evaluated—the high-stress and low-stress operator function models were validated using concurrent protocol and recall methods, and the implementation of the model (the fusion system) was evaluated based on the following variables: the time taken to identify the targets in the images, the accuracy of the target designations, and the participants' confidence level in those designations. The robustness and sensitivity criteria could not be evaluated due to lack of available image data.

4.7.1. Experimental Design and Procedure

A medium-fidelity fighter jet simulator was used to approximate the real-world conditions experienced by fighter pilots. The simulator utilized three separate personal computers to operate a flight simulation, an instrument panel simulation, out-the-window (OTW) graphics, and a Heads-Up Display symbology. The OTW graphics were projected on a dome display offering approximately 120 degrees field of view (FOV). A complete description is given in Appendix D.

Four sets of imagery were used, with each image set consisting of a standard digital image and two FLIR images (Jade and Phoenix). Two of the image sets were taken at a medium FOV, and were identical to those used in Preliminary Experiment Two. The remaining two image sets were unique: one had a wide FOV, and one had a narrow FOV.

The target in each image was a military or civilian vehicle. The order of the conditions was randomized based on a Latin Square design. Half of the subjects viewed the separate, unfused images, and half viewed fused imagery (see Appendix D).

The simulator scenario, shown in Figure 14, was designed with the help of an active-duty fighter pilot to approximate a real-world, high-stress combat and targeting situation. The participants were given a pre-flight brief on the scenario, and told that all hot or warm targets should be considered hostile. They were asked to verbally “designate” the target in the image if it was hostile, or to declare the target “neutral” if it was not hostile. They were also asked to declare the vehicle type and make. During the pre-flight briefing, the participants were also shown pictures of six military vehicles, two of which were included in the simulation, to assist them in making their target identifications. The subjects who would be viewing the fused imagery were given additional training to explain the fusion process.

During the simulation, the participants were asked to fly to four separate waypoints, indicated on the instrument panel (Figure 15). When the plane came within three miles of a waypoint, the images were displayed automatically. The participants had 30 seconds to view the images before they disappeared (variable display times were not possible in this simulation as in Preliminary Study 2). Due to the size of the display, only one image could be displayed at a time (Figure 15). The participants could cycle through the three images using a button on the simulator. The display also indicated threats, both air and ground, that the participants were instructed to avoid using evasive maneuvers.

Mission:

Deep Interdiction, Time Sensitive Target Strike

Mission Objectives:

Identify and Destroy High Value Target
Zero Collateral Damage to Civilians
Negate and/or Kill all A/A & A/G Threats to Survive

Risk Level:

High

Threats:

Integrated Air Defense –

SA-10 / Mig-29 JEZ with SA-13's to fill SA-10 blind spots.
Mig-29 CAP north of Tgt area
SA-10 coverage above 1000' AGL along route of flight
Multiple SA-13 along route of flight
AAA throughout area

Target:

Terrorist Leader Caravan - Intel reports have identified a Caravan, including both military and civilian vehicles, suspected to contain the Jack of Spades. The Caravan has recently stopped in a neutral village for the night. The Jack of Spades should not leave his vehicle for fear of being recognized and turned over to coalition authorities. The targets of interest are warm from running recently. All cold vehicles should be considered neutral.

A/A ROE:

Shoot any aware FSU Aircraft threatening mission accomplishment

A/G ROE:

Any hot/warm vehicle in the Tgt Area

Package:

You are single ship, self escort.

Loadout:

4 x AMRAAM
3 x GBU-38's (500lb JDAM)
Fuzor AT Targeting pod – EO/IR sensor image fusion

Mission Flow:

Descend to 500' before point 1 to remain below SA-10 coverage. Each waypoint was chosen to give the Fuzor AT pod a brief, low altitude view of the target area. The Pod will cue automatically to one of four vehicles in the target area after each waypoint. You will have 30 seconds to view each vehicle of interest in the target area, before terrain blocks the view. Cycle through the images the pod provides to decide if each vehicle meets the A/G ROE. If is does, "Designate" it as a hostile target and declare vehicle type and make. If it does not meet the ROE, declare it "Neutral" and declare vehicle type and make. After waypoint 4 (the IP) proceed to the target (point 5) to release all of your JDAMs in a single pass on the targets you have designated.

Attack:

The attack will be a single pass, multiple warhead (JDAM) release on multiple targets in the intel provided target area. It will be a 500' AGL, 540 KCAS auto level delivery at waypoint 5.

Figure 14: Combat simulation scenario. This scenario was designed with the assistance of an active-duty fighter pilot to simulate a high-stress combat and target situation.

Figure 15: Combat simulation instrument panel. Images are displayed on the top left, waypoint headings in the bottom center, and threats on the center left.

The participants were allowed to practice the simulation using a training image until they felt comfortable using the simulator and the imaging system. The practice session lasted at least ten minutes. During practice, the participants were vulnerable to the air and ground threats in the simulation, and each participant was shot down and forced to restart the simulation at least twice. During the actual data collection session, the simulator settings were changed to render the participant invulnerable to enemy fire in order to ensure uniform data collection; however, the participants were not informed of this invulnerability in order to keep their stress at a realistic level. During data collection, the time taken for each participant to designate each target or to declare it neutral was recorded. The vehicle identification was also logged.

Following data collection the participants were debriefed. In order to evaluate the high-stress fusion model, the participants who viewed the unfused imagery were asked to watch a videotape of their experience and to explain their thought process in reaching their target designations. They were instructed not to re-analyze their designations. This recall form of analysis is not as ideal as concurrent protocol for identifying cognitive processes, but since concurrent protocol could not be used without affecting the other variables to be analyzed (time and accuracy), it was the best possible method. The participants were also asked to rate their confidence in their target identifications on a scale of 1-5, with 1 being extremely unconfident, 2 being somewhat unconfident, 3 being neutral, 4 being somewhat confident, and 5 being extremely confident.

The participants who viewed the fused imagery were also asked to rate their confidence level. They were then asked the following questions to assess the image fusion algorithms:

- What is your overall impression of the imagery system that you just used?
- Did the way in which the images were presented help you to determine what the target was?
- Would a system like this make your job in the cockpit easier?
- If you could change anything about the system, what would it be?
- How does this system compare to any automated targeting systems you may have used in the past?

The participants were then asked to view separate, unfused images, and to think out loud in a concurrent protocol in order to evaluate the low-stress model. The full testing protocol appears in Appendix D. All data collected during the study appear in Appendix G.

4.7.2. Participants

Twelve active-duty military subjects were recruited from the Air Force Institute of Technology. The subjects ranged in rank from Captain to Lieutenant Colonel. All subjects had at least 30 hours of military flight or simulator experience.

4.8. Empirical Analysis

For the model validation portion of the empirical study, three modeling experts unaffiliated with this project were asked to evaluate the participants' responses for both the low-stress and high stress scenarios. One expert works in industry, and the other two are government employees. All three experts have a graduate degree in a related area (M.S. in human factors engineering or Ph.D. in psychology) and have managed research programs on modeling or have published technical articles on human operator modeling. For each image set, they assessed whether the responses fit the prescribed model. For those that did not, a state or transition event that would need to be added to the model in order to make it complete was identified.

For the quantitative variables, a t-test was used to compare the time taken to identify the target in the image (whether correctly or incorrectly), the accuracy of the target identification, and the subjects' level of confidence between fused and unfused imagery. P-values less than 0.10 were considered significant.

5. RESULTS

5.1. Model Validation

Three independent modeling experts evaluated the subjects' concurrent and recall responses for the low-stress and high-stress scenarios, respectively (see Appendices I-J for complete results). The results of this analysis appear in Table 6. For instances where the experts felt that the models did not agree with the subjects' responses, they recommended changes to the models to accommodate these responses. The recommendations appear in Table 7.

Table 6: Validity of initially-proposed low-stress and high-stress models as determined by modeling experts. Validity is represented as the percentage of instances where subject responses for a given image set agreed with the model.

Expert Number	**Low-Stress Model Validity**	**High-Stress Model Validity**
1	88%	70%
2	100%	78%
3	67%	96%

Since no model can be expected to completely describe all cases of human behavior, the experts' recommendations affecting less than 10% of cases were not incorporated into the model, with the exception of Expert #3's recommendation to change the arc between "Take snapshot of visible image" and "Identify man-made objects" to read "Identify color and physical features" in the low-stress model, since this was a matter of semantics and did not appreciably alter the complexity of the model. Recommendations that affected more than 10% of cases were added to the model. The completed models appear in Figures 16 and 17. With these changes, the model validity increased substantially (Table 8).

Table 7: Experts' recommendations for changes to the model.

Expert Number	Low-Stress Model Recommendations	% of Instances Affected	High -Stress Model Recommendations	% of Instances Affected
1	Change arc that says "All noticeable details gleaned from image" to read "features of interest gleaned from image"	13%	Need a new subfunction node to include filtering of the object of interest or features of interest from all man-made objects and clutter in the scene	25%
			Need a bi-directional arc between the "Create mental image of the scene" node and the "Specify target" node to encompass second-guessing of designation after target has been selected	4%
2	No changes		Need a new subfunction node to include filtering of the object of interest or features of interest from all man-made objects and clutter in the scene	13%
			Need another node that states "Establish context"	8%
3	Need an arc that leads to "Identify man-made objects" node directly from "Review visible image"	13%	Need to change arc between "Take snapshot of visible image" and "Identify man-made objects" to read "Identify color and physical features"	4%
	Need an arc to directly link "Create mental image of the scene" and "Review IR image"	21%		

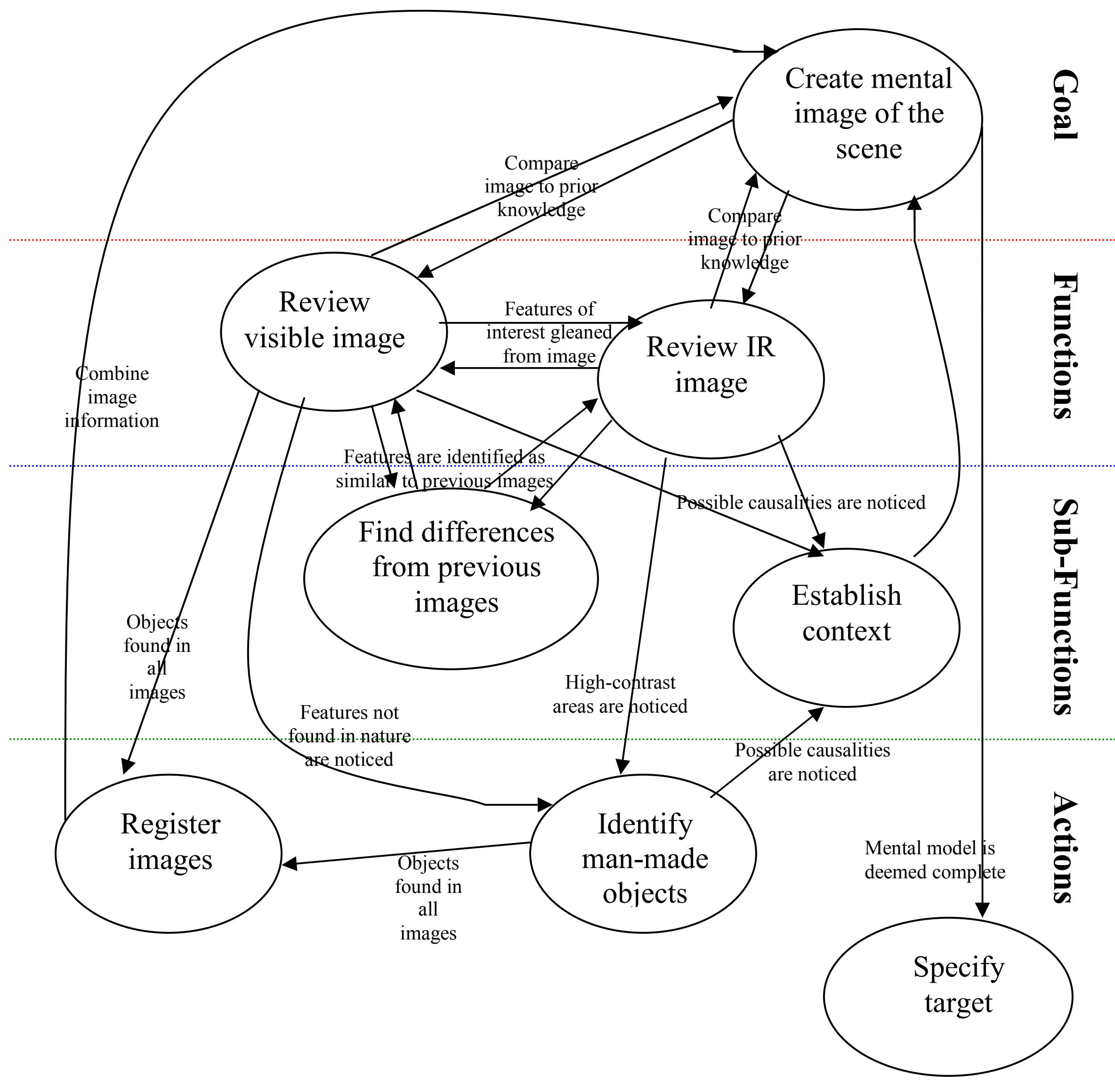


Figure 16: Revised low-stress operator function model for human interpretation of multisensory images.

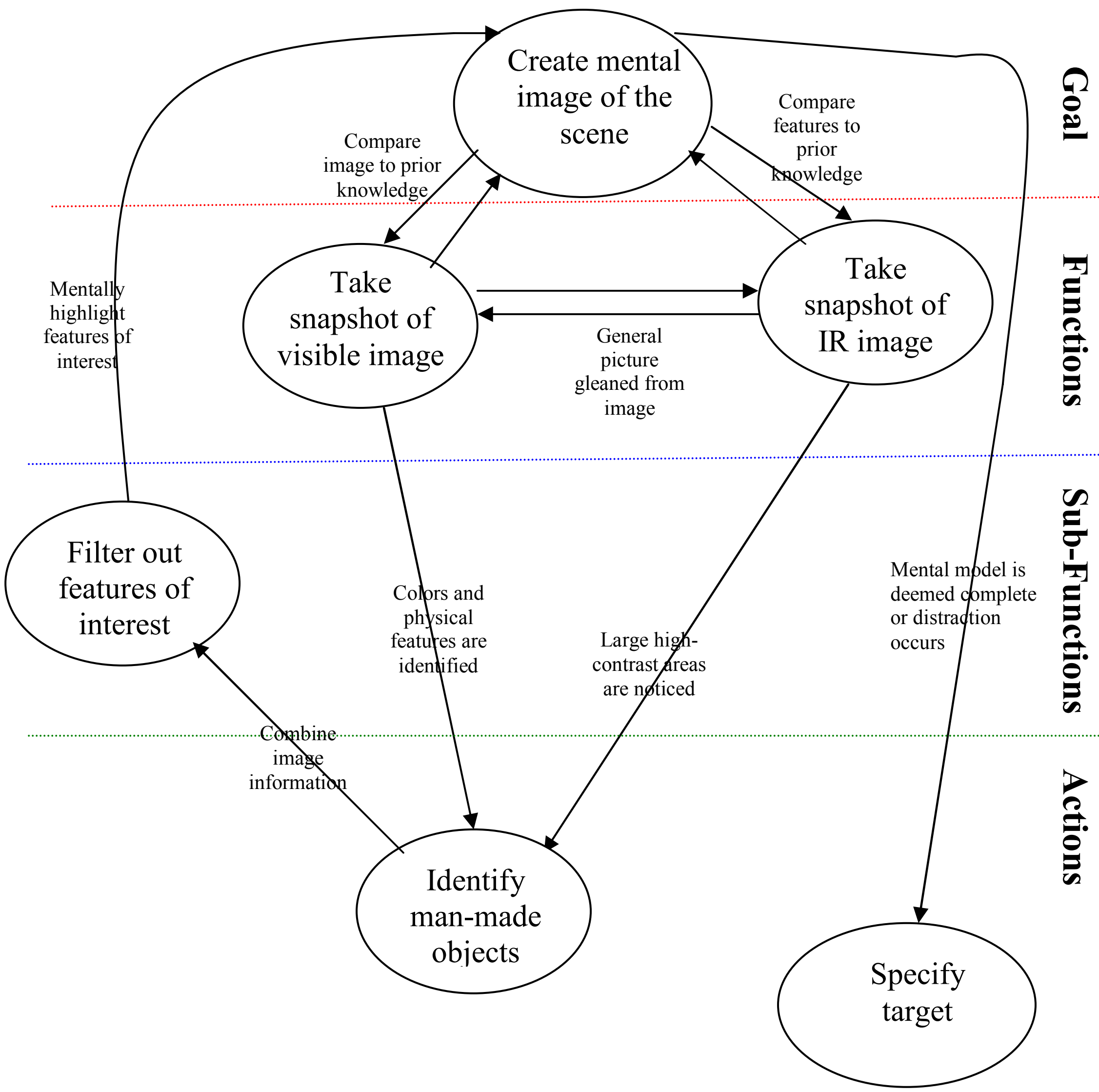


Figure 17: Revised high-stress operator function model for human interpretation of multisensory images.

Table 8: Validity of revised low-stress and high-stress models as determined by modeling experts. Validity is represented as the percentage of instances where subject responses for a given image set agreed with the model.

Expert Number	Low-Stress Model Validity	High-Stress Model Validity
1	100%	96%
2	100%	92%
3	100%	100%

5.2. Algorithm Evaluation

The fusion algorithms were evaluated based on three quantitative variables compared with unfused imagery (time to identify a target, accuracy of target identification, and confidence in target identification), and several qualitative points determined through interviews (overall impression of the imagery system, willingness to use the system in the cockpit, desire to change elements of the system, comparisons to other targeting aids).

The quantitative results are shown in Figures 18-20. Statistically significant differences ($p < 0.10$) between the fused and unfused imagery were seen for time to identify the medium FOV cold target (unfused imagery was faster) and the wide field of view hot target (fused imagery was faster). Significant differences were also seen in the accuracy of identification of the medium FOV hot target (fused imagery yielded more accurate identifications), and in the confidence level of the subjects with relation to the narrow FOV hot target (participants who saw the unfused imagery were more confident). For all other images with all other variables, there was no significant difference between the fused and unfused imagery. When all targets were considered together, no significant differences were found between fused and unfused imagery for the variables in question.

The algorithms were also evaluated qualitatively by the study participants who viewed the fused imagery. The results of the post-test interviews for the participants who viewed the fused imagery are shown in Table 9.

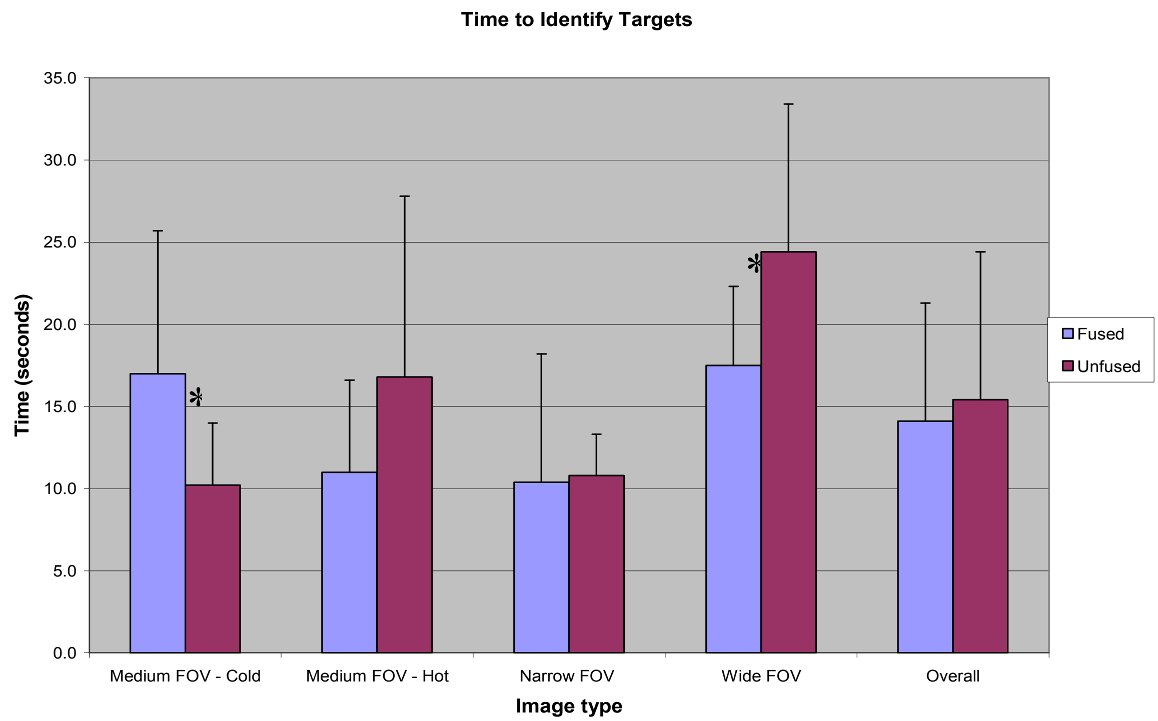


Figure 18: Time-to-identify results. Statistically significant differences ($p < 0.10$) are indicated with an asterisk (*). Error bars indicate standard deviation.

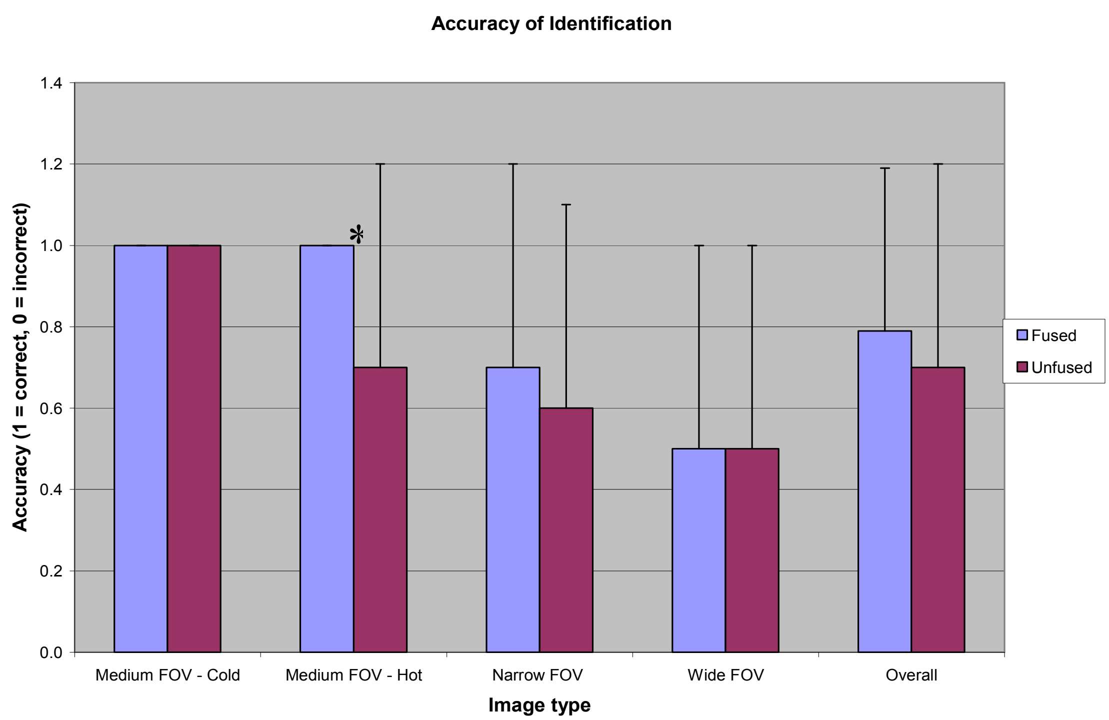


Figure 19: Targeting accuracy results. Statistically significant differences ($p < 0.10$) are indicated with an asterisk (*). Error bars indicate standard deviation.

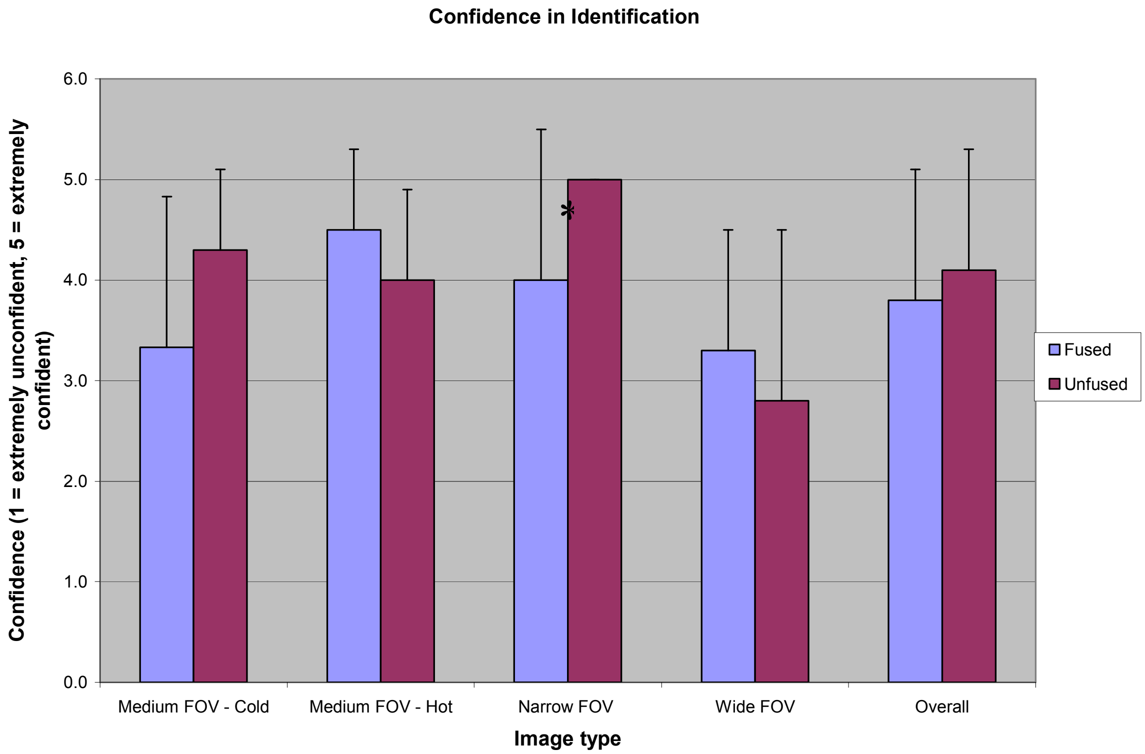


Figure 20: Participant confidence results. Statistically significant differences ($p < 0.10$) are indicated with an asterisk (*). Error bars indicate standard deviation.

Table 9: Responses to interview questions by participants viewing fused imagery

% of respondents	
33%	Thought system was difficult to use
67%	Thought system was good
33%	Wanted to be able to zoom in
50%	Wanted more contrast, ability to control contrast/gain
50%	Distracted by background and noise
17%	Found it difficult to determine target in wide FOV
50%	Wanted more training
33%	Wanted IR images to be presented first, or more prominently
17%	Found fusion system draws the eye to high-contrast areas
83%	Liked that the system has color
33%	Liked being able to flip through different images
33%	Found fusion system to be similar to other imaging systems
67%	Found fusion system to be better than other imaging systems
17%	Wanted to see what would happen in thermal crossover
17%	Used first image to make initial decision, then used additional images to refine
100%	Thought fusion system would make job in cockpit easier

6. DISCUSSION

6.1. Summary and Discussion of Results

Multisensor data fusion is a complex field of study with nearly limitless applications. The ever-growing body of research on this topic is evidence that no ideal method has been discovered. Numerous fusion schemes, from battlefield scenarios to human biology, have been attempted. However, strikingly few researchers have tapped into the human end-user as a basis for multisensor fusion design.

Yet, research in cognitive engineering has shown that the consideration of the human end-use is a must in the design of any decision aid. This research was therefore done from a cognitive-engineering perspective.

Overall, the empirical results of this research are promising. The models were validated by three independent experts, whose feedback indicated that the initial models were accurate for a majority of cases. Their recommendations allowed the models to be fine-tuned such that they are accurate more than 90% of the time. While these tests were limited in scope (only a small amount of image data were available), they show that the models are able to accurately depict how humans interpret multisensory image data. These models can therefore be used as a starting point for investigations of how humans interpret mutisensory data in other problem domains with different types of data. Further research would serve to further validate the models and allow for their expansion in other fields of study.

The quantitative results of the empirical experiments show that the multisensor fusion algorithms developed from these models have promise, but that there is still work to be done. For the most difficult and realistic target, the wide FOV, the test participants were able to identify the target significantly more quickly with the fused imagery than with the unfused. This shows that the fusion system may assist pilots in quickly locating a hard-to-find target in a real-world situation. However, there was no increase in accuracy, indicating that while the fusion system may help pilots in finding the target on the screen, it does not assist them further in making a designation.

For the medium FOV cold target, all participants correctly identified the target, but the participants viewing the fused imagery took longer to do it. In their post-test interviews, half of the subjects indicated that they were distracted by the background information in this particular image, and would have probably been able to identify the target in that image more easily with additional training on the image fusion system. This should be taken into consideration for future work.

For the medium FOV hot target, the participants were more accurate in their identifications when using the fusion system. This result indicates that the fusion system works particularly well in assisting pilots in target identification when large high-contrast areas are present. Since the system was designed to highlight high-contrast areas in the infrared, and since the preliminary experiments indicated that humans tend to notice large areas of contrast more readily than small, this result is not surprising. The more accurate identification results for this image, combined with the faster identification results for the wide FOV image, show that the fusion system is doing what it was designed to do.

The level of automation for the decision aid in this project was low, about a two on Parasuraman's (2002) scale (Table 1). This was done with regard to prior research suggesting that fighter pilots given status-only displays performed better than those given command displays (Sarter & Schroeder, 2001). For the most part, the level of automation in this fusion system appears to be appropriate. In all cases save one (the medium FOV cold target), the participants performed as well or better with the fusion system than they did with the unfused imagery. As stated before, this one exception could be attributed to insufficient training, and more research is needed to determine if that is, indeed the case.

As discussed in the Background section, a human user's trust in a decision aid is crucial to its performance. In this research, trust was determined by asking the participants to rate their level of confidence in their targeting decisions. For three out of the four image sets, the results show that the participants had as much confidence in their targeting designations with the fusion system as they did without. For the remaining target, the narrow FOV hot vehicle, the confidence was lower with the fused imagery. The reason for this could be the fact that the target was extremely easy to identify (as indicated by the post-flight debrief of all of the participants) due to the very narrow FOV. All of the participants were 100% confident (5 out of 5) when viewing the unfused imagery, but those viewing the fused imagery were a little more unsure (an average of 4 out of 5). Again, this lower level of confidence could be due to insufficient training on the imagery system. Future work with additional training should be performed to investigate this possibility. However, for the most part, the participants showed a high level of trust in the fusion system; 100% of the participants who viewed the fused imagery said that it would make their job in the cockpit easier.

The results of the interviews with the subjects who viewed the fused imagery offer some more indications of how the fusion system may be improved. 67% of the participants thought the system was easy to use, and 50% thought they could learn to use the system better with additional training. The colormap was popular among the subjects, with 87% stating, unprompted, that they thought it was a good feature that made their targeting decisions easier. This shows that the colormap feature should definitely be included in future iterations of the fusion system. Half the subjects wanted the ability to control the level of contrast in the images with a scroll bar or some other device, and one-third wanted the ability to zoom in on areas of interest. Additional research should be performed to determine if these functions will assist in target designations without causing information overload or task saturation.

A few of the subjects (33%) wanted the IR images to be displayed before the visual image in the image sequence. This could be because the targeting task required the subjects to designate the targets based on their IR signature. Additional tests should be performed with different targeting goals to determine which image should be displayed first, or most prominently.

A majority of the subjects (67%) thought the fusion system was better than other targeting decision aids they had used in the past, indicating that this cognitively-engineered fusion system shows great promise.

6.2. Benefits, Limitations, and Future Work

The fields of multisensor data fusion and cognitive engineering continue to grow. This research shows that studies in multisensor data fusion, and image fusion in particular, can benefit greatly from a marriage with cognitive engineering. Future work in this area may strengthen this claim.

The fusion methodology utilized in this research has numerous benefits in addition to those already discussed. While the feature-level fusion method developed here does require that the images be registered optically, it does not require that the registration be perfect at the pixel level. Slight differences in field of view between separate sensors (which will occur if the sensors are mounted side-by-side) will be masked when the clustering and smoothing operations are performed. Additionally, prior knowledge is not required, as would be in Bayesian fusion methods. However, any prior knowledge that is available, such as the heat signature of a target of interest, for example, could be used to establish initial seed points for the k-means algorithm and would help enhance the contrast in the imagery to an even greater extent. A disadvantage to using this feature-level type of fusion is that some IR information is lost in the process—extremely small areas and close levels of contrast will not show up in the fused imagery. This trade-off of smaller details for larger and, presumably, more important features, is inherent to feature-level fusion. However, the gains made in the ability to more easily locate those features and to use them to identify targets of interest ought to outweigh the loss of information.

Numerous limitations were placed on the execution of this research. Most notably, a limited amount of image data were available. All images used in the development and evaluation were of military or civilian vehicles in a limited geographical area. Future work should include a broader range of imagery and targets to ensure that the results of this research were not limited due to the restricted scope of the imagery.

Additionally, the user interface of the simulator cockpit could not be altered for the empirical evaluation experiments. Future research should include cognitive task analysis of the entire user interface to ensure complete cognitive coupling between the human user and the machine.

Due to constraints on time and resources, the fusion algorithms developed here could not be compared directly with other existing fusion algorithms. A direct comparison, particularly with the biologically-derived MIT fusion scheme (Waxman et al., 1997), would be an interesting assessment, and could strengthen the argument for including cognitive engineering in the design process of multisensor data fusion systems. An investigation of how this system compares with the TNO scheme (Toet & Walraven, 1996), particularly in situations of thermal crossover where the TNO scheme is purported to work particularly well, would also be of value.

As discussed previously, cognitive systems must be empirically evaluated to ensure that they are functioning as they should. While this project has broad-reaching applications in many different areas (weather, medicine, security and surveillance, to name a few), the system developed in this research was not evaluated in these domains. Future work in these areas should include testing with human subjects to identify possible areas of application-specific weakness and to evaluate Hollnagel's (1988) criteria of sensitivity and robustness in a cognitive system. Such experimentation would serve to make the system more robust.

To further broaden the scope, the system developed in this project should also be evaluated in different work situations within each of these domains. In the military domain alone, there are numerous possible situations where multisensor data fusion could be of benefit. Only one simulation scenario was evaluated in this research; others could be tested to further validate the effectiveness of the system.

Due to the limited amount of image data available in this study, the imagery had to be processed prior to fusion in order to register the images. Therefore, no automated fusion system could be developed. Future work should be done with image data registered optically. This will allow the development of automated fusion algorithms, based on the algorithms described here, that can be applied to image data in real-time.

6.3. Contributions of the Research

Prior research has shown that cognitive engineering results in better-performing decision aids. Since a multisensor data fusion system is a decision aid, it follows that such a system should be designed according to cognitive principles. However, little work has been done in this area. The goal of this project was to assist the warfighter by creating a system which will allow faster, more accurate interpretation of images from multiple sensors.

The contributions of the research are threefold: a model of how humans make decisions from multisensory data, a model-based algorithm and support system, and an empirical evaluation of the system as a whole. Currently, little research is being conducted to understand the cognitive aspects of multisensor data fusion. The results of this study provide a better understanding of how humans function cognitively when presented with images from different types of sensors. Additionally, it provides a baseline for future research in multisensor data fusion and assisting the warfighter in high-stress conditions.

Other applications of this research may exist outside the military domain. Any high-stress situation involving imagery from multiple sensors (i.e., surgery, weather forecasting/tracking, security and surveillance, quality and defect inspection, airport precautions) can benefit from the proposed research. While military images were used in the proposed study, the results can be used as a starting point for further research in numerous areas of scientific interest. In this sense, the major, generalizable contribution of this research is the methodology used to gather information about how humans fuse multisensory information, and to implement those results into fusion algorithms. This methodology could feasibly be used with different types of imagery in countless applications.

6.4. Conclusions

Multisensor data fusion is a quickly-growing field with applications in numerous domains. It is particularly of interest to practitioners in the military domain, where the ability to make fast, accurate decisions based on information from multiple sensors can result in a significant operational advantage. However, despite the fact that multisensor data fusion is a decision aid, and the vast body of research in cognitive engineering has proven that decision aids must be cognitively engineered in order to function as intended, precious little has been done to include the human end-user in the design process of multisensor fusion algorithms.

This research represents an initial effort towards cognitively-engineered multisensor data fusion. The model developed in this research represents a unique, verified contribution to fundamental knowledge about how humans interpret multisensor imagery. While the data used in this study were limited to the military domain, the possibility exists to extend the methods used here to numerous other areas, including medicine, security and surveillance, and weather. The model may even be further refined in the military domain, beyond the algorithms developed here, to other types of sensors and other applications. While the quantitative results of the algorithm testing showed that work remains to be done on the implementation of the model, the model itself has been proven accurate. This research represents an important first step in a realm of infinite possibility in the field of cognitively-engineered multisensor data fusion.

APPENDIX A: DIFFICULT TARGETS LADAR ACQUISITION TEST PLAN

This memorandum contains a description of the procedures for the Difficult Targets Laser RADAR (LADAR) Data Acquisition Test. This memorandum serves to finalize the safety coordination efforts in support of this testing. For further information, contact Larry Barnes.

TEST ENGINEER: Lawrence Barnes
ORGANIZATION: AFRL/SNJM
3109 P St, Bldg 622
WPAFB, OH 45433-7700
255-9614 x222
lawrence.barnes@wpafb.af.mil

1. OBJECTIVE: The objective of this test is to acquire a complete data set of obscured objects for Automatic Target Recognition (ATR) Analysis. The data set is comprised of various active/passive imaging and Ladar modes of targets obscured in natural and manmade clutter. The goal is use passive FLIR imagery and active flash imaging, gated imaging, and non-imaging Ladar modes to build this complete data set for the ATR analysis. All of these LADAR systems, with the exception of the FAR IR Flash LADAR Imager and FMCW System have been operated under other safety plans. It is desired to have all LADAR systems acquire data of partially obscured targets under identical conditions to support the analysis.

2. APPROACH: Various approaches will be used
   2.1. Imaging modes :
      2.1.1. Passive FLIR Imaging : FLIR (3-5 μm and 8-12μm) systems and other passive (ICCD and CCD) sensors will acquire passive (naturally illuminated) images of the test sites containing targets. These images will be acquired in the same conditions as other active data collects and be registered to the active data.

	Camera	Band	Array size	Notes
1	Watec 902H CCD	0.3-1.0 μm	768 x 494	570 lines, visible
2	PTI I-300 ICCD	0.5-0.9 μm	768 x 494	40 lp/mm, video, night vision (NV)
3	Princeton 1024HQ ICCD	0.4-0.9 μm	1024 x 1024	64 lp/mm, gated, digital, NV
4	Indigo Merlin	0.9-1.7 μm	320x240	12 bit digital, SWIR
5	Sensors Unlimited	0.9-1.7 μm	320x256	12 bit digital, 60 Hz, 25μm pitch
6	Phoenix InSb FLIR	3-5 μm	640 x 512	12 bit digital, MWIR
7	Jade MCT FLIR	8-12 μm	320 x 256	14 bit digital, LWIR

Table 1. Passive Imagers for Active/Passive Imaging Experiments

2.1.2. Active Imaging :

2.1.2.1. Laboratory Development and Characterization: Laser systems will be developed and/or characterized in bldg 622, room 132 to verify laser power and characteristics and then installed in the 11th floor of the Building 620 tower.

2.1.2.2. Range Gated LADAR Imaging :

2.1.2.2.1. Controlled Area Testing: The laser shall first be characterized and co-aligned to a passive camera and/or low power visible laser within the laboratory. It shall then interrogate the laser test range controlled area in order to verify pointing, beam control, energy levels, and overall procedures. The testing begins with tightly controlled hard stops to ensure all laser radiation leaving the tower falls onto the test site of the controlled area. The passive camera will be co-aligned to this laser for pointing of the eye-safe energy later in the test plan. A co-aligned visible laser used to verify pointing may also used for atmospheric characterization. Its divergence shall be eye-safe at the minimum range. Controlled Range testing shall ensure the laser divergence provides eye-safe laser beam diameters at the minimum range assessable, which shall be determined by physical stops. The concrete balcony shall serve as a physical stop to ensure the laser cannot be directed to ranges shorter than minimum range assessable. The eye-safe beam diameters are calculated by AFRL's LHAZ software program to not exceed the unaided viewing Maximum Permissible Exposure (MPE). Once the divergence, systems, and procedures have been validated, the systems would be directed to the specified test sites and targets within the WPAFB reservation.

2.1.2.2.2. Clutter Testing: The test sites shall have ground control personnel to control access and verify that there are no aided viewing devices (binoculars) in the area. The Ladar imagery shall be acquired with verified eye-safe beam diameters. The laser systems will be used to scan an area of the test site target area using large (unaided viewing) eye-safe footprints and a gated camera. The test will run intermittently over the change in seasons to acquire data at different states of vegetative clutter.

2.1.2.2.3. Laser parameters for Range Gated LADAR tests:

	Laser	Energy (mJ)	RepRate : pulse-width	Eye-safe Diameter (m)	Diameter at range	Wave length	Permit	Camera
1	Melles-Griot	5	mW – CW	0.015	0.175 m	543 nm	92L978	Alignment laser
2	Laser Compact	50	mW – CW	0.08	0.3 m	532nm	95L083	Alignment laser CCD camera
3	Coherent 532-100	100	mW – CW	0.12	0.5 m	532nm	99L068	Alignment laser CCD camera
4	Alexandrite	25	30Hz : 7ns	6.02	10.0 m	800nm	03L031	Roper Scientific ICCD
5	Big Sky CFR 800	800	10Hz : 10ns	9.21	10.0 m	1064nm	99L066	Sensors Unlimited InGaAs
6	Big Sky CFR 800	200	10Hz : 7ns	0.238	3.0 m	1570nm	99L066	Sensors Unlimited InGaAs

Table 2. Gated imaging Test Laser Characteristics – Eyesafe Beam Diameter (waist) from LHAZ 4.2.4 diameter required for NOHD=0 at 30000s of unaided viewing

2.1.2.3. Flash LADAR imaging :

2.1.2.3.1. Controlled Area Testing / Clutter Testing : Will follow the gated imaging safety procedures exactly. The only difference, aside from wavelength, is that the pulsewidth of the laser and camera integration times will not support range gated imaging at rates necessary for clutter suppression. The laser, a GSI Lumonics Transverse Electric Field Atmospheric Pressure Carbon Dioxide (TEA CO_2) and long wave FLIR imager (HgCdTe) are the same for line items 1 and 2 this test. After the laser wavelength is selected and the laser is characterized in the laboratory, the Controlled Area will be used for verification of beam pointing laser, energy levels, procedures, and divergence control before testing begins out of the Controlled Area Test Range. Again a hard stop shall prevent lasing of areas nearer than the minimum range.

2.1.2.3.2. Laser parameters for Flash LADAR tests:

	Laser	Energy (mJ)	RepRate : pulsewidth	Eye-safe Diameter	Diameter at range	Wave Length	Permit	Camera
1	GSI Lumonics	4400	15Hz : 300ns	1.06 m	10 m	9300 nm	04L01	Jade MCT FLIR
2	GSI Lumonics	5000	15Hz : 300ns	1.13 m	10 m	10600 nm	04L012	Jade MCT FLIR

Table 3. Flash Imaging Test Laser Characteristics – Eyesafe Beam Diameter (waist) from LHAZ 4.2.4 diameter required for NOHD=0 at 30000s of unaided viewing

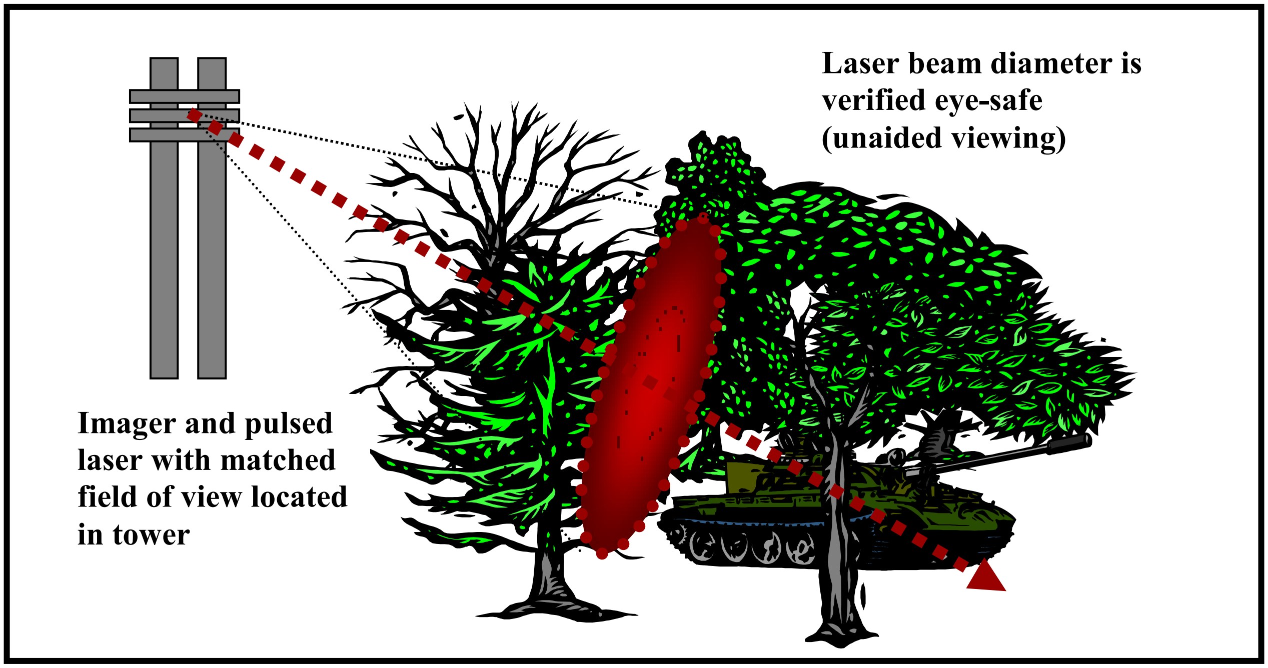


Figure 1. Active Imaging Modes

2.2. Non-Imaging LADAR

2.2.1. Laboratory Development and Characterization:

2.2.1.1. MultiFunction LADAR for Identification (MLID) System : Is currently characterized and testing from the tower to the Controlled Area Test Range.

2.2.1.2. Frequency Modulated Continuous Wave System : The FMCW systems will be developed, assembled, and characterized in bldg 622, room 132 to verify laser power and characteristics and then installed in the 11th floor of the Building 620 tower.

2.2.2. Clutter Testing :

2.2.2.1. MLID System : The MLID system is eye-safe at the aperture and will be raster scanned via a gimbaled mirror to build a data set. Scanned data sets of the target at the test sites will be taken with the MLID System. A co-aligned camera through the steering optics (gimbaled mirror) will be used for aiming of the MLID system. A co-aligned visible laser (item 1, 2, or 3 in Table

2) will be used to verify pointing and also used for atmospheric characterization. It will be eye-safe at the minimum range.

2.2.2.2. Frequency Modulated Continuous Wave System (FMCW) : The FMCW system shall also be eye-safe at the aperture and will be raster scanned via a gimbaled mirror to build a data set. A co-aligned camera through the steering optics (gimbaled mirror) shall be used for aiming of the FMCW system. Scanned data sets of the target at the test sites will be taken with the FMCW system. A co-aligned visible laser (item 1, 2, or 3 in Table 2) will again be used to verify pointing and also used for atmospheric characterization. It shall be eye-safe at the minimum range.

2.2.3. Laser parameters for Non-Imaging LADAR tests:

	Laser	Energy (mJ)	RepRate : pulsewidth	Eye-safe Diameter	Diameter at aperture	Wavelength	Permit	Camera
1	MLID	1	2000Hz : 10ns	0.06 m	0.1 m	2091nm	03L01	none
2	FMCW	5	Watts – CW	0.12 m	0.15 m	1555 nm	04L013	none

Table 4. Non-Imaging Test Laser Characteristics – Eyesafe Beam Diameter (waist) from LHAZ 4.2.4 diameter required for NOHD=0 at 30000s of unaided viewing.

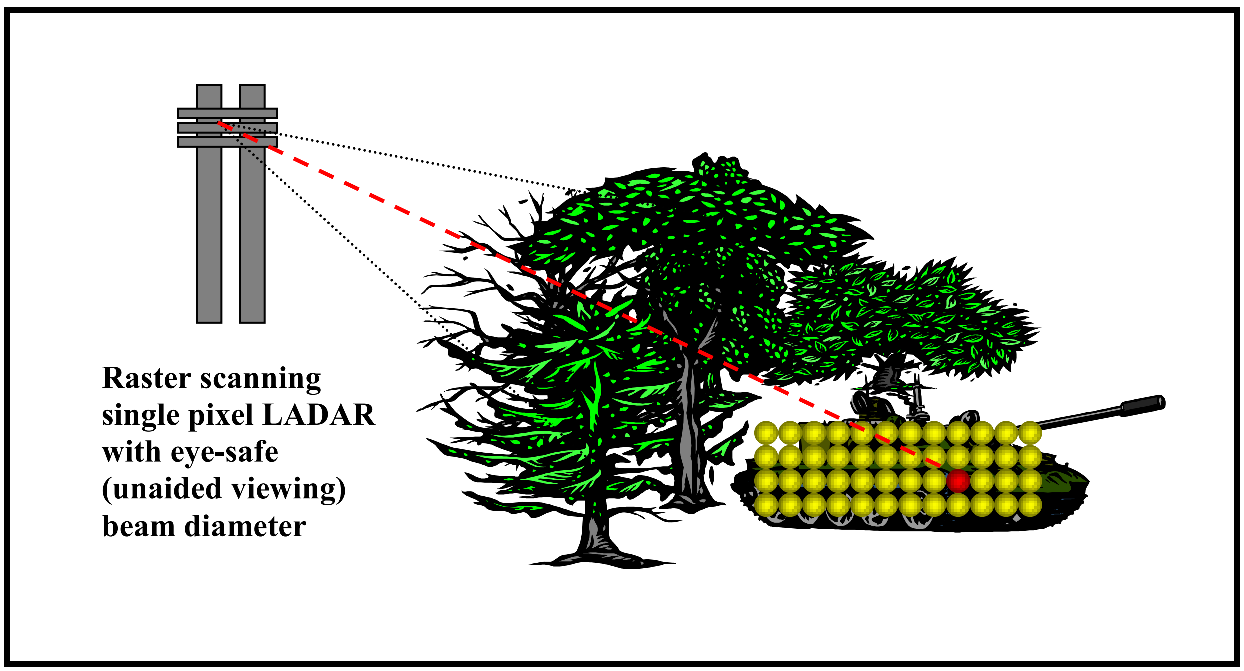


Figure 2. Scanned Non-Imaging LADAR Systems

3. ALTERNATIVES TO PROPOSED TESTING: The only alternatives to the proposed action would be to transfer the planned exercise to a more remote or dedicated laser range at one of the Test Ranges (e.g. Eglin AFB or White Sands Proving Grounds). Foliage coverage at these sites is unknown or inadequate. The desired data will contain various states of natural vegetative clutter, which would entail multiple TDYs to acquire data at the seasonal vegetative states if available. The overall costs for range use/support, TDY and equipment transportation would be prohibitive.

4. EYE-SAFETY :
   4.1. Passive Imaging : No eye-safety concerns.
   4.2. Active Imaging :
      4.2.1. Wavelengths: LHAZ results for the lasers are attached. Eye-safety will be verified by energy measurements within the 11^{th} floor laboratory and divergence measurements within the Controlled Area Test Range before testing outside the Controlled Area Test Range begins.
      4.2.2. Hours of Operation: Most testing will take place at night to take advantage of reduced solar background and better atmospheric turbulence. Limited day testing will take place during low traffic hours. Safety observers will be used to insure that inadvertent exposure is prevented.
      4.2.3. Eyewear: Workers at the source location and Safety observers at the controlled area of the test range will wear appropriate and approved laser safety goggles. Safety observers at sites out of the Controlled Area Test Range will not be required to wear eyewear because the beam will be eye-safe for unaided viewing.

OD 6+ @ 810nm
OD 6+ @ 840 nm
OD 10 @ 1064 nm

Table 5. Laser-Gard Laser Goggle LGS-YAG[Nd]GA OD Specifications

OD 2+ @ 800nm
OD 3+ @ 850-900 nm
OD 4+ @ 900-950 nm
OD 5+ @ 950-1000 nm
OD 7+ @ 1000-1600 nm
OD 5+ @ 1600-2400 nm
OD 5+ @ 2940, 9300, & 10,600 nm

Table 6. Trinity Technologies Laser Goggle 1111 OD Specifications

   4.3. Non-Imaging LADAR
      4.3.1. Wavelengths: The laser wavelengths will be >1.4μm. The pulsed (MLID, 2091nm, 1W) and continuous wave (CW, 1555nm, 5W) lasers

will raster scan the target at the desired test site. LHAZ results for the laser are attached.

4.3.2. Hours of Operation: The MLID and FMCW systems are eye-safe (unaided viewing) at the aperture. No restrictions should be placed on the time of its operation.

5. GEOMETRY:

5.1. The source location is the Building 620 11th Floor lab. The slant ranges to target sites shown in Photo 1 are calculated from GPS survey coordinates found in Table 7. Operations will be conducted on the Controlled Test Range first verifying footprint control, co-aligned camera field of view, and energy density at the target range (Site 4). The laser energy and beam diameter will be kept eye safe (not to exceed MPE) when lasing outside the controlled laser test range. The concrete balcony railing or other hard aperture stops will be used as a beam stop to ensure beam stopping at ranges less than the minimum range for eye-safe beam diameters.

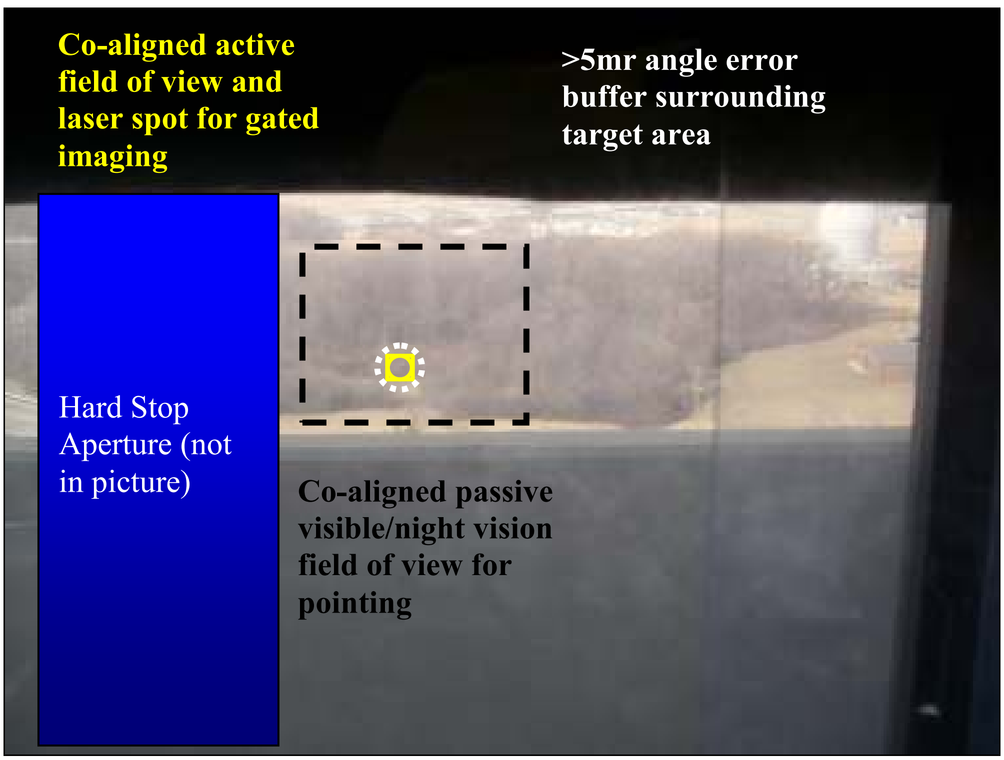


Photo 1. Laser Beam Stop

Photo 2. Aerial Photo of Test Sites

Site	Descriptor	Lat N	Long W	Altitude (m)	range m	Angle (deg)
0-11	tower 11th	39.7775	84.08294	343.5096	0	
0-13	tower 13th	39.77743	84.08297	351.4344	11.40397	
1-A	Fire Station Path A	39.77741	84.08548	301.1424	220.9926	-11.1
1-B	Fire Station Path B	39.77699	84.08585	299.9232	258.334	-9.71
1-C	Fire Station Path C	39.77709	84.08624	298.704	288.6634	-8.93
2-A	Old Road	39.77672	84.08896	285.9024	523.9692	-6.31
2-B	Opening Across Old Rd	39.77593	84.08924	287.4264	567.8624	-5.67
2-C	Opening grass near Bldg 4	39.77637	84.09225	275.5392	806.9082	-4.83
3	Test Range access Rd	39.77525	84.09253	272.4912	858.443	-4.75
4	Test Range Mid Cross Rd	39.77415	84.10412	259.08	1846.659	-2.62
5-A	Fence Area Near Bldg 4	39.77791	84.09332	267.0048	889.8839	-4.93
5-B	Storage Bldg near woods	39.77762	84.09163	273.7104	744.6558	-5.38
6	Quonset Huts	39.77964	84.09508	261.5184	1065.739	-4.41
5-C	Fence Area Nearer tower	39.77845	84.09091	277.9776	691.1281	-5.44
7	Bldg 622 Parking Lot S	39.77993	84.08553	297.7896	352.2032	-7.46

Table 7. GPS Survey of candidate test sites and Controlled Area Test Range site

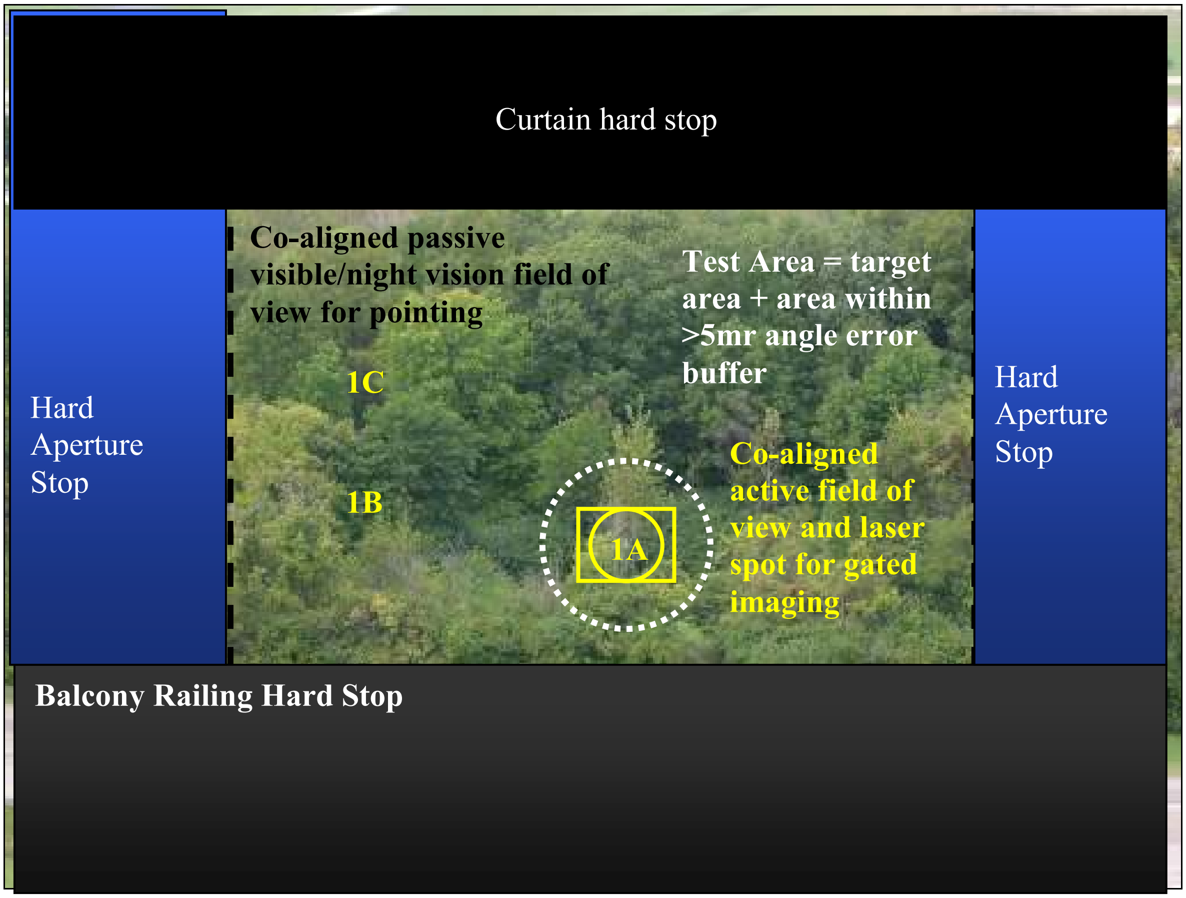


Photo 3. Fields of View of Sites 1- A, B, and C taken with beam stops in place

Site	Description	Lat N	Long W	Altitude (m)	range m
1-A	Fire Station Path A	39.77741	84.08548	301.1424	221
1-B	Fire Station Path B	39.77699	84.08585	299.9232	258
1-C	Fire Station Path C	39.77709	84.08624	298.704	289

Table 8. Site Parameters for Photo 3

6. RANGE CONTROL
    6.1. Procedure Agreement:
        6.1.1. Gated Imaging/Flash Imaging: The lasers are to be verified eye-safe for unaided viewing at the minimum range that is to be illuminated. Safety observers shall verify that no aided viewing is taking place and control access to the test area. The test area shall be defined to be the target area and area within the 5mr angle error buffer area.
        6.1.2. Non-Imaging LADAR : The MLID and FMCW laser systems shall be verified eye-safe at the aperture of the laser. Safety observers shall verify that no aided viewing is taking place and control access to the test area.
    6.2. Safety observers:

6.2.1. Active Imaging : Safety monitors with radios stationed at key locations will be used to monitor the activity of the laser test area to insure that no one other than test personnel travels through the test areas during the test period. The guards will also be equipped with radiometric instruments and shall insure that the footprints of the beams do not leave the USAF reservation. Additional backstops will be employed if necessary. The safety observers shall have complete authority for laser activity. No laser activity will begin without their approval, and operations will be halted at anytime and for any reason that they deem it necessary. Radio communication with cell phones back up will be used and lasing will terminate at any disruption in communication. Safety observers shall verify that no aided viewing is taking place and control access to the area.

6.2.2. Non-Imaging LADAR : MLID and FMCW are eye-safe at the aperture and shall be used with range personnel to control the test area. Safety observers shall verify that no aided viewing is taking place and control access to the area.

6.3. Laser Activities Log : A log of test activity will maintained during all test periods and will include all pertinent laser parameters, personnel involved, date/time, and comments on conditions or occurrences noted during testing. This log will be maintained on file for a minimum of three years after the testing.

7. SOURCE CONTROL: Source control is of prime importance to the safety solution for these tests.

7.1. Active Imaging :

7.1.1. Divergence/Footprint Control : A beam expanding telescopes shall be designed and implemented. The telescope optics shall be configured such that the minimum divergence is commensurate with the required footprint on the minimum assessable range. This divergence control shall be validated within the Controlled Area at low energy before testing outside of the Controlled Area range begins. All LADAR radiation shall terminate within the USAF reservation. Source beam stops will be used to insure foot print control. This includes lasing to ranges shorter than the minimum range, lasing areas out of the test area, and ensuring all radiation terminates within the WPAFB reservation.

7.1.2. Alignment Procedures: Proper alignment procedures shall insure that the precise knowledge of the laser pointing is known. The prime systems shall co-boresighted with a (unaided viewing) eye-safe visible CW laser as well as passive imagers. All pointing aids shall be validated within the Controlled Area prior to testing outside the Controlled Area.

7.1.3. Energy Verification: Energy will be measured in the laboratory. Observers with radiometers will be positioned in the beam to verify energy densities on the ground, first at the controlled area and then the other test sites.

7.1.4. Footprint Verification: Detectors designed to quickly determine beam positions will be used to locate and monitor the extent of the beam footprint. The imagers in the tower shall confirm these footprints with the active imaging data.

7.2. Non-Imaging LADAR:

7.2.1. Divergence/Footprint Control : The divergence control shall be validated on the Controlled Area Range at low energy before testing outside of the Controlled Area range begins. All LADAR radiation shall terminate within the USAF reservation.

7.2.2. Alignment Procedures: Proper alignment procedures shall insure that the precise knowledge of the laser pointing is known. The prime systems shall co-boresighted with a (unaided viewing) eye-safe visible CW laser as well as passive imagers. All pointing aids shall be validated within the Controlled Area range prior to testing outside the Controlled Area.

7.2.3. Footprint Verification: The laser safety observers will verify that no specular reflection surfaces exist within the coaligned camera FOV (passive verification of beam footprint) prior to lasing the target area. The laser beam will lase the area at reduced power while the safety observers determine that the footprint is within the desired test area. The laser safety observers shall use detectors to verify beam position on target during the tests.

8. Attachments

8.1. Permit #04L014 for the Difficult Targets Test Plan signed by the WPAFB LSO.

8.2. LHAZ data sheets.

8.3. Check List for the Difficult Targets Test Plan.

8.4. Target Area Photos : showing target areas and buffer angles for all test sites.

COORDINATION/APPROVAL

KEVIN MCCAMEY
AFRL/SNJ, Deputy Chief

RUSSELL SHERER
AFRL/SNOO, Safety Officer

APPENDIX B: TEST PLAN FOR PRELIMINARY STUDY NUMBER ONE

Testing will be conducted in a private room with as few distractions as possible. Subjects will be videotaped to capture their verbal commands and actions. The concept of a concurrent protocol will be explained to them in the following way:

"You will be shown several sets of images. I would like you to look at each set of images, and try to identify the object or scene. Explain what makes you think the object is what it is, as if you were explaining it to a child. Describe all properties of the scene that you can discern. Think out loud, and describe your thought processes, uncertainties, and opinions."

The following simple IR image will be shown to the subject for practice:

(Image courtesy Russell Hardie, Ph.D.)

The subjects will be asked to identify the object in the image, and to provide reasons why they believe that assertion. They will be prompted, as necessary, to describe their thoughts. This exercise should allow the users to understand the concept of concurrent protocol.

Once the users are comfortable with concurrent protocol, the experiment will begin. The users will be given the option to view the images one at a time (fullscreen) or simultaneously (split screen). Four sets of images will be shown. The order of presentation will be a between-subjects variable determined by a Latin square design. Images from the Phoenix (3-5 µm, MW FLIR, 500 mm focal length lens), Jade (8-12 µm, LW FLIR, 200 mm focal length lens), and standard digital camera will be used. Active imagery was not available for these data sets, and will not be used.

The first image set consists of images[2] of a woodchipper that has been running:

[2] All images were taken as part of the Difficult Targets Test Plan, conducted in AFRL/SNJM.

Hot woodchipper—Phoenix

Hot woodchipper—Jade

Hot woodchipper—visual

The second set of images shows the same woodchipper after it has been turned off for one day:

Cold woodchipper—Phoenix

Cold woodchipper—Jade

Cold woodchipper—visual

The third set of images shows the Dayton skyline on a foggy day:

Dayton skyline—Phoenix

Dayton skyline—Jade

Dayton skyline—visual

For the fourth set of images, no visual data was available. The FLIR images show two men behind trees:

Men behind trees—Phoenix

Men behind trees—Jade

As part of this fourth set of images, movies of the men behind the trees will be shown following analysis of the still images.   This will allow the subjects to provide information on how they process images with a time variable.

APPENDIX C: TEST PLAN FOR PRELIMINARY STUDY NUMBER TWO

Subjects for this phase of testing will be the same as those in the previous phase. Testing will be conducted in a private room with as few distractions as possible. Subjects will be videotaped to capture their verbal commands and actions. The procedure will be explained to them in the following way:

"This experiment will be similar to the previous one you participated in a few months ago. You will be shown several sets of images. I would like you to look at each set of images, and try to identify the object or scene. Explain what makes you think the object is what it is, as if you were explaining it to a child. Describe all properties of the scene that you can discern. Think out loud, and describe your thought processes, uncertainties, and opinions. Each set of images will be displayed for a fixed amount of time, after which it will disappear. Feel free to continue talking after the image is gone. The time between images will vary, as well. While you are looking at the images, you will also be required to perform some other tasks.

The tasks are included in the SynWin program. SynWin consists of four tasks, as shown in this figure:

The first is a memory task. You will be shown a series of letters in this top box at the beginning of the session. Memorize the letters—they will disappear after 5 seconds. When a letter is displayed in this bottom box, your task is to click "YES" if the letter was shown to you in the original list, or "NO" if it was not included in the original list. You will get ten points for a correct answer, and you will lose ten points for an incorrect answer. You will hear a "clank" if the answer is incorrect. If you need a reminder of the original letters, you can click on the top box. However, you will lose ten points for doing so.

The second task is arithmetic. There is no time limit on this task. Simply do the arithmetic problem, and use the scroll buttons below to indicate your answer. You can scroll either up or down, and the numbers wrap (i.e., clicking "-" from zero will give you a nine). You will get ten points for a correct answer, and you will lose ten points for an incorrect answer. You will hear a "clank" if the answer is incorrect.

The third task is visual monitoring. You need to click the fuel gage to refill your fuel tank. Ten points will be awarded if you click the meter when the needle is in the red zone. You can click the meter at any time, but the points will be proportionally less if the needle is outside the red zone. If the needle is allowed to reach zero, you will hear an "uh-oh" sound. Fifty points will be deducted for each second the needle is at zero.

The last task is auditory monitoring. You will hear a tone every 5 seconds. When the tones are low-pitched, do nothing. When the tone is high-pitched, click the "ALERT" button. You will receive ten points for a correct hit, and you will lose fifty points for a false alarm (i.e., clicking the button on a low-pitched tone).

Following the active part of the experiment, you will be asked a series of questions about your experience."

The subjects will first be allowed to practice using the SynWin program. They will be instructed to get wrong answers in the arithmetic and memory, and to let the fuel gage run to zero in the first minute of the practice session, so they can hear the resulting auditory cues. When they feel they are comfortable with SynWin (a minimum of one 11-minute session will be required), they will then be allowed to practice the whole experiment, including images used in the previous experiment.

Once the users are comfortable with the experimental procedure, the actual test will begin. Five sets of images will be shown. The order of presentation will be a between-subjects variable determined by a Latin square design. Images from the Phoenix (3-5 μm, MW FLIR, 500 mm focal length lens), Jade (8-12 μm, LW FLIR, 200 mm focal length lens), and standard digital camera will be used. Active imagery was not available for these data sets, and will not be used.

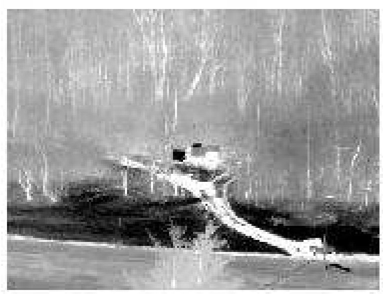
The preliminary results of the first test show that the visual image is most important to the subjects. Therefore, the images will be displayed with the visual on top, and the Jade and Phoenix images below it.

The orientation of some of the image sets will be rotated, based on the recommendation of Lt. Col. Brian Ewert. The relative order of presentation for similar images is based on the realistic scenario that a pilot would fly over a scene, double back and fly over again. The Latin square design keeps the relative order of these events the same, therefore allowing the scenario to remain realistic.

Some of the image sets in this session will consist of a single image. This allows for study of the possible situation where two of the sensors have been incapacitated, and also allows investigation of how subjects interpret single images under stress.

The time allowed for each image was determined using Matlab's random number generator using a standard Normal distribution with a mean of 30 seconds and a standard deviation of 20 seconds (values determined in interview with Lt. Col. Brian Ewert). In between each image set, a blank screen will be displayed. The time allotted for each blank screen was determined in the same way, with a mean of one minute and a standard deviation of 15 seconds.

The first set of images[3] shows a Humvee after it has been running, with a wide field of view. A flame-sprayed aluminum (FSA) target is located in front of the front wheel of the vehicle. No visual image is available, so the space normally occupied by the visual image is blank:



Wide FSA hot Humvee

[3] All images were taken as part of the Difficult Targets Test Plan, conducted in AFRL/SNJM.

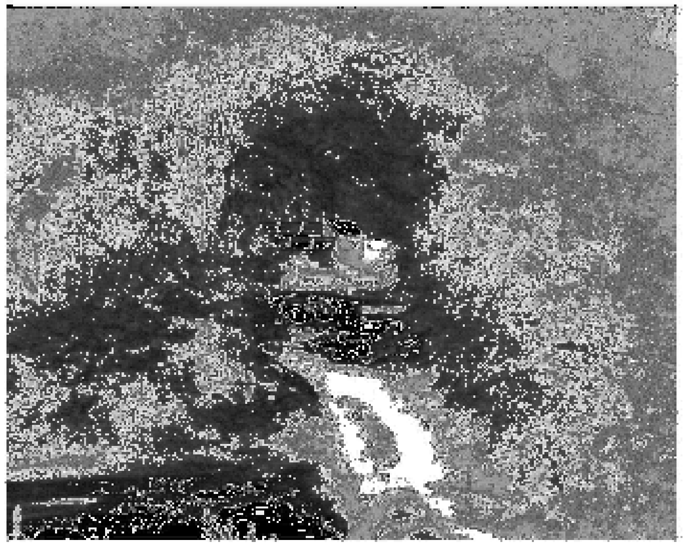
The second set of images shows the same Humvee after it has been running, with a wider field of view and no FSA target. No visual image is available, so the space normally occupied by the visual image is blank. The orientation of this image is also rotated 180 degrees:

Wide hot Humvee rotated

The third set of images shows the Humvee in a different location at a wide field of view with no FSA target.

Wide Humvee

The fourth condition is Phoenix image of a Humvee partially obscured by foliage. The Humvee has been running, and was recently driven into position.



Narrow hot Humvee Phoenix

The fifth condition is a visual image of the Humvee in a different location, with a flame-sprayed aluminum target.

Narrow Humvee visual

The final condition is a Jade image of a ten-wide trailer and a 2.5-ton M35 taken at a wide field of view. The vehicles had been turned off for several hours at the time the imagery was taken.

Wide cold 2.5-ton M35 and 10-wide Jade

Following the active part of the experiment, the following questions will be asked of the subjects in a semi-structured interview format.

1. How would you describe your experience overall with this testing session?
2. How did this session compare to the last session?
3. Did you feel overwhelmed or stressed out?
4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?

APPENDIX D: TEST PLAN FOR EMPIRICAL EVALUATION STUDY

The following test plan was approved by the Wright State University and Wright Site (Wright-Patterson Air Force Base) Institutional Review Boards.

Empirical Evaluation of a Cognitively-Engineered Multisensor Data Fusion System Protocol F-WR-2006-0015-H

1. Principal Investigator

Amanda Muller/Contractor/Anteon, AFRL/SNJM, (937)775-5044, muller.4@wright.edu

2. Associate Investigator

S. Narayanan, Ph.D./Professor and Chair/Wright State University Department of Biomedical, Industrial, and Human Factors Engineering, (937)775-5044, s.narayanan@wright.edu

3. Medical Consultant or Monitor

Jeffrey Bidinger/Major/U.S. Air Force, AFRL/HEPG, (937)255-4563, jeffrey.bidinger@wpafb.af.mil

4. Facility/Contractor

Protocol will be carried out at the Aircrew Performance and Protection Branch, Building 33, 2215 First Street, Wright-Patterson Air Force Base, OH 45433-7947.

5. Objective

The purpose of this study is to empirically evaluate a multisensor data fusion system to ensure that it is functioning as intended. Human subjects must be used in the evaluation, because in a cognitively-engineered system, it is the actual function of the system, rather than the theoretical or ideal function, that is important (Hollnagel & Woods, 1999). Three basic research questions will be addressed in the proposed study:

1. Is there a significant difference in operator trust between solutions obtained using raw images and those obtained using the multisensor data fusion system?
2. Is there a significant difference in time between solutions obtained using raw images and those obtained using the multisensor data fusion system?
3. Is there a significant difference in accuracy between solutions obtained using raw images and those obtained using the multisensor data fusion system?

6. Background

Human operators in battlefield situations are bombarded with substantial amounts of information and expected to make near-instantaneous decisions. Particularly with the advent of modern information networks, the pace of war has significantly increased, forcing human operators to make decisions within increasingly small windows of opportunity. The large amounts of information, coupled with short decision times and the need to reduce the potential of making incorrect decisions, create the potential for information overload and loss of operational advantage.

The problem of information overload and the struggle for operational advantage are especially prominent in military applications involving imagery from multiple sensors. As the amount and complexity of image information grows, decisions based on multisensor imagery become more difficult, error-prone, and time consuming.

Computer-based algorithms for fusing pertinent sets of imagery have proven useful for alleviating this problem (Li & Wang, 2002). Fusing the images from the different sensors, while enhancing the supplemental information contained in the images, can serve to decrease the operator's workload and improve overall performance by making targets more visible (Fay et al., 2001).

However, research in multisensor data fusion has focused primarily on computation and algorithm development. Little has been done to cognitively couple multisensor data fusion systems with their operators. Previous operations research has shown that interactive optimization, rather than strict focus on algorithmic issues, helps address practical problems in human-computer systems (Scott et al., 2002). However, even in interactive optimization research, the human operator has been considered as an afterthought (Nulty & Ratliff, 1991; Scott et al., 2002). In high-stress situations, it is vitally important that these systems are designed according to cognitive principles, with the human operator as a central element in the design process (Ardey, 1998).

To this end, a system is being designed to fuse imagery from different types of sensors (visible and infrared) to allow a pilot to make decisions more quickly and accurately. This system should be extremely effective in reducing operator error in military situations.

7. Impact

Prior research has shown that cognitive engineering results in better-performing decision aids. Since a multisensor data fusion system is a decision aid, it follows that such a system should be designed according to cognitive principles. However, little work has been done in this area. The goal of the proposed project is to assist the warfighter by creating a system which will allow faster, more accurate interpretation of images from multiple sensors.

The contributions of this research project will be threefold: a model of how humans make decisions from multisensory data, a model-based algorithm and support system, and an empirical evaluation of the system as a whole. This study represents the third and final contribution. Currently, little research is being conducted to understand the cognitive aspects of multisensor data fusion involving infrared and laser radar. The results of this study will provide a better understanding of how humans function cognitively when presented with images from different types of sensors. Additionally, it will provide a baseline for future research in multisensor data fusion and assisting the warfighter in high-stress conditions. The system has the potential to prevent loss of life and materiel for the Air Force.

8. Experimental Plan

a. Equipment:

The Aircrew Performance and Protection Branch (AFRL/HEPG), located at Wright Patterson Air Force Base, currently maintains two static FIGHTER JET simulator cockpits. Both cockpits are reconfigured FIGHTER JET cockpits with 13 degree seatback angles. The audio communications between these cockpits are conducted using General Dynamics MODIOS Voice Communicator software operating over DIS networking.

Cockpit 1 utilizes three separate personal computers (PC) with distributed functions. The first computer operates the flight simulation and instrument panel simulation. The NAWC F-18 instrument panel is presented on a 24-in 16:9 liquid crystal display (LCD). The second computer is responsible for generating the out the window (OTW) graphics. It also generates the Heads-Up Display (HUD) symbology. The OTW graphics are projected on a dome display (Elumens Vision Station) offering approximately 120 degrees field of view (FOV). The projection is driven by an Epson LCD projector. The graphics software for the display is Quantum 3D (CG2) Mantis software with DIS connection to the flight simulation. The software used to correct for the dome shape is written into the Mantis graphics software. The HUD display is projected over the OTW dome display and presents MIL-STD- 1787B symbology. This is projected by a separate Epson LCD projector. The third computer is utilized to connect the simulation with the SAF simulation allowing multiple users to be connected to the same battlespace.

Cockpit 2 differs from Cockpit 1 in only one aspect. Cockpit 2 utilizes a flat OTW projection onto a standard white projection screen. The software, cockpit layout, communications, HUD, and instrument panel in Cockpit 2 are identical to Cockpit 1.

b. Subjects:

Subjects will be active-duty Air Force fighter pilots currently stationed at the Air Force Institute of Technology (AFIT). Twelve subjects will be recruited. Attempts will be made to include at least one female subject, thereby representing the approximate ratio of male to female pilots in the Air Force. Since most active-duty pilots at AFIT hold the rank of Major, subjects will likely range in age from 30 to 40 years. No special subjects (45 CFR subparts B-D) will be included. Subjects will not be offered compensation. The time commitment for each subject will be the duration of the experiment (see below). No screening or special tests will be required; however, subjects will be asked to supply a current AF Form 1042 to establish that they are free from any medical deficiency (including vision defects). Subjects will be recruited via email.

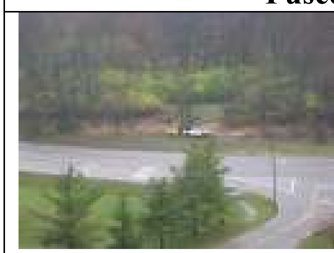
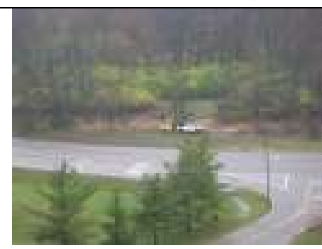
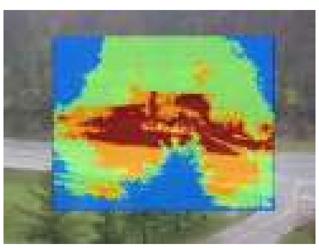
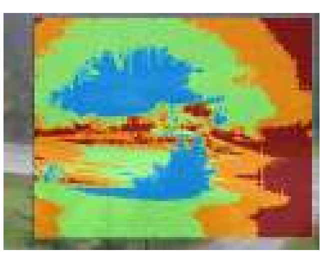
c. Duration:

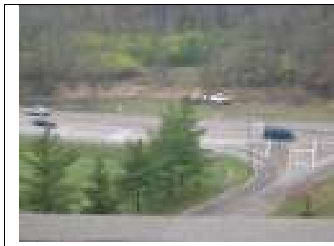
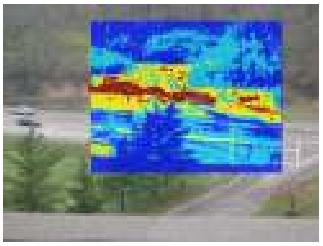
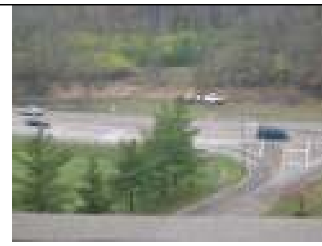
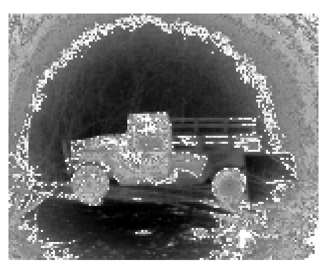
The duration of the experiment will be approximately one hour.

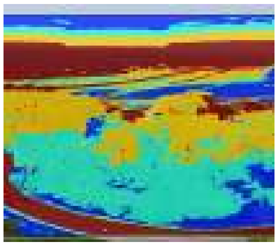
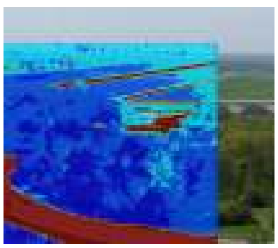
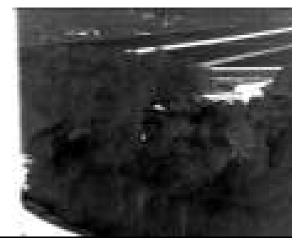
d. Description of experiment, data collection, and analysis:

Subjects will be asked to simulate flying a fighter jet aircraft in a combat scenario. While performing the flight mission, they will also be asked to verbally identify targets displayed. Subjects will be asked to practice the test protocol with a ten-minute scenario They will be allowed to repeat the practice session as many times as they wish until they are comfortable with the procedure. Image display will be a between-subjects variable, with half the subjects viewing the multisensor fusion user interface, and half viewing the same images displayed without the interface (unfused).

The following images will be shown, with the order of presentation varied using a Latin square design:

Fused		**Unfused**	
	Cold woodchipper – visual		Cold woodchipper – visual
	Cold woodchipper – visual + Jade		Cold woodchipper – Jade
	Cold woodchipper – visual + Phoenix		Cold woodchipper – Phoenix

 Hot woodchipper – visual  Hot woodchipper – visual + Jade  Hot woodchipper – visual + Phoenix	 Hot woodchipper – visual  Hot woodchipper – Jade  Hot woodchipper – Phoenix
 Humvee – visual  Humvee – visual + Jade  Humvee – visual + Phoenix	 Humvee – visual  Humvee –Jade  Humvee – Phoenix

	M5 – visual		M5 – visual
	M5 – visual + Jade		M5 –Jade
	M5 – visual + Phoenix		M5 –Phoenix

Following the simulated scenario, the subjects who viewed the unfused images will view a videotape of their simulator session. They will be asked to rate their trust in their analysis of the targets in the images, and to explain their thought processes in reaching their target identity conclusions. The subjects who viewed the fused images will be asked the following questions:

- On a scale from 1 to 5 (with five being extremely confident, four being somewhat confident, three being neutral, two being somewhat unconfident, and 1 being extremely unconfident), what is your confidence in your target identifications?
- What is your overall impression of the imagery system that you just used?
- Did the way in which the images were presented help you to determine what the target was?
- Would a system like this make your job in the cockpit easier?
- If you could change anything about the system, what would it be?
- How does this system compare to any automated targeting systems you may have used in the past?

These subjects will also be asked to view the unfused images, and explain the thought process they would use to identify the targets in the images.

Other data collected will be the time taken to identify the targets in the images (recorded using a stopwatch), and the accuracy of the model of how humans make decisions from multisensory data. Data from subjects viewing the fused images with the user interface will be compared to data from subjects viewing the unfused imagery using parametric and nonparametric methods.

e. On-site monitoring:

All tests will be run by the principal investigator. Due to the low risk of the protocol, on-site medical monitoring will not be performed.

f. Safety precautions:

Subjects will have the ability to stop the experiment at any time for any reason.

9. Medical Risk Analysis

Medical risks will be minimal, but may include nausea and/or headache due to viewing the simulated scene. Slight neck strain is also possible due to the size and orientation of the display.

10. References

a. Ardey, G. F. (1998, 14-17 Sept. 1998). *Fusion and Display of Data According to the Design Philosophy of Intuitive Use.* Paper presented at the Sensor Data Fusion and Integration of the Human Element, Ottawa, Ont., Canada.

b. Fay, D. A., Verly, J. G., Braun, M. I., Frost, C., Racamato, J. P., & Waxman, A. M. (2001, April 16-17, 2001). *Fusion of multi-sensor passive and active 3D imagery.* Paper presented at the Enhanced and Synthetic Vision 2001, Orlando, FL.

c. Hollnagel, E., & Woods, D. D. (1999). Cognitive systems engineering: new wine in new bottles. *International Journal of Human-Computer Studies, 51*(2), 339-356.

d. Li, S., & Wang, Y. (2002). Multisensor data fusion and its applications. *Advances in Modelling & Analysis B: Signals, Information, Patterns, Data Acquisition, Transmission, Processing, Classification, 45*(2), 19-37.

e. Nulty, W. G., & Ratliff, H. D. (1991). Interactive Optimization Methodology for Fleet Scheduling. *Naval Research Logistics, 38*, 669-677.

f. Scott, S. D., Lesh, N., & Klau, G. W. (2002, 20-25 April 2002). *Investigating human-computer optimization.* Paper presented at the Proceedings of CHI2002. ACM SIGCHI(Special Interest Group on Computer-Human Interaction). Minneapolis, MN.

APPENDIX E: PRELIMINARY STUDY NUMBER ONE—CONCURRENT PROTOCOL RESULTS

Subject 1 (1Lt., Male)

Condition 1 (Hot woodchipper)

- ◻ Starts with visual image—does it full screen. Uses color of trees and grass to discern the season. Says scene is of "the flightline down by the museum."
- ☐ Says the only new info in IR is the dirt—hot—otherwise, compares all features to the visual image
- ☐ Was able to determine that the cars are moving due to the heat signature
- ☐ Compares woodchipper to the dirt, and concludes that it is hot due to solar energy
- ☐ Uses context, color, and shape to ID highway cone

Condition 2 (Cold woodchipper)

- ☐ Thinks tree colors are different [mistake]
- ☐ Uses phx to ID the haze
- ☐ Uses phx to ID vehicle tracks
- ☐ Finds the other equipment behind woodchipper

Condition 3 (Dayton skyline)

- ☐ Visual first, again
- ☐ Compares to previous image
- ☐ Uses prior knowledge of the area to discern viability
- ☐ Zooms in on image to get more detail
- ☐ Uses context—since road is wet, finds standing water
- ☐ Picks out similar features to get FOV

Condition 4 (Men behind trees)

- ☐ Without visual, flips back and forth between IR images
- ☐ IDs trees
- ☐ IDs MMO—road/line/pipe
- ☐ Can't ID people (says the more he looks, the more they look like blobs)

Condition 4—movie (Men behind trees)

- ☐ Can ID 2 people in phx movie
- ☐ Uses the fact that they're moving together, bending down, and walking away separately to discern that they're dropping something off

Subject 2 (Lt.Col., Male)

Condition 2 (Cold woodchipper)

- ☐ Looks at 3 images simultaneously
- ☐ Immediately tries to recognize where the scene is—goes from big picture to smaller details
- ☐ Can't tell whether woodchipper has been running
- ☐ Has trouble finding wagon behind woodchipper
- ☐ Uses color of the trees to ID the season
- ☐ Finds puddle in visual and confirms in IR

Condition 3 (Dayton skyline)

- ☐ First tries to recognize the scene
- ☐ Uses Jade to ID downtown
- ☐ Uses visual to tell that it's wet
- ☐ Since FOV is different—he says it's harder—wants a landmark to "merge" the images
- ☐ Focuses on "bright" spots—lots of contrast makes him interested

Condition 4 (Men behind trees)

- ☐ Thinks they're the same image with different magnification
- ☐ IDs fall season by lack of leaves on trees
- ☐ Focuses on linear object
- ☐ Finds bright spots, but can't ID them—definitely thinks there's something there—guesses it's an SUV

Condition 4—movie (Men behind trees)

- ☐ Phx—IDs 2 individuals
- ☐ Phx—IDs climbing into truck
- ☐ Jade—Sees guy standing and moving slowly
- ☐ Able to ID men right away
- ☐ Motion catches eye

Condition 1 (Hot woodchipper)

- ☐ Relates this image set to previous
- ☐ Hones in on visual first
- ☐ Jade—says that WC has been running
- ☐ Hones in on Jade second
- ☐ Pixellation (noise) doesn't bother him
- ☐ Can identify type of vehicle in visual
- ☐ Can ID gater in visual
- ☐ In visual, uses shape, grill, wheel openings, to ID truck as GM vehicle
- ☐ Can't type vehicle in IR

Subject 3 (1Lt., Male)

Condition 3 (Dayton skyline)

- ☐ Looks at visual first (he says “color one”)
- ☐ Foreground is only detail that can be gleaned from color
- ☐ First IDs the location from prior knowledge
- ☐ Uses shape to ID buildings
- ☐ Uses context, shape to ID cars
- ☐ Uses color on trees to ID season
- ☐ Uses color and location to ID stop sign
- ☐ Jade—Uses straight lines to ID roads—says they’re “too straight to be natural”
- ☐ Jade—uses to make out city
- ☐ Jade—IDs skyline
- ☐ Phx—says can <u>definitely</u> tell the roads in this one
- ☐ Uses visual to tell it’s a hazy day

Condition 4 (Men behind trees)

- ☐ Looks at one at a time and flips back and forth
- ☐ Uses “long straight thick jagged lines crisscrossed with skinny jagged lines” to ID trees
- ☐ Uses straight line to ID MMO, but can’t tell what it is (also that it’s elevated from the ground around it)

Condition 4—movie (Men behind trees)

- ☐ Jade—IDs someone walking
- ☐ Jade—fits “shape of person in the distance”
- ☐ phx—Thinks it’s a person and his reflection since they move together
- ☐ Once he IDs the truck, can start making out the wheels, etc.

Condition 1 (Cold woodchipper)

- ☐ In jade—sees “splotchy” bright spots on vehicles, making him think it’s running and not just reflected light

Condition 2 (Hot woodchipper)

- ☐ Says can’t tell on visual, but on IR can see vehicle tracks going back into woods
- ☐ In IR, sees that top of vehicle is hotter than underneath

Subject 4 (2Lt., Male)

Condition 4 (Men behind trees)

- ☐ Trees IDed by solid trunk and patches of leaves multiplied several times
- ☐ Uses heat signature differences to identify anomalies such as the path through the woods
- ☐ Can't decide if the differences between the two images are due to changes in shade or hardware differences

Condition 4—movie (Men behind trees)

- ☐ Immediately notices the people in jade—he didn't notice them in still
- ☐ IDs person based on size relative to surroundings, two legs (shape) and the way he's moving
- ☐ Views movies full screen
- ☐ Phx: IDs people based on body mvmts, legs, arms
- ☐ Can tell movies are sped up/slowed down
- ☐ Uses the fact that they're carrying the object together to discern that it's heavy

Condition1 (Hot woodchipper)

- ☐ Looks at all 3 full screen, then starts with "the most obvious one"
- ☐ First states "it's an intersection, but I don't recognize it"
- ☐ IDs "your car, a kidnapper van" [relates to known things]
- ☐ Thinks it's overcast b/c there are no shadows—not noon because it's not sunny
- ☐ Thinks car is turning left because of angle. Knows it's running because of heat signature on the engine. Says "if it was moving, I'd be able to tell more"
- ☐ Mistakenly thinks it's raining
- ☐ IDs machinery (doesn't know what it is) as being "on" because of heat signature
- ☐ Doesn't understand why there are no people near the machine that's on

Condition 2 (Cold woodchipper)

- ☐ Notices that the truck has moved
- ☐ Uses info from other picture and notices that trees are missing to discern that the machine is a woodchipper—also, the fact that the machine doesn't move, because woodchippers don't move
- ☐ Most info is discerned from visual, then added to from IRs—big picture first, then details
- ☐ IDs that machine isn't running
- ☐ Notices that the ground is warmer than the air
- ☐ Thinks from IR that it's dark out

Condition 3 (Dayton skyline)

- ☐ Immediately IDs the base, AF Museum, Hangar 4, Gate 22B, and Loop Rd.
- ☐ Looks at Jade next to see buildings
- ☐ Doesn't recognize the same area right away in Jade
- ☐ IDs that jade and phx are same basic area
- ☐ Again, thinks it's dark
- ☐ Confused by halo in Jade [could be taken out digitally]

Subject 5 (1Lt., Male)

Practice 1 (Man in front of town houses)

- ☐ Uses context to ID sidewalk, also shape, straight lines
- ☐ Can't tell if it's day or night from IR—thinks it's night because of lights, but thinks that it could just be reflectors behind the lights causing the glow [visual would be able to tell him]

Practice 2 (People on golf course)

- ☐ IDs people by shape
- ☐ Focuses on bright spot and tries to figure out what it is (sun, moon, star, plane?)

Practice 3 (Man with a can)

- ☐ IDs can with shape (rounded part with lip), cold, and because of the way he's holding it
- ☐ IDs t-shirt by collar, folds, no shirt on his arms, no buttons or zipper

Condition 1 (Hot woodchipper)

- ☐ Goes to visual image first
- ☐ Says "there's people here clearing out…well, there's no people here now, but there must have been because there's a woodchipper"
- ☐ IDs person after woodchipper
- ☐ Uses color of trees and lack of leaves to ID season as late fall
- ☐ Says it's not too cold because person is wearing a tee shirt and running
- ☐ Uses phx to find street light and syas you can see it well, then goes back to visual and finds it again on road
- ☐ Wonders why paint isn't reflecting—concludes it's shot with a longer wavelength, and goes from diffuse to specular when looking at it off-angle
- ☐ Says he's trying to see if he gets "any better information from jade or phx, then sees tracks
- ☐ Finds tracks in both IR images—says he can't see them in visual image
- ☐ Said he looked at IR images to try to find more info that's not in visual
- ☐ Flips back and fort between images

Condition 2 (Cold woodchipper)

- ☐ IDs that little truck has moved
- ☐ Notices difference from last time in truck—didn't mention truck's heat signature in the last condition
- ☐ IDs that one of the highway cones is missing
- ☐ Focuses on similarities and differences with previous images
- ☐ First flips back and forth between all three, then looks at jade and visual side-by-side
- ☐ Notices the artifacts—corners are dark in jade and light in phx
- ☐ Notices differences in resolution

Condition 3 (Dayton skyline)

- ☐ IDs it as the same intersection from "the things that I noticed from the other one," including truck and chipper, the y-curve of the road, and the guard rail, light post, and red trees
- ☐ IDs weather as overcast
- ☐ Says it's raining or just rained because of the color of the road, "general look of the sky"

- ☐ At first stays it doesn't appear to be the same FOV, but then uses double runway to find FOV between visual and IR images
- ☐ Uses the ability to go through the clouds to determine something about the imaging—can use wavelength to find transmissivity of atmosphere
- ☐ Says longest wavelength lets you see city, and darkness of the road shows it has gone specular rather than diffuse

Condition 4 (Men behind trees)

- ☐ Looks at jade and says initial reaction is that we're under an overhang
- ☐ IDs a road/guardrail due to straight line
- ☐ Uses variations in color and edge to ID a path through trees
- ☐ Since he can't see the path in the other image, he concludes the camera must be closer
- ☐ Uses shape to ID trees and branches
- ☐ Says "same season as before," but just from these images, he can't tell for sure—thinks it could be late fall because sees a few leaves, but trees are mostly bare
- ☐ Thinks line across the top could be an artifact

Condition 4—movie (Men behind trees)

- ☐ IDs as the same view as before
- ☐ Says "something is moving"
- ☐ Jade first—uses the silhouette to ID as person
- ☐ Can't ID frame rate—wants to see branches blowing or some other reference to determine frame rate
- ☐ In phx, IDs 2 people—thinks they're working together because they move in sync and they're facing each other—therefore thinks what they're moving is heavy or awkward
- ☐ Since see leaves moving on trees, confirms it's late fall
- ☐ Thinks they're climbing into a truck—because they're stepping up at first thinks it's stairs, but as he looks "over and over again" he sees shape of truck—tires, etc. He was focused on the people first, but then puts the climbing together with the actions of the people and starts to see the shape of the truck. Puts it together with one of the men disappearing—he must move behind the truck. He then confirms his initial suspicion that there is a guardrail because the truck must be on a road.
- ☐ Looks back at jade to see if he can confirm the presence of the truck, but can't see it.

Subject 6 (2Lt., Male)

Practice 1 (Man in front of townhouses)

- ☐ Uses shape to ID person and different color to ID jacket
- ☐ When told practice image is thermal, gets more info from it

Practice 2 (People on golf course)

- ☐ Bright spots tend to grab attention—if they are camera artifacts, they can be removed

Practice 4 (Trees)

- ☐ IDs tree trunks from leaves (context)

Condition 2 (Cold woodchipper)

- ☐ Looks at visual and phx and jade one after another, then places visual next to jade. Can't tell if 2 IR are different from each other, so then puts 2 IR side by side. Then zooms in on each. Then focuses on visual—IDs woodchipper based on seeing one before. Then checks IR and says he can't tell if anything has been running. Zooms in on visual, IDs trailer
- ☐ Uses visual to say truck is off the road
- ☐ Uses 2 roads and road markings ("straight only, turn only") to ID intersection
- ☐ Uses color of leaves to ID season as fall
- ☐ In phx, says it looks like sun might be off to the right (from bright spot)
- ☐ IDs type of intersection /road from lane markings

Condition 3 (Dayton skyline)

- ☐ Looks at all 3 first
- ☐ IDs same intersection as before in visual
- ☐ Counts the visible cars
- ☐ Notices fog
- ☐ Uses runways to ID the FOV between jade and visual
- ☐ IDs buildings in jade
- ☐ Thinks the differences in the background on phx are mountains
- ☐ IDs hangar in IR and verifies in visual

Condition 4 (Men behind trees)

- ☐ Uses shape—trunks, branches, leaves—to ID trees
- ☐ IDs a fence running through trees—a fence because he can't imagine anything else going through trees

Condition 4—movie (Men behind trees)

- ☐ In phx, IDs 2 people
- ☐ Sees a glare/artifact in trees
- ☐ Can ID people in jade after seeing phx

Condition 1 (Hot woodchipper)

- ☐ Scrolls through all 3 images
- ☐ IDs "same intersection, same truck"
- ☐ IDs that truck and woodchipper are hotter than in previous pictures
- ☐ IDs white spots as noise

Subject 7 (Capt., Female)

Condition 3 (Dayton Skyline)

- ☐ Scrolls through all 3 first
- ☐ Hones in on IR first and IDs roads/runways (wide, straight clear), trees—recognizes location
- ☐ IDs city in jade

Condition 4 (Men behind trees)

- ☐ Dark, dense branches to ID trees
- ☐ Sees leaves near the tops—branches "stick out from the trunk part"
- ☐ IDs long, straight thing running across trees but can't ID
- ☐ Says image must have been taken close to trees because you can't see any field before
- ☐ Looks at images side by side

Condition 4—movie (Men behind trees)

- ☐ Watches first movie a few times, then switches to phx
- ☐ In phx, IDs 2 people—says line is in front of them
- ☐ IDs as people because of limbs, move like people (not animals), seem to be working together moving something
- ☐ IDs more of leaves because they are moving

Condition 1 (Hot woodchipper)

- ☐ IDs intersection in IR
- ☐ IDs truck and "mulcher"
- ☐ IDs intersection from roads, stop sign

Condition 2 (Cold woodchipper)

- ☐ IDs same intersection, but notices no vehicles
- ☐ IDs dirt road from phx and jade
- ☐ Says everything else is the same

Subject 8 (2Lt., Female)

Practice 1 (Man in front of town houses)

- ☐ Says he's tall because of relationship with car behind him
- ☐ Says it's a man because he's not curvy
- ☐ Says man looks "upset" because his hands are out

Practice 3 (Man with a can)

- ☐ Doesn't think it's cold because he's wearing a short-sleeved shirt

Practice 4 (People on golf course)

- ☐ Says it looks like a person sitting on a dog (later revealed that she was worried about putting her dog in a kennel)

Condition 4 (Men behind trees)

- ☐ Zooms in on phx, then on jade—goes back and forth
- ☐ IDs "a lot of trees" by branching out at top, and there's a lot of them, and fallen branches "makes it look like the woods"
- ☐ Confused by the top of the Jade image
- ☐ IDs season as winter because there's not a lot of foliage
- ☐ Doesn't know what straight line is—reminds of a bridge or street because of "basic outline" and IDs a sign—a post and some message attached—would associate with a road or a bridge
- ☐ In jade, IDs a body of water because of shape difference with surrounding area
- ☐ After some time, IDs that you're underneath something and looking out—that's the reason for the line at the top

Condition 4—movie (Men behind trees)

- ☐ Says it looks like a scary movie (later revealed that she had just seen "The Grudge")
- ☐ Says it looks like there's some kind of body roaming through the woods
- ☐ Walking with same distance between them—working together
- ☐ Looks like one is climbing because hands were out and moving up

Condition 1 (Hot woodchipper)

- ☐ Goes back and forth between all 3, but keeps visual visible (at least partly) at all times
- ☐ Thinks trees look like a park
- ☐ Because it's a person running, thinks area isn't too secluded
- ☐ In jade, IDs car as turning—would think from jade alone that there's a median, but from visual can see there isn't
- ☐ Zooms in on visual
- ☐ IDs season as late fall because most of leaves are off the trees—or spring because one tree looks like it's blooming
- ☐ In jade, thinks it looks like snow, even though she knows it's "probably not—it's just the image"—gives impression of winter

Condition 2 (Cold woodchipper)

- ☐ Says picture looks earlier than the last because leaves are on the trees
- ☐ Truck looks like it moved—but then thinks it may just be the camera angle
- ☐ "Not getting anything" out of IR images
- ☐ Says looks like sun is out in phx

Condition 3 (Dayton skyline)

  - ☐ IDs Area B due to hangars and road looks like Loop Rd.

- ☐ Justifies that she saw someone running and that it's a protected area (the base)
- ☐ IDs a city in jade—buildings due to rectangular shape and some are taller than others
- ☐ IDs road or runway because it looks fairly level and straight—then says it looks more like a runway because it's long and doesn't have any angles or curves and looks like a cleared area
- ☐ Not sure how to make sense out of phx

Subject 9 (Capt., Male)

Practice 3 (Man with a can)

- ☐ Uses "prior knowledge" and the way he holds a can to determine the man is holding a can
- ☐ Uses hairline and thick neck to ID as a man, jawbone structure—but he's not "for sure"

Condition 1 (Hot woodchipper)

- ☐ Looks at each image individually, then starts with the "easy one" (visual)
- ☐ Uses stop sign and roads going in different directions to ID intersection
- ☐ Uses prior knowledge and location to ID "shredder"
- ☐ Said at first, from IRs, he thought the woodchipper was a tow truck
- ☐ Since the tires are hot, and engines, determines cars are moving
- ☐ IDs dirt road in jade—rechecks visual to see if he can see it there, too, and can't
- ☐ Uses phx to confirm info from other pics (tracks, intersection, etc.)
- ☐ Finds a car ready to turn in phx, a "hot device"

Condition 2 (Cold woodchipper)

- ☐ Notices one less come in visual ("there were 2 in the other picture")
- ☐ Notices "no cars or vehicles on the street this time"—compares to other picture
- ☐ Says "can't gain much from [jade] that I didn't already know"
- ☐ Tries to find cone in phx—doesn't see it at first, but then finds it
- ☐ Says it's hard to tell if vehicle has recently been driven because of white in background
- ☐ Notices sunshine heating up the ground—says it wasn't apparent in the other picture—concludes that sun may have also heated up the truck—thinks it's later in the day

Condition 3 (Dayton skyline)

- ☐ IDs haze—"typical Dayton day"
- ☐ Says "probably taken from tower"—IDs hangar, AF museum
- ☐ Says 3 images don't look like same FOV
- ☐ IDs "same intersection as before"
- ☐ IDs bldgs in jade—tall rectangular structures that stick up into the air—IDs as Dayton because it's the only city in the local area with high risks
- ☐ Looks at jade and visual side by side to coordinate FOV
- ☐ Only thing he can say about jade is that he can see bldgs that he couldn't see in other picture

Condition 4 (Men behind trees)

- ☐ IDs trees from shape/patterns
- ☐ Thinks phx is "more clear"
- ☐ IDs a fence in phx—long, straight, man-made looking structure
- ☐ From jade, thinks it may be a road
- ☐ Can't ID think at top of jade—thinks it may be window of a car, but hard to say
- ☐ Notices "white circular smudge" in jade, but not sure what to make of it—"optics issue," maybe
- ☐ In phx, thinks bright spots may be "brightness from the sky"

Condition 4—movie (Men behind trees)

☐ Notices something moving in jade—“something hot is moving—maybe it’s a person”
☐ In phx, says “there’s definitely people” from the way they’re moving about, 2 legs, bending over and picking something up or putting something down
☐ Goes back to jade—says he only sees one person—looks like a body, something walking upright, the way it moves
☐ Says it’s happening on the opposite side of the fence because the bar is blocking out the heat signature—IDs in jade and confirms in phx

Subject 10 (2Lt., Female)

Practice 1 (Man in front of town houses)

- ☐ IDs a garage because it "looks like a door and there's a car parked in front of it"

Practice 3 (Man with a can)

- ☐ Nose definitely colder

Condition 2 (Cold woodchipper)

- ☐ Uses visual first—fullscreen
- ☐ Uses lane markings to ID street
- ☐ Then goes to phx and jade and puts them side by side, then goes back and forth
- ☐ Uses phx to ID road/track, then confirms in visual
- ☐ IDs pole with a light on it in jade and confirms in visual—gets shape from jade and color from visual
- ☐ Uses visual to ID trees—shape (trunk, branches)
- ☐ In phx, IDs a bright spot in tree that she can't verify in other pics—can't tell if it's behind the tree or in the tree
- ☐ IDs orange cone—can see in visual, but not in other 2—also a white baseball base beside the cone
- ☐ IDs a sign on the side of the street from shape/color (in visual)

Condition 3 (Dayton skyline)

- ☐ Looks at visual first
- ☐ IDs same scene as before from street, pickup truck, trees, "yellow vehicle" (woodchipper)
- ☐ In phx, IDs roads/runways because they're long and straight
- ☐ In phx, IDs trees from shape—round and uneven—different from ground—confirms in visual
- ☐ In jade—IDs buildings from rectangular shape, sticking up out of the ground
- ☐ Looks for area between trees—"biggest in [jade]," but can't tell what's there—from visual, thinks it may be a road because it lines up with the other road
- ☐ IDs hangars from round tops in visual—also, several of them in a row
- ☐ Always keeps part of each image visible—rarely goes fullscreen
- ☐ In phx, IDs bright spots, but can't tell what they are—on either side of runways on road
- ☐ IDs a car in visual from color (different from road)
- ☐ Spends a lot of time looking at all image—didn't in practice

Condition 4 (Men behind trees)

- ☐ IDs trees from "trunks and branches that cross each other"
- ☐ IDs something behind trees that goes in straight line—thinks it could be RR tracks or road because 2 parallel lines
- ☐ In jade—IDs something dark across top, but doesn't know what it's from
- ☐ In jade, notices that the back of the two parallel lines shows up more than the front one

Condition 4—movie (Men behind trees)

- ☐ In jade, IDs something moving—brighter than what's around it—might be a person because it's "taller than it is wide and might have a head shape on top of a body"
- ☐ In phx, IDs 2 people that walk along to the right and put something down—tall and then get short and then are tall again

- ☐ Says once they move over to the left they “do something else” and then move more the left and then are gone
- ☐ In jade, says she only notices differences because, when movie stops it jumps back to the beginning, and the images are so different at the beginning and the end, but in phx, movement jumps out right away

Condition 1 (Hot woodchipper)

- ☐ Notices different color on top of truck in visual
- ☐ Notices 2 white cones in visual
- ☐ IDs person jogging toward left because of the way the back foot is coming off the ground
- ☐ IDs van with ladder on top—rungs, side of ladder used to ID
- ☐ Notices that ground looks “different” behind the cars in both IR
- ☐ IDs road/tire track underneath truck
- ☐ **Doesn’t make a lot of direct comparisons with condition 2—she took a long time though—could have forgotten?

Subject 11 (2Lt., Male)

Practice 1 (Man in front of town houses)

- ☐ Thinks person just got out of car because engine is still warm

Condition 3 (Dayton skyline)

- ☐ IDs Wright-Patt scene from tower in visual
- ☐ IDs runway because of "long straight patches of cement"
- ☐ Zooms in on jade—sees "blobs" on runway—thinks there may be something on the runway
- ☐ IDs city in jade—bldgs square in shape
- ☐ IDs street light in phx and cars because of bright spots
- ☐ Bright spot in sky on phx—thinks it may be an airplane with a flasher on its wingtip
- ☐ Confirms "blobs" on runway in phx
- ☐ IDs trees in jade—fairly tall compared to surroundings, "brushy"
- ☐ In jade, IDs streetlights at end of runway because they are "fairly high up compared to the horizon"
- ☐ IDs a street sign in jade, but can't confirm in phx—goes back to jade and says "it still looks like a sign"—2 legs, and square "almost *too* square"

Condition 4 (Men behind trees)

- ☐ IDs trees/forest—branches everywhere, leaves at top of phx
- ☐ IDs fence in phx—long, very straight line, double, going across
- ☐ IDs a clearing in jade
- ☐ In jade, thinks there is a log or something at the top—very close to camera
- ☐ Zooms in on all images and scrolls around

Condition 4—movie (Men behind trees)

- ☐ In jade sees something moving—thinks it's a person due to "shape of a body, maybe a head on top"
- ☐ In phx, IDs a couple of people—put something down and are walking away—then thinks there may be a third person behind the trees

Condition 1 (Hot woodchipper)

- ☐ In visual, uses shape and "looks like a woodchipper" to ID
- ☐ Visual—IDs truck, wood chipper, someone running, sign, cones
- ☐ In jade, thinks there may be rain or snow
- ☐ IDs light post in jade, a car at the stop sign

Condition 2 (Cold woodchipper)

- ☐ In phx, sees "shape of a car" driving past a tree
- ☐ In phx, IDs tracks driving back into wooded area
- ☐ In phy, thinks "engine area of truck looks hotter than the rest—thinks it could be sunlight coming off heating up the surface of the truck.

Subject 12 (1 Lt., Female)

Practice 1 (Man in front of town houses)

- ☐ Bright spots catch attention, but can't figure out why bright under car
- ☐ IDs road from straight lines, distinct differences with surrounding area
- ☐ IDs garage doors from windows
- ☐ IDs houses from garage doors, shrubbery

Practice 2 (People on golf course)

- ☐ IDs a park from trees—trees from trunk, leaves
- ☐ IDs 5 or 6 people from shape, "outline of their figures"
- ☐ Bright spots catch attention—can't ID—may be a person on a bike
- ☐ Open, smooth looking IDs grass field
- ☐ Maybe water in the back

Practice 3 (Man with a can)

- ☐ Immediately says "'Don't take a picture of me,' or 'Hi!'"
- ☐ Uses shape to ID person
- ☐ Uses shape and proportion relative to hand to ID can
- ☐ IDs hair
- ☐ Uses physique (broad shoulders, bigger neck, hands, short hair) to ID as a man

Condition 4 (Men behind trees)

- ☐ IDs "norther trees"—winter, not a lot of greenery, shape—maybe a burnt forest
- ☐ IDs a "straight line"—can't tell if it's a road or RR tracks
- ☐ In jade, thinks pic is taken underneath "some kind of overhang"
- ☐ Notices "one is more zoomed in than another"
- ☐ Says she doesn't see any people, but maybe figure in jade can be a person—but can't confirm in phx
- ☐ Thinks it's daytime b/c sky is pretty bright thru the branches
- ☐ Bright spots between trees catch attention in jade and phx, but can't ID—thinks maybe an optical illusion—in phx, looks like water or sky, in jade thinks straight line is something that "could be stood on"

Condition 4—movie (Men behind trees)

- ☐ In jade, sees something "getting dark and then flashing again" that catches her attention—then notices that it's "slowly disappearing"
- ☐ Phx—"so now it's obviously people walking around"—long legs, human's figure—looks like they're carrying something and then dropping it off
- ☐ IDs "at least 2" people
- ☐ Looks like they're carrying something and dropping it off

Condition 1 (Hot woodchipper)

- ☐ IDs street in visual because of cars, street markings, signs, guardrails
- ☐ Recognized "right out front" (outside of building)
- ☐ Notices change in FOV from visual to phx—"same road, same truck parked," but angle is different
- ☐ In jade, says it looks dusty
- ☐ In jade, IDs same road, a street sign (new—didn't notice in other images), truck and trailer
- ☐ IDs shrubbery and foresty stuff
- ☐ Thinks jade is a "lower angle" than phx

- ☐ In jade, notices car is “crooked”—thinks he’s about to change lanes
- ☐ In phx, bright spot in lower right corner catches her attention—could be barrel, top of car, van
- ☐ Notices person running—bare legs, running shoes

Condition 2 (Cold woodchipper)

- ☐ In visual, says “kind of looks like the same area”
- ☐ Notices a change in FOV—“angle is different—see more of part of road”—from previous
- ☐ Can see more of trees than in previous
- ☐ In phx—says it looks like the “other picture’s” FOV
- ☐ phx—says “It’s funny how the light makes it look like snow”
- ☐ In jade—recognizes a difference in FOV—more over to the side and zoomed in
- ☐ Says truck is the same—trailer hitch on the back, outline of tires, shape and “size of everthing”
- ☐ In jade, says you can still see the “same streetlight” and the markings on the road
- ☐ Notices trail “in all of them”

Condition 3 (Dayton skyline)

- ☐ In visual, “looks like the Air Force Base”—IDs AF museum, hangars
- ☐ Finds truck, “same curve in the road” from previous conditions
- ☐ Uses ledge at bottom of visual to say it’s taken from “some sort of balcony”
- ☐ Says phx is “hard to make out”—assumes “smooth darkness” is sky
- ☐ In phx, IDs road or flightline—cleared ara around it, 2 straight, clear, long areas
- ☐ Phx: IDs trees—faint lines of branches and tree trunks, lots of leaves
- ☐ Phx: doesn’t know what it is at the bottom
- ☐ Phx: thinks there may be a town—a bunch of random chunks of things
- ☐ Jade—says it looks like more of the same—IDs trees, thinks the lower rights area may be a building—IDs buildings in back b/c they are “straight up, geometric”—IDs building in lower right corner—thinks white dots may be imperfections in the picture, but may be a building b/c it “just looks different” from the surroundings
- ☐ IDs overlapping area in visual, and then IDs the road area she was seeing before—more definite about it now
- ☐ While looking at visual, changes her mind about seeing a building—may be part of the road

APPENDIX F: PRELIMINARY STUDY NUMBER TWO—CONCURRENT PROTOCOL RESULTS

Subject 1 (1Lt., Male)

- SynWin session 1 – Practice
  - Says "This is a bad day to have me try this" [mentioned prior to testing that he has midterms coming up]
  - "In general I would say that this game is too challenging for me"
  - Score: 727
- SynWin Session 2 – Practice with imagery
  - I1:
    - [Image disappears]
    - "Saw a truck in the scene, with some kind of trailer, I think it was lawn equipment like a chipper/shredder, something like that, I could make out some of the tracks from previous vehicles' movement in the infrared. That was about all I got that time."
  - I2:
    - [Looks a long time before talking]
    - "All the images are inverted, they're at different times, the traffic pattern has changed, I've lost a pair of cars on one side of the road, the truck with its lawn-care-looking-thing is still in place, the position is pretty much still the same area…
    - [Image disappears]
    - "I need to start talking more about the image as it's there."
  - I3:
    - "We've got two different fields of view. One, the upper image is closer, near the intersection of Loop Road and the 620 tower, we've got an overcast day, and on the second one, it's much smaller, I can still see that there's looking out the runway test area with two different cameras, one appears to be like a white-hot, one looks like a black-hot, given the horizons, fair change, at the top looks like maybe a white-hot…no, they're the same they're just picking up something else on the lens, there's a central distortion that's different, I don't know what's causing that, one of them's picking up a bandwidth in the fog, and then it's not or something like that. It's hard to compare the traffic at this point….I don't know if it's wet or not, it may be.
  - I4:
    - "OK, imaging through trees, maybe ah, there might be two, some kind of bright spots along the center. One is…is it?...a focal length or a contrast difference, one sort of dark in the center and it goes fading to the outside, the upper one is the opposite of that, I can see, it but can't get it out in words,"
    - [Image disappears]

        - some sort of contrast shifting, I don't know what caused that, and I couldn't identify what the two bright spots were, parallel to where the center would be."
    - Score: 1202
- SynWin Session 3 – Real images
    - I1:
        - "OK, we have two images, one is of something in the treeline back in the 620 area, you have fresh tire tracks in both, maybe there's some snow or something causing that, the big temperature difference. The upper image is black, I can't see anything in that at all. It's square, I don't know what's giving those—target panels, maybe? It's something at the ground that's causing this, you can see clearly, maybe there's some sort of sign in front of the road, that's propped up. Something's been driving around back there, there's two black panels…almost like a black panel, it's not very reflective, or cold or hot relative to these images. It's right beside the main target, a spot. We have some sort of symmetry that's going down, right to left."
        - [Image disappears]
        - "It's like a stair-step type function"
    - I2:
        - "OK, top image is blank, they're inverted, I can see some sort of target with varying contrast, parked behind the trees. I can still see what looks like a sign post in this. I don't think that's what it is, but I've got no clue otherwise. I can see tire tracks leading from what's probably the road, inverted heading in towards the target site. I think maybe it's maybe it's a target of one general reflectance"
        - [Image disappears]
        - "with something reflective in front of it, that's in a square shape."
    - I3:
        - "OK, three images, two infrared, one visible. On the top, it's slightly overcast there, looking towards the corner out onto the flightline area. There might…ah, it's too hard to see…there are things out on the flightline, but I *know* that, I can just barely see some blips that might or might not be actual information. In the infrared, I see a real hot spot, I think…yeah, it's just the road that comes between the trees, so the road's reflecting very brightly as compared to the rest of the imagery. On the Dayton skyline, there's something dark on the middle image, on the left, it's maybe just out of frame"
        - [Image disappears]
        - "because of this different field of view on the bottom image"
    - I4:
        - "OK, new image, it's clearly our Humvee, it's hot, its engine compartment is still hot, as well as the wheel well, you can see a temperature gradient along the...probably from water or soil turnover

where it went into the covered area. It's in the patch of trees over across from the building, see, I know that—that's clearly where it's at. I can see some spots where it might have been that people stood for a little while, you can see where there are some different colors from the ground, and there's no other obvious reason why they would"
        - [Image disappears]
        - "change, maybe where some other targets *had* been placed in a previous part of the experiment. But there definitely is a vehicle that had been stopped…either been running for a while then been stopped, or just recently been turned on then stopped, because the wheel wells were hot from crap being thrown around in them, as well as the engine compartment still showing heat."
    - I5:
        - "OK, regular image of the Humvee in the target area, now you can see there's snow on the ground, there's a flame sprayed aluminum target leaning against the rear of the vehicle, the nose of the vehicle is switched from some of the previous images, facing to the right. So it's been pulled in, you can see where the snow's been disturbed, it was pulled in and then pulled back, to get to its current position in the field of view.
        - [Image disappears]
        - Can't tell if there's anything else inside the vehicle.
    - I6:
        - "OK, single image on the flight line, it's the trailers and something else looks like it may be the air conditioning vent showing up kind of hot, there's a darkened spot, a dark spot, it's just short of one of the crossovers on the…you can see the taxiway and also the other part of the runway, taxiway's darker than the primary runway. You can see the crossover, actually it's very near one of the other crossovers, and that's what that is here. There's been a moving vehicle, I think that's what this is, the windscreen's showing up as cold, or dark, maybe due to some air conditioning or heating inside it. There's this extra little hot spot that I think is probably the engine compartment of the vehicle. I think this is a hot air conditioner, where it's"
        - [Image disappears]
        - "been exchanging heat to the outside, so it's why there's one little globule on the trailer facing towards us."
    - Score: 1366
- Questions
    - 1. How would you describe your experience overall with this testing session?
        - "Well, it takes some practice to get this, and then you start to over-focus on the game. It was easy enough to watch out of the corner of my eye and see for the black-to-image transition that I could stop to

change really easy, then switch back over. But I had to learn in the practice session that when the image comes up, to only be concerned with the "uh-oh" and the high-pitched beep. Everything else, the point value wasn't so important, but if you missed the high-pitched beep or the uh-ohs, you're going to lose a lot of points. So I was trying to switch my auditory over here [to the SynWin], and my visual with the image—that's how I was trying to split my attention. Then I had to go and hear those over myself talking, so it's a good multitasking experiment. When I'd start to analyze the image, it takes time to look at each, then start comparing. I could go out and pick things, like how many images are there, are they upside-down, I got color vs. infrared, I didn't always get it spat out in time, but I could usually spit that out while I was still looking at trying to gather some more information of what was in the image, and keep listening to the two tones that I decided were important. Just having worked on the experiments that most of this was taken from, it's good and bad, because it gives me some extra information to go from , but then I'm sort of postulating where I remembered things being, and you couldn't always see them, because they weren't there all the time, but I would start looking for information in my memory instead of just on the screen. Like I would see something, then I would start to postulate, 'well there's a spot where the targets were set, because we tore up the ground there, but you couldn't really tell whether that was just a spot where maybe the snow was stuck there a little better, or what have you. I would actually sort of distract myself from the information in the image with my familiarity with the area"

- 2. How did this session compare to the last session?
  - "It's a lot harder! Quite a bit more difficult to do amidst distractions. The big stuff I think I got in the images both times, but I got a lot more detail, the unique variance, I think, when I didn't have other things going on."
- 3. Did you feel overwhelmed or stressed out?
  - "It's more stressful. At first it was like….when I first started playing the game [SynWin], I was like, 'How am I actually going to look at the image while doing this?' But that's just the brain at work—once I learned the task, I was able to sort of categorize the importance in value, and develop sort of a plan, it became a manageable workload. I would do the math problems…it was kind of the same attention shifting. I was over here focusing on the math problems, and when I would see a change, in the letter pop up, I would stop the math problem and hit that, while just king of clocking the gauge going down and listening. Kind of my primary focus was on the math problems until I had an interrupt here. And then, so it was primary [math] – interrupt [memory] - interrupt [visual] - and then audio interrupt. When the image would be up, I was focusing on the

image, and only listening for the *audible* interrupt. So it was at first, it looked like it would be more overwhelming that it was finally, because I could see that I could build up a good buffer of score (I don't know if the score have any *importance* at all, but I want to score well!), I would build up a good score, so would be, 'OK, so I miss a few math problems, and don't see the letters popping up, but I can still get those big point ones, like not hitting the buzzer, and…' while focusing over here [images]. So it kind of settled into a groove, but it keeps the heart rate going a little more than looking at the images for all the time that you want.

- 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?
    - "Any sort of cuing, like, since it was thermal imagery, a little false color for the really high contrast zones, like you have the hot engine compartment against the otherwise cool background. I mean, you can look at it in a thermograph in the black and white and see white, but you also have things that are just reflecting, you know about the complicated photon interactions here. You know, when it's white-hot, there's a lot of white on the screen, that's really…if you can do something to draw out hot-and-alone contrast in an environment, as opposed to white-fade in some areas, that would be good. Unless I had it up there—I might find it distracting, but in general, because the contrast—white kind of starts to look kind of white on that monitor….but that's sort of the conundrum of our business—more contrast would be better. In particular, cuing towards those unique spots, like the vehicle, those last vehicles in the far distance, where there was probably an air-conditioner box on the trailer, because it was showing very hot compared to the rest, that's why I think it was an exchanger…it was almost highlighted by the dark around it, but if you could draw attention to those abnormalities.

Subject 3 (1Lt., Male)

- SynWin session 1 – Practice
  - After a few minutes, says "This is hard."
  - After a few more minutes, says, "It's not impossible now, but it's gonna be hard to do this and the other stuff [indicated image computer]"
  - "I keep missing the high-pitched beeps."
  - Score: 1315
- SynWin Session 2 – Practice with imagery
  - I1:
    - "I see a truck and some sort of yellow utility thing next to it."
  - I2:
    - "OK, I see everything is upside down from what I saw the first time, oh, it's a little different from last time, there's a car back in the trees, with some sort of shredder utility thing next to it. It's a sunny day, no, it's a *warm* day, I can see from the heat pictures. That's a about all I can see.
  - I3:
    - " I see a road with several cars on it, one pulling up to an intersection, there's some equipment back in the woods, off right-of-center, it's the flight line, a couple of long straight roads. The middle picture…it looks like it might have been taken on a cold day because the sky was dark"
  - I4:
    - "Looks like a picture of trees, in the second picture I can see it looks like there is some equipment behind the trees, the top picture looks like it may be an upside down version of the scene in the bottom picture."
  - Score: 925
- SynWin Session 3 – Real images
  - I4:
    - "It looks like a truck in the woods, looks like it was recently driven in there because the tire tracks look hot, the engine looks hot, it may have been running recently, if it's not still running, because the top of the truck is hot."
  - I5:
    - "It looks, that's a truck, taken on a cold winter day, tracks in the snow that look fairly fresh, hard to tell, there's a light target in front of it, some snow accumulated on the edge rail of the truck."
  - I6:
    - "It looks like something down on the range there, maybe a box car, maybe a person standing inside the building, it may be a truck there on the left because it looks like a hot spot under what may be the hood…that's about all I can tell [stops looking before the image is gone]."
  - I1:

        - "Looks completely dark in the first picture, other two look upside down, maybe not, maybe a house with a drive up to it…it looks like it's upside down though, maybe not, no, no it's not. A truck may be pulling up to the driveway, looks hot compared to its surroundings, driveway looks like it's hot or reflective compared to its surroundings."
    - I2:
        - "Looks like the same picture as before upside down, so I can see a couple of trees in the foreground right up to the front of the picture and there's a light post"
        - [Image disappears]
        - "It was the same picture as before and seeing it upside down made me believe it was right side up in the previous one."
    - I3:
        - "This is a picture taken out of one of the towers of the flight line, there's a car on Loop Rd. going down around, it looks like the same picture down below with some infrared camera, you can see Dayton in the background."
        - [Image disappears]
    - Score: 1046
- Questions
    - 1. How would you describe your experience overall with this testing session?
        - "It was fun, it was stressful. I wouldn't want to do that and have it be a matter of life or death. I wouldn't want it to matter what the pictures look like. I learned the third time [after the 2 practice sessions] that the fuel was the most important thing. I wasn't getting any points for the pictures, so they were more of a distraction."
    - 2. How did this session compare to the last session?
        - "Time definitely went faster this time. I was less…when I saw the pictures this time I was focused on quickly identifying what was there; last time I ran out of things to look for. This time I just quickly railed off what I saw. It was a relief when the pictures went away. Last time it was a different stress—wondering if I was missing something. This time I wanted it to be quick.
    - 3. Did you feel overwhelmed or stressed out?
        - "A couple times, but it wasn't completely unmanageable. I got too wrapped up in a picture one time, which caused me to lose the fuel. Being wrapped up in the tasks led to my mistakes, but a few times, I had to go with instinct on the math, which kind of helped—I couldn't second-guess myself.
    - 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?
        - "Beforehand, had I known what I should be looking for in the pictures would have helped. Or, if it would have been like, 'Find this and then stop worrying about the pictures' would have been

helpful. With the three pictures at the same time, if I had known more about why they were grouped and how they were taken, it would have given me clues about how to interpret them."

Subject 4 (2Lt., Male)

- SynWin session 1 – Practice
  - During Practice w/ SynWin, he says "I'm supposed to do all this *and* the other think [imagery] too? That's kind of daunting."
  - Score: 1500
- SynWin Session 2 – Practice with imagery
  - Misses images the first time
  - I1: IDs woodchipper and daytime after images are gone
  - I2:
    - IDs same woodchipper
    - "Upside down for some reason"
    - Daytime
    - Gets basic gist, then stops looking at images before they've disappeared
  - I3:
    - Top of tower
    - Cars going down the road
    - Foggy (top image is blurred)
    - Daytime
    - Can't see Dayton in the bottom one
  - I4:
    - IDs trees in the woods
    - IDs "2 guys, maybe 3 guys, they're hanging out, but I don't know what they're doing—one's got his hands up."
  - Score: 1512
- SynWin Session 3 – Real images
  - I1:
    - IDs nighttime from top image
    - Says "Some kind of vehicle that left of when into the area"
    - Thinks there's a woodchipper because it's the same as the previous location/area
    - Says vehicle is on
    - Truck has recently moved because of the tracks
  - I2:
    - "Same picture but it's upside down"
    - "Tractor is still hot, everything else I said last time holds because it's the same picture."
    - "Same picture, or if not, it's very close."
    - [Comment: Given time, subjects can ID small changes. Under stress (including different oriention), they see similarities but miss differences.]
  - I3:
    - "From the top of the tower looking down." [In visible image] see trees, it's daytime, not foggy, car going down the toad.

        - [In IR image] "Something in the middle of the clearing that looks like it's on—looks like a machine b/c it's hotter than everything else, but that's it.
    - I4:
        - "It's a truck—I can tell by the gate on the back" recently traveled along this path. It's on, its engine is hot, it's in the middle of these trees—it could be what was in the middle of *those* trees [in the previous image set]
        - [Image disappears]
        - "Everything is hotter than the air, but not by much—it's either a cool day…no…a *warm* day, or it's nighttime"
    - I5:
        - Same truck as last picture, except you can't see how long it's been there. It's got some metal or a plate in front of it. It's recently snowed and it's sitting in a clearing.
    - I6:
        - Looks like it's taken from the tower, based on what I know from other pictures. 2 vehicles on a road or a runway, some sort of heat source, but cold areas too. 2 buildings or trailers—from what I know about the are, I'd say it's the LID range down there and there are 2 trailers and someone has the lights on or something.
        - Score: 1539
- Questions
    - 1. How would you describe your experience overall with this testing session?
        - It was just "a task." Parts of it were annoying—the multitasking, when you're in the middle of a math problem which is easy to ignore, and a picture comes up, you *have* to look at it (the picture), because you don't know how long it's gonna be there. Every now and then I missed the high-pitched beeps because I just "zoned out."
    - 2. How did this session compare to the last session?
        - Last time I spent a lot more time staring at the pictures, got a lot more time to divulge what was going on in them. It was more difficult to see the detail in these. Hard to process information from the pictures—i.e., I couldn't process that tress being the same temperature as the air meant it was a cool day, because I was thinking about the other tasks.
    - 3. Did you feel overwhelmed or stressed out?
        - When the images were there, I felt overwhelmed. I completely ignored the math when the picture was there. I knew it would be there when I got back, and I wouldn't lose points for not doing it. I *would* lose points if I tried and got it wrong. If the math *was* timed, I would have been stressed because it's another task. I gave each task a weight—the photos were the most important, and the math the least, the sound and the fuel second, the letters worth less, so if I'm into a picture, I looked for the letters but I didn't go crazy with them.

- 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?
    - When there wasn't a visual image, the visual would have helped, and when the IR wasn't there, it would have helped. IR helps ID machinery and toad—in some, I couldn't tell if it was nighttime, or if it was a blacked-out picture. It would have helped if I could know which it was. I looked as the visual images first to determine what was going on, and then went to the others to see what I was missing in the first.

Subject 5 (Capt., Male)

- SynWin session 1 – Practice
  - Score: 1858
  - [Carpet being torn up outside the room—much talking and other noise going on]
- SynWin Session 2 – Practice with imagery
  - I1:
    - "There is a truck pulling a yellow trailer down there"
    - [Image disappears]
    - "Wow, that was fast. A white truck pulling a yellow trailer, there was a little clearing, and the bottom two images were not visual."
  - I2:
    - "Um, they're upside down, same images, there's a truck and a van at an intersection, the white truck is still pulling a yellow trailer, a row of trees, a blue van, I'm not getting too much from the others [IR], I'm not getting a whole lot more information [stops looking before images disappear]
  - I3:
    - "OK, this appears to be looking at the same intersection as the upside down image with a wider field of view, you can still see the white truck pulling the yellow van, it's cloudy, you can see the city in the background in the second image, the third image doesn't give you *too* much—there might be another vehicle in the intersection that I missed the last time."
  - I4:
    - "Is that upside down? OK, there's trees, there's something behind the trees that's lighting up…there's something behind the trees, it looks like…
    - [Image disappears]
    - "It looks like a road because it's very….straight."
  - Score: 1838
- SynWin Session 3 – Real images
  - "All that's going through my head over and over is those letters, and the fuel thing was really freaking me out."
  - I3:
    - "OK, we're looking at a road that is curving, there's a car on it, there appears to be something in the clearing there—yeah, when you looks at the other ones [IR] you can see that it's highlighted, you can see more cars at the intersection as you follow the road down
  - I4:
    - "There's a truck, a flatbed, it's go slats, it looks like an old style truck used for hauling, got a road in front of it, it's in the brush, looks like it's been running because the engine compartment is hot—could be a reflection, but I think it's hot because the wheel well it white, too"
    - [Image disappears]

        - “it’s parked sideways, perpendicular to the road.”
    - I5:
        - “OK, Humvee, camouflaged, it’s got the slats, it’s got a calibration panel sitting next to it, it’s in the trees, it’s wintertime, there’s snow, there’s little path leading up to it”
        - [Image disappears]
        - “All the leaves are off the tress, there’s a lot of mud”
    - I6:
        - “This is a road, I can recognize it, it’s the flightline, there are cross roads, there’s two vehicles, well, one’s a trailer, you can see windows, a couple of hot spots, looks like the vehicle is facing the camera”
    - I1:
        - “OK, the images are upside down, top one I see nothing, looks like trees, some sort of vehicle, possibly a road with a clearing afterward, hard to tell with it being an upside down view, trees in front, looks like a road sign or a tree in front, there’s a lot of brightness…”
    - I2:
        - “Um, same thing? No, it’s a different viewpoint. I think road looks to be flipped left/right from last time, but there’s a vehicle, maybe a road or…*something* there.”
    - Score:
- Questions
    - 1. How would you describe your experience overall with this testing session?
        - “This one was a lot more stressful than last time. I wasn’t bad….it wasn’t *stressful*. If you put in another task, I would have been hard-pressed when the images came up. I could get into a rhythm, and like I said, I just kept those letters in my head going over and over and over. I felt peaceful once the images would go away, to get back to just adding.
    - 2. How did this session compare to the last session?
        - “This one was a lot more difficult. Last time I had time to scrutinize little details and put it together with other visual cues. This time you almost had to get lucky to see the little details and visual cues to put the scene together”
    - 3. Did you feel overwhelmed or stressed out?
        - “I didn’t feel *stressed out*, I felt like because of the points that I had to do good, but I felt very focused. I felt like the images were a nuisance because I wanted the points—the addition stopped when the images came up, so when they came up I had to deal with it but I wanted to go back—as you could tell, I was a little distracted with my [verbal] answers”
    - 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?

- “Maybe some sound cues, but I can’t think of what a good sound cue would be…to keep a little more focus. The visual focus was pretty tough on the Syn Win because of the gauge and the letters, so trying to keep the vision over here… Having them right side up would help—it’s amazing how much of a difference that made. Knowing what I was looking for—a particular target—that way I could eliminate certain areas and find thing that catch my eye”

Subject 6 (1Lt., Male)

- SynWin session 1 – Practice
  - Hears all he sounds right away through mistakes on his own—doesn't need to be instructed to let fuel run out or to get a wrong answer to hear the sounds
  - Score: 1622
- SynWin Session 2 – Practice with imagery
  - I1:
    - [Image disappears]
    - "Ooh, it's gone, well, there was a truck, and that's about all I noticed. It was parked next to the road, off the road, and it looked like it was parked next to an intersection."
  - I2:
    - "It's another intersection, all the images appear to be upside down, also parked off the road just like before and there's a van and two other cars and it looks like the van may be stopped at the intersection, can't really tell, and there's a bunch of trees"
    - [stops looking before image disappears]
  - I3:
    - "Intersection again, looks like a foggy day, a couple of vehicles, same truck parked off to the side, it's a different view, there are a couple of buildings there, they're kind of long and metallic looking"
    - [gets distracted by several alert beeps in a row, turns his attention to SynWin]
    - [Image disappears]
    - "Ah, picture's gone"
  - I4:
    - "Looks like some images of trees, looks like might be thermal, bottom image looks like some bright spots in the trees, they're not as bright in the other image, but I could just be making that up because the trees in the middle look darker."
  - Score: 1827
- SynWin Session 3 – Real images
  - I5:
    - "Looks like a military truck parked in the snow, there's tire tracks behind it that may have been from it, but it's hard to tell because they don't look like they're the right shape to have been from it."
    - [Image disappears]
    - "And now it's gone"
  - I6:
    - "This looks like some sort of a large open field and there's two square-shaped things in the middle of the picture, they have some bright spots on them and some dark spots as well, and it looks like there's a road that runs right through it as well because there's some light areas and some dark areas at the top of the image."
  - I1:

        - "Top image is completely dark, can't see anything, middle image looks like there's some trees, looks like a building of some sort, there's some light areas and dark areas in the middle of the image, and there's some light areas in the bottom image too, there's a road of some sort going up to it, looks like some water or something in the bottom there, the first thing I thought of when I saw this is some sort of lakehouse or something."
    - I2:
        - "This looks like pretty much the same thing upside down, the top image is completely black again, the bottom image and the middle image look pretty much the same as the last screen except they're inverted."
    - I3:
        - "Looks like kind of similar to the other ones from the practice, there's a road, a bunch of trees, some buildings in the background behind a bunch of trees, some smaller roads in the background…"
        - [Image disappears]
        - "that looks kind of like an airport runway"
    - I4:
        - "This looks like a bunch of trees, there's something lighter in the middle, some different terrain, there's a deck or something, some slat railings…"
        - [Image disappears]
        - "Looks like some kind of building to the right of the deck as you look at the picture."
    - Score: 1794
- Questions
    - 1. How would you describe your experience overall with this testing session?
        - "It was fun. It was kind of tricky to watch this [images] not knowing when it would pop up and when it would go away, and concentrate on this [SynWin]. Whenever this [image] popped up, I tuned out the math one."
    - 2. How did this session compare to the last session?
        - "There was definitely a lot more going on—this time it was so divided between the tasks and the images—I had to look at the image, pick out what I wanted, look back to the other stuff, back to the image—then the image disappeared before I got everything I wanted to see."
    - 3. Did you feel overwhelmed or stressed out?
        - "No. There was a lot going on, but it didn't seem too much."
    - 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?
        - "Maybe knowing what type of image each one was."

Subject 8 (2Lt., Female)

- SynWin session 1 – Practice
  - "I don't know how to pay attention to everything at once!"
  - [Has trouble with the memory task]
  - Score: 292
- SynWin Session 2 – Practice with imagery
  - I1:
    - [Looks for a while, image disappears]
    - "I remember a truck and trees…a truck along the road, but…"
  - I2:
    - [Looks for a while]
    - "There's threes care, there's a road and an intersection, ti's a T intersection, and a lot of the leaves are off the trees"
  - I3:
    - "It's foggy, I see 2 cars, or maybe more, actually, I think I see 4 cars, it's overlooking a hill or going downhill, and again all the leaves are off the trees."
  - I4:
    - "A picture, pictures of just tress, looks like there's something behind the trees, but it's hard to tell what it is, and it looks very cluttered."
  - Score: 878
- SynWin Session 3 – Real images
  - I2:
    - "Not sure what this is—the first picture is completely dark. The second is upside down, not sure what it is, I see trees…"
    - [Image disappears]
    - "…and something in the middle—kind of reminded me of the Eiffel tower on its side, but I don't know why…but only part of it."
  - I3:
    - "First picture shows a bunch of trees with a road, a curvy road going between it and an airfield at the bottom of the hill. Next two pictures are really similar and there are trees and either a road or a runway."
  - I4:
    - "This picture is…looks like a truck in the woods, kind of off a dirt road, and lots of trees…it's the side of the truck."
  - I5:
    - "Another picture of a truck, a Humvee, with a screen or something else beside it, which is a little bit bigger than the wheel well…"
    - [Image disappears]
    - "…and there's snow on the ground? And there's a road leading up to it and it's perpendicular to the road and there's trees to the back and to the sides of it."
  - I6:
    - "I'm not sure what this is. There's two objects in the middle something that looks like a path, or a road, and the objects are squarish—it reminds me of a field.

- I1:
    - "I've seen this image before, it's the Eiffel Town on the side, now it looks like a house in the middle, on top of something that's flat, with a little road or something that goes down to the street, and there's lots of tree behind the house"
  - Score: 848
- Questions
  - 1. How would you describe your experience overall with this testing session?
    - It was mentally difficult, but it got easier over time. IT was easier after getting used to the four things at once. I thought the sound was easiest to attenuate to and go the other things at the same time, but everything else was visual and so I was trying to concentrate on three visual tasks at once. The math was hard if I went to something else and came back to it, and I'd forget where I was and then I ran out of fuel. If the pictures were on, I forgot about the math—I just tried to get the fuel, *then* get the letters, *then* the sound. I could do the three things and the pictures, but not the math. [Why couldn't you do the math?] Because the math required more thinking and everything else was an automatic response. I could think about the letter while looking at the picture, then go back and click yes or no…but not the math.
  - 2. How did this session compare to the last session?
    - I though this session was more fun. It was more difficult, and I don't know that I described the pictures very well because my focus was somewhere else. I would look at the picture, then look away, and it would be gone and I'd realize I didn't really *look* at the picture—I *saw* it, but didn't *look* at it. But over time, that got easier.
  - 3. Did you feel overwhelmed or stressed out?
    - I felt overwhelmed in the beginning. If I was *really* going to crash, then I'd be stressed.
  - 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?
    - Given the time constraints, then NO! More time always helps in anything. I was OK with the ones that had a moderate amount of time, but the ones that were on and then off were hard.

Subject 9 (Capt., Male)

- SynWin session 1 – Practice
  - Says he's "a little foggy this morning"
  - Clicks on the letter box quite a bit to remind him of the letters—has trouble with the memory task
  - Score: -563
- SynWin Session 2 – Practice with imagery
  - Still having trouble with the memory task
  - I1:
    - [Image disappears]
    - "I saw a truck, three images, one had a truck in it, a bunch of trees, it was a pickup truck or something—that's all I remember right now."
  - I2:
    - "Pictures are upside down! Looks like the same three pictures, the fork in the road down toward the gate, looks like a tree shredder behind the truck, there are a couple of trees in the way there."
  - I3:
    - "Different view, looks like taken from the tower, foggy day, there's a car in the road there, a few cars in the road there, lots of trees"
    - [Image disappears]
    - "This is pretty difficult"
  - I4:
    - "A couple pictures of trees, there's a fenceline there, there's a couple of white, shiny things, it's hard to tell what they are, it looks like there's something behind the fence on the lower image."
  - Score: 971
- SynWin Session 3 – Real images
  - I6:
    - "Image of the flight line area of the test range, has two structures on it, a couple of hot spots, two structures are on a road, you can see the grid in the background, looks like the flightline back there too."
  - I1:
    - "Three images again, top one's completely black, next one down, looks like a road going up there, road looks like a hotter temperature, there's a structure in the woods there, hard to see what it is, could be a truck, could be a building, there's a bush by the road here"
    - [Image disappears]
    - "There's a stop sign too, so looks like the road came to a T"
  - I2:
    - "Another three images, looks like same images as before except upside down, top image is black, middle—yeah, definitely same as before, middle image shows area that's hot, a road that's a different temperature than the surrounding grassy area.
  - I3:
    - "Three images again, looks like all three images are the same thing, first is visual, bottom two are infrared, looks like the test range, got a

car going down the road, looks like the downtown area in the background—hard to find the little details on there."

- I4:
    - "OK, image, got a big truck there, looks like it's recently driven up there because we've got hot spots there, it's in the trees, maybe a humvee, looks like something in the bed there, definitely recently driven vehicle because the engine compartment is white in the IR"
- I5:
    - "OK, another picture of a truck, definitely a humvee, there's something up against it, a screen or a solar panel, I don't know, definitely recently driven up there because of tracks in the snow, there's snow on the ground, a little muddy"
- Score: 950

- Questions
    - 1. How would you describe your experience overall with this testing session?
        - "Gets easier over time, but it's a lot of things to pay attention to—anywhere from 4 to 6 simultaneous tasks you have to do. It's difficult, but once you get into a practice of putting your mouse button over the arrow [on the math task] and knowing you have to click 4 or 5 times, then look over, but I must have got it wrong sometimes because I heard the 'clank' sound. Definitely a good exercise in situational awareness."
    - 2. How did this session compare to the last session?
        - "It was much more difficult because in the last one I just had to focus on the pictures and I could get the little details. In this one, you didn't have time to analyze, you just took a snapshot and had to analyze what you saw."
    - 3. Did you feel overwhelmed or stressed out?
        - "A little bit at first. I was getting frustrated with the silly mistakes on the math, but once I got into a rhythm, it got easier, more second-nature."
    - 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?
        - "Having them on the same screen—I would have been able to use my peripheral vision or real quick glances. Turning my head took up valuable time. Even if the images had to be a bit smaller, that would be easier to do."

Subject 10 (2Lt., Female)

- SynWin session 1 – Practice
    - When program opened, says "Wow, there's a lot to do here"
    - When asked to let the fuel run out, leaves it at zero for a little while until told to refuel—score will be lower because of this
    - Score: 1484
- SynWin Session 2 – Practice with imagery
    - I1:
        - [Image disappears}
        - "That was quick. That was the truck one, there was a white truck, there was a street."
    - I2:
        - "This one's upside down, and there's a truck, it looks like a truck, and a crane, there's trees and a street and it's very hard for me to tell what's going on in the bottom two [when asked why after the study, she stated that she couldn't tell what was in the pictures because "They were dark, they had white specks in them—it didn't help that they were upside down. In the top one I could tell what it was, in the bottom two it was hard to tell if they were even showing the same thing as the top one."]
    - I3:
        - "This view is from higher up. There's a road and runways because they're long and straight. There are trees and there are two runways."
    - I4:
        - "This one, there are trees, it looks like railroad tracks in the background because they're long, two parallel lines running across the bottom. They're running something through the trees, but I'm saying that from before, so I don't know."
    - Score: 1842
- SynWin Session 3 – Real images
    - I3:
        - "This, there is a road with trees, in the background it looks like two runways because they're long, different from the grass around them, they're parallel to each other, they're…"
        - [Image disappears]
    - I4:
        - "There is a truck surrounded by trees, it looks like it has an open back, it doesn't look like there's anything in it from this picture, the front of it is hot—it's whiter than the rest, and"
        - [Image disappears]
        - "something was also hot by the back tire"
    - I5:
        - "This is also a truck that is painted in camouflage and there's a screen or something leaning up on it, it's square and has white edges and there's also nothing in the back of the truck."

- I6:
    - “Um, it’s kind of hard to tell what’s going on in this one because the things going on are smaller, but there are two small objects and the one on the right is rectangular, and it looks like they’re on a road or something different from the surroundings, there are bright spots on the top of the”
    - [Image disappears]
    - “I don’t know if they were buildings or something else.”
- I1:
    - “In this one it looks like there might be tracks with something at the top of the tracks and something at the bottom that might be a vehicle. It looks like it might have wheels and there’s something at the top of the tracks and there are trees all around it and”
    - [Image disappears]
- I2:
    - “This looks the same as the last one except that it’s upside down. It has the car with the tracks behind it, there are a couple of trees in the front and maybe”
    - [Image disappears]
    - “a pole next to the car, like a telephone pole?”
- Score: 1641

- Questions
  - 1. How would you describe your experience overall with this testing session?
      - “It was mostly fun—there’s a lot going on, I’m not used to doing that many things at the same time”
  - 2. How did this session compare to the last session?
      - “This was much more stressful, the activities in this one.”
      - [What about your descriptions of the images, how were those different?]
      - “I was not nearly as descriptive—there wasn’t as much time to look at them, and even when I was looking at them there were other things going on.”
  - 3. Did you feel overwhelmed or stressed out?
      - “When the pictures disappeared, that was the most stressful, because there was more to say about them and I wanted to say more about them.”
  - 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?
      - “If they were all on the same screen [the tasks and the images] that would be more helpful. Maybe if the sounds were more different from each other.”

Subject 12 (1Lt., Female)

- SynWin session 1 – Practice
  - "Oh my god, there's so much going on!"
  - "Holy crappers, there's a lot of stuff going on."
  - [Leaves the needle at zero for a while when told to hear the sound—results in a low score—refuels when reminded]
  - [Lets fuel run out accidentally and has to be reminded that she's losing 50 points for every second it's a zero]
  - Score: -94
- SynWin Session 2 – Practice with imagery
  - I1:
    - [Image disappears]
    - "That's it?!"
  - I2:
    - "It's upside down—on purpose? OK, it's upside down, it's a street, there's a van out there, and a truck parked out there in the distance, cars driving by—looks like the street right up here [outside the building]. And then maybe zoomed in on the other [IR] images."
  - I3:
    - "OK, well, I see a road, I see cars on the road, trees, looks like it's on the base, the abandoned runways out on the left, the hanger there on the right, cloudy day it looks like up top, looks like the two down below are zoom-ins of the runway"
    - [Image disappears]
    - "and that's all I get"
  - I4:
    - "OK, looks like close-ups, forest scenes, trees, might be a road or tracks, or something behind that….I don't see much else, just looks like trees"
  - Score: 449
- SynWin Session 3 – Real images
  - I2:
    - "OK, looks upside down, can't see anything on the top image, maybe a street with trees and stuff around, some kind of clearing, yeah, a street, looks like it's splitting, yeah, if you re-reverse it, it looks like it's splitting."
  - I3:
    - "Looks like the runway here on base, and the street leading up to I where the gate's at, lots of trees, it looks like they're zoomed in on the bottom ones, there's something overlapping on the bottom one, could be from wherever the person was taking the picture, could be a boom or a window or something."
  - I4:
    - "OK, this is sideways maybe, no, doesn't look sideways, it looks like a street, and a truck parked at the end of this clearing kind of thing, it

has side rails, and trees all around that look sort of foresty, or off the beaten path."

- I5:
    - "OK, this looks like maybe a zoom-in of that same truck, it's in color, it's got some kind of screen, I don't even know what that is in front of it, it's camo painted, there are trees around."
- I6:
    - "OK, this one's a little harder to see, it looks like the runway again, there's two of them, looks like some trailers out there, they look lit up or something, I can't really tell what it is, but there's some kind of structure there on the runway, maybe toward this end [foreground] "
    - [Image disappears]
    - "That's about all I can see. There's not any trees around, it's clear, that's why I said it's a runway."
- I1:
    - "Three pictures, can't see the top, seems right side up, trees, looks like some sort of street or road, some sort of clearing off a main road, I can see tops of trees up close, looks like there's some sort of structure at that Y point"
    - [Image disappears]
    - "Yeah, at the top of that Y point, in the clearing that goes off the road, there's a structure—I can't tell if it's a truck or a trailer or something."
- Score: 1052

- Questions
    - 1. How would you describe your experience overall with this testing session?
        - "It seems like with the added stress of having to perform [with the images], I could do better at the tasks [SynWin]. There wasn't much time to describe the pictures, so you had to figure out the basics quickly and figure out what you're looking at quickly. I have my private pilot's license, and it reminds me a lot of flying, looking from one instrument to another, you have to quickly recognize what you're seeing because you don't have time. It's kind of fun!"
    - 2. How did this session compare to the last session?
        - "Definitely there's no stress in the last session, all the time in the world to nit-pick what I was looking at. This time the stress made you figure out quickly."
    - 3. Did you feel overwhelmed or stressed out?
        - "Not so much. Compared to the last time, yeah. It's overwhelming like flying a plane is overwhelming, but your eyes and mind just have to get used to going from one item to the next. You can't dwell on any one thing. I'm not sure I'd want to do it for 10 hours, but…"
    - 4. Is there anything that could have helped you interpret the images more effectively, given the other tasks and the time constraints?

- “If they were on the same screen somehow, so you don’t have to move your whole head, just your eyes, so you could use your peripheral vision. Anytime there was something obvious, like a tree, so you could use the size to compare other things to, like ‘this is a vehicle.’ Parts of it I know because it’s on the base, so I know, but if I didn’t know, then it would be helpful to have that reference. I mean, some of them were obvious, like a road with cars on it, but …”

APPENDIX G: EMPIRICAL EVALUATION RESULTS

Pilot 1 (Maj., Male)—Unfused imagery

- Target 1 (Cold woodchipper)
  - Time:
  - ID: Pickup truck
  - Designation: Neutral
  - Confidence rating: 4
  - Thought process:
    - "I used the visual image to identify the pickup truck. I declared the target neutral because there was no white in the infrared associated with the truck itself"
- Target 2 (Hot woodchipper)
  - Time:
  - ID: Intersection, 3 hot vehicles
  - Designation: Hostile
  - Confidence rating: 5
  - Thought process:
    - "I only expected one vehicle, but saw multiple. The third image [Phoenix] didn't help much—based the determination on the second one [Jade]. Designated the target because each of the vehicles looked white."
- Target 3 (Humvee)
  - Time:
  - ID: Humvee
  - Designation: Hostile
  - Confidence rating: 5
  - Thought process:
    - "It was an obvious warm vehicle. Both IR images showed white on the vehicle. I only had to look at each image once to see that."
- Target 4 (M5)
  - Time:
  - ID: Car in a field, surrounded by trees
  - Designation: Hostile
  - Confidence rating: 2
  - Thought process:
    - "My first thought was 'is there even a vehicle in this picture somewhere?' I picked up the white dot on the second IR image [Phoenix], then when I got back to the visual image I verified. If it had been a real combat situation I would have gone back and reconfirmed that one."

Pilot 2 (Lt. Col., Male)—Unfused imagery

- Target 1 (Cold woodchipper)
  - Time: 13.28
  - ID: Pickup truck with some machinery
  - Designation: Neutral
  - Confidence rating: 4
  - Thought process:
    - "In this situation I have a very large field of view for the optical target, and I don't see a large contrast in the IR scene, so I declared a neutral. It's a confidence of 4 neutral, because when I look at it I can imagine some contrast there, but I'm pretty confident, 4 that it's neutral."
- Target 2 (Hot woodchipper)
  - Time: 8.00
  - ID: Pickup truck
  - Designation: Hostile
  - Confidence rating: 5
  - Thought process:
    - "I could definitely tell there were hot vehicles—this was the group of 2 or 3 hot vehicles, so just based on the heat contrast I was able to designate. The heat contrast was good, so based on the contrast alone, it was definitely hostile in my mind."
- Target 3 (Humvee)
  - Time: 12.85
  - ID: Half-track vehicle
  - Designation: Hostile
  - Confidence rating: 5
  - Thought process:
    - "This was a close-up shot, so I had good contrast and resolution, based on the visual, it looks like a half-track vehicle. That's good contrast there, in the first IR, in the second IR. So that was about a 5 confidence on designating hostile, again, based on the IR contrast."
- Target 4 (M5)
  - Time: 18.81
  - ID: M5
  - Designation: Hostile
  - Confidence rating: 4
  - Thought process:
    - "OK, here's a situation where the field of view is very wide compared to the target size, so that decreased my confidence a little bit, but I still was able to pick out in IR a good white on dark contrast there in the grassy knoll in those mountains, so I would call that a 4. You can see I'm leaning in trying to see the target there, but it's a good point contrast. It's just a wide field of view, otherwise I would have gone 5."

Pilot 3 (Capt., Male)—Unfused imagery

- Target 1 (Cold woodchipper)
  - Time: 14.78
  - ID: White Chevy truck
  - Designation: Neutral
  - Confidence rating: 5
  - Thought process:
    - "So I could definitely see that it's a white truck from just the visual, and then the other, the IRs, I was looking for tires, but I couldn't find any hot engine."
- Target 2 (Hot woodchipper)
  - Time:20.93
  - ID: White truck
  - Designation: Hostile
  - Confidence rating: 3
  - Thought process:
    - "OK, now the confusion sets in, because it's same picture I just saw. I see the white truck. I'm thinking that's what we're going to be going after again, so I cycle through again, and now [jade] I see hot, all over the outside of the car, I try one more time the next sensor [phx], and now I make out what I thought was a hot engine"
- Target 3 (Humvee)
  - Time:13.0
  - ID: Half- track personnel carrier
  - Designation: Hostile
  - Confidence rating: 5
  - Thought process:
    - "Right here, this is the first infrared, I can see the engine compartment where hot metal might be, and especially the front, the tires are all hot"
- Target 4 (M5)
  - Time: 19.75
  - ID: Tack APC
  - Designation: Hostile
  - Confidence rating: 5 for hot, 2 for APC
  - Thought process:
    - "Here I couldn't even see the target, so I cycle through, and I didn't even know what the target was, and now [jade] I can see that there's something definitely hot. In the final one [phx] I can make out a tank APC, a tracked vehicle. My confidence in that being hot is high, track is high, tank or APC—2."

Pilot 4 (Maj., Male)—Unfused imagery

- Target 1 (Cold woodchipper)
  - Time: 6.57
  - ID: Civilian truck
  - Designation: Neutral
  - Confidence rating: 3
  - Thought process:
    - "That was the…A lot of color was what I used to determine if it was civilian or not, but it just didn't have the boxed off characteristics that I would see in a military vehicle. It didn't look like the engine was hot, it looked like it was all cold."
- Target 2 (Hot woodchipper)
  - Time: 32.79
  - ID: Civilian truck
  - Designation: Hostile
  - Confidence rating:3
  - Thought process:
    - "This to me looked like the same exact setup as before, except there were two vehicles in front that were passing on the road or whatnot. So if I remember right, I just gained confidence based on the fact that I saw a similar image again—I don't think I got anything different from this look."
- Target 3 (Humvee)
  - Time: SIMULATOR MALFUNCTION
  - ID:
  - Designation:
  - Confidence rating:
  - Thought process:
    - ""
- Target 4 (M5)
  - Time: MISSED
  - ID:
  - Designation:
  - Confidence rating:
  - Thought process:
    - "I didn't expect it be so far away. I thought I saw a blue vehicle on one of the access roads in the runway environment. I mostly based my decision on whether it was a military or civilian target based on the color. When I cycled through I didn't get any more information. When I cycled, nothing in the infrared gave my anything, at least I wasn't very confident whether the engine was hot or anything like that because of the distance."

Pilot 5 (Maj., Male)—Unfused imagery

- Target 1 (Cold woodchipper)
  - Time: 5.41
  - ID: Truck with yellow vehicle--wodchipper
  - Designation: Neutral
  - Confidence rating: 5
  - Thought process:
    - "The visual was very striking, there's a lot of contrast involved, you can see the truck by the trees, and it had that yellow-whatever-that-was behind the trailer, and then when I cycled through the IR, it looked cold. I used the visual to identify, and then the IR to declare."
- Target 2 (Hot woodchipper)
  - Time: 10.75
  - ID: 2 trucks and a car
  - Designation: Hostile (but on wrong target)
  - Confidence rating:4
  - Thought process:
    - "Now, I was a little confused by this scene, because it appeared to me that the visual was…mybe this is farther over in the frame than what the IR was showing, because I thought that looked like a different vehicle type to me. But when I was cycling through, I could see where it is in the frame. I saw three vehicles here, they were easy to identify in the visual, and I'm trying to correlate the visual to the IR. The car is hot, you can see the heat of the tires and the hood. The truck in the background [w/woodchipper] still looks cold. It looks like the same truck as before, previously, as far as it has a trailer on the back, um, and the truck to the left [on the road], it looks hot, but I can't be 100% sure, I didn't get the IR cues that I did with the car. So I designated the car, so the car was a 5, and the truck that was in the street was more of a 4. And I would like to have cycled through that, obviously, I would have liked to have more time just to verify that I was seeing what I thought I was seeing and I wasn't designating anything just because of its position."
- Target 3 (Humvee)
  - Time: 7.28
  - ID: Humvee—truckbed type
  - Designation: Hostile
  - Confidence rating: 5
  - Thought process:
    - "This Humvee filled up the whole screen, sot it was very easy to identify visually. This infrared right here [Jade] I could see that the cab was hot, the tires were hot, the hood was hot, the tracks were also hot. I wanted to see heat from the other band [Phx] but it wasn't as vivid to give me those cues. But all three of those build upon each other to show me the target, so I was pretty confident on that."
- Target 4 (M5)

- Time: 32.52
- ID: Hot target—don't know what
- Designation: Neutral (due to no positive ID on the target)
- Confidence rating: 1
- Thought process:
  - "In this one, I couldn't really see the target that I was looking for until I cycled through to the infrared. So there was a lot of background involved, a lot of concrete, a lot of dark shade and light shades. So you can see I'm kind of leaning in there, trying to see what it is. But once I cycled through to the infrared, I could see there's something hot over along the treeline. But I was never able to resolve whether that was a vehicle or not. I couldn't make out the shape enough for me to be confident in the target. So as far as the designation goes, I know that there's something there, but I felt like it was a 1, because I didn't…I couldn't make out that definitely that was a vehicle and not some small hut or something."

Pilot 6 (Capt., Male)—Unfused imagery

- Target 1 (Cold woodchipper)
    - Time: 9.34
    - ID: Civilian vehicle
    - Designation: Neutral
    - Confidence rating: 5
    - Thought process:
        - “”
- Target 2 (Hot woodchipper)
    - Time: 4.00
    - ID: No target
    - Designation: Neutral
    - Confidence rating: 4
    - Thought process:
        - “[Vis] What I was thinking is I saw a road, didn’t look militarized, I saw vehicles there, I thought ‘they must be OK,’ and I didn’t even change it to IR there. In my mind it didn’t look like a military environment. So I did not designate.”
- Target 3 (Humvee)
    - Time: 9.87
    - ID: Humvee
    - Designation: Hostile
    - Confidence rating: 5
    - Thought process:
        - “[Vis] That one, the truck itself…my first thought was ‘Well, no one’s in it! Looks like it’s been there for a while’ OK, rules of the game, have to check to see whether it’s hot or not. Flip the thing [to Jade], looked hot. It must be designated. It’s been recently driven. And then my second thought was ‘What the hell is that white thing doing there?’ It’s kind of a side, thing, why is that thing there, I was trying to figure out as an afterthought, why is it there when it doesn’t fit the picture.”
- Target 4 (M5)
    - Time: 15.0
    - ID: Car in clearing
    - Designation: Hostile
    - Confidence rating: 4
    - Thought process:
        - “This one was a little weird for me, because my first thought was that they’re not all at the same scale. They’re different scales, you have one farther away, and one focusing in, it all looks like you’re focusing in on the car. So when I went to the white-hot image, it was a hot car in the middle of this ravine right over here, so I said that must be a target, designate it, although it looks like a very civilian scene because I’m used to WPAFB, and seeing that it’s WPAFB there shouldn’t be anyone there. I was seeing Mig-29’s like

I was in Russia, so it didn't lend itself to being something I should designate, but by the rules I did because it was white-hot."

Pilot 16 (Maj., Male)—Fused imagery

- Target 1 (Cold woodchipper)
  - Time: 6.38
  - ID: Truck
  - Designation: Hostile (but then says "But it's hard to tell—it may be cool")
  - Confidence rating: 1
- Target 2 (Hot woodchipper)
  - Time: 8.16
  - ID: Truck
  - Designation: Hostile
  - Confidence rating: 5
- Target 3 (Humvee)
  - Time: 23.47
  - ID: Humvee
  - Designation: Neutral
  - Confidence rating: 4
- Target 4 (M5)
  - Time: 23.91
  - ID: Car on the road [wrong target]
  - Designation: Hostile
  - Confidence rating: 4
- Question 1: What is your overall impression of the imagery system that you just used?
  - "It was difficult to use. On the first one, the truck—everything around it was red and a small bit was blue-green. There wasn't enough distinction in the engine compartment. With the car on the road, I couldn't see the target because I thought the colors would make it easier, but they made it more difficult. I was distracted by the background and the noise."
- Question 2: Did the way in which the images were presented help you to determine what the target was?
  - "On all of them except the last one, just because they were so big. But the last one seemed the most realistic because it was a further range, further away. In my experience, I've never gone after a target at a low level except for in training. Especially with targeting, we're usually at a medium level."
- Question 3: Would a system like this make your job in the cockpit easier?
  - "It could with the right training. In this simulation, they were just pictures—it would be different if it were actual moving imagery, or live imagery. It's easy to tell these were just pictures."
- Question 4: If you could change anything about the system, what would it be?
  - "I guess…[long pause]…increase the contrast."
- Question 5: How does this system compare to any automated targeting systems you may have used in the past?
  - "It's similar, I guess, just in color—all I've seen is the monochrome, or the green and white, basically. I do like the color image with no infrared as another system, because I haven't seen that before."
- Low-stress model validation

- Cold Woodchipper
  - The things that I'm used to using, for a stationary target, is find the big things first, like the roads, I know my target should be here, north of the intersection [indicates truck and woodchipper]. And then if I'm looking for the actual target, here in the trees, I look for the truck—the square shape, the manmade shape of all vehicles. There's a trailer, and then, with the IR system, if it's white-hot or black-hot, I toggle back and forth to try to have that image jump out at me, hopefully the hot spot. As far as…with the truck, the things that stick out are the right angles, the things you don't see in nature much. The main thing is toggling back and forth between the white hot and black hot to see what jumps out at you. Things like the road jump out with the white hot and black hot."
- Hot Woodchipper
  - "I assume the white truck's still the target, but you have the possible collateral damage of the vehicles on the road. There's a runner on the road too, it looks like."
- Humvee
  - "In these ones, looks like the engine compartment is hot—this is the one I had trouble with, too. It looked like a lot of it was hot, like the bed was hot from the sun, and the engine compartment was warm. In this one, looks like there's a reflecting panel covering the wheel well, and in these two it's different. The sun does appear to be out [determined from visual], so it looks like the sun is warming up the roof and the cab. It's kind of hard to tell if the engine compartment is *really* hot."
- M5
  - "This one I thought was difficult—the main way I found the target was on the picture [visual]—I couldn't see it on the infrared ones. See it easily on the normal picture and I don't see it on this one at all. Now I wonder if there's another target here [indicates M5]…the car is the one I was looking at. Oh, and this one [M5] appears to be hot in the infrared. That's probably the target right there. This [M5] looks like the hottest target, with a cool background.

Pilot 17 (Maj., Male)—Fused imagery

- Target 1 (Cold woodchipper)
    - Time: 24.6
    - ID: Pickup truck
    - Designation: Hostile
    - Confidence rating: 4
- Target 2 (Hot woodchipper)
    - Time: 11.3
    - ID: Pickup truck
    - Designation: Hostile
    - Confidence rating: 5
- Target 3 (Humvee)
    - Time: 6.43
    - ID: Pickup truck
    - Designation: Hostile
    - Confidence rating: 5
- Target 4 (M5)
    - Time: 22.04
    - ID: Vehicle on the left [wrong target]
    - Designation: Neutral [later changed to hostile]
    - Confidence rating: 2
- Question 1: What is your overall impression of the imagery system that you just used?
    - "Difficult to use for me—somewhat difficult. Distinguishing the objects. It looks like there's something hot there, but for me it wasn't just a matter of seeing red, but seeing what's supposed to be red. So I picture in my mind, OK, it's supposed to be a truck, I'm supposed to see a hot engine block, and the outline surrounding the truck, but it just seemed like a smattering of colors. More like a Rorschach test."
- Question 2: Did the way in which the images were presented help you to determine what the target was?
    - "Yes, overall. It helps you move your eye to an area, a point on the screen, so you develop that contrast, and you go back to the visual image and you can say, 'oh, I see him hiding out in the trees, wherever he is. Worked well, I guess, hot on cold, when the one that had the vehicle on the highway that I originally designated as neutral, I saw that it was probably a high-traveled road, and it was hot, so it was going to be the same color. That's why I went back to 'designate.'"
- Question 3: Would a system like this make your job in the cockpit easier?
    - "Yes."
- Question 4: If you could change anything about the system, what would it be?
    - "I'm not sure…[later says seeing IR first might have been helpful because he got "task saturated with all of the information in the visual]"
- Question 5: How does this system compare to any automated targeting systems you may have used in the past?

- “I fly with a FLIR. The image is better than a FLIR, it just helps you break out more colors. IT seems like it might be….I would be interested to see how it works during crossover time—day or night, when thermal crossover, 2 hours before or after sunrise or sunset. When it starts to cool down. The ground and everything around it becomes the same temperature. It’s one of our particular challenges, especially with the FLIR.”

- Low-stress model validation
    - Cold Woodchipper
        - “[Vis]Looks like a target, it’s pulled off to the side of the road, looks like he’s using some kind of cover or concealment. [IR] I wouldn’t be able to tell much from this other than it looks like the vehicle hasn’t been there for very long. Just because there’s not much contrast There’s the really really cold snow, and then the vehicle that looks like it’s been there a short amount of time, but it’s not like somebody just turned off the engine [does he mean it’s been there for a while?]. I don’t see really any significant heat marks. So the vehicle looks like it’s cold compared to everything else, no fresh tracks standing out. Same thing with that one [PHX]”
    - Hot Woodchipper
        - “In the color one, not a whole lot of information there, just a car off the road, but I can’t really glean much from that. [Jade], definitely draws your eye to it, pulls it out of the picture, compared to the other vehicle it definitely seems like it’s very warm, like it just recently ran. The tracks leading up to it look cold, so it’s been there a while. But it’s been running. [PHX] Same type of thing, very bright, stands out against everything. No really warm tracks leading up to it. Looks like the engine might be running, but the ground underneath it’s not showing too much of a heat signature, so it’s hard to tell from this angle.”
    - Humvee
        - “[Vis] Well, it looks like a military vehicle, which is a nice thing to know. I can see the camouflage. [Phx] I don’t really get too much from that one. Doesn’t look like it’s been running or anything else, looks like possibly just the sun hitting it. Just heating up the metal. [Jade] Same thing here. Something that’s out there—whatever that reflective thing is—is not absorbing any heat. In the previous two, I could distinguish where the tracks were leading up to it, the ingress or egress for the vehicle, but I don’t have any of that data. Looks like it’s just sitting there, almost abandoned. ”
    - M5
        - “[Vis] Again, just tells me it looks like a major road, not very well-traveled, I can pick out one vehicle on the road. I see the vehicle now, or something on the hillside. It’s in the center of the picture, but I can’t tell what it is at all, I don’t know if it’s a manmade object or a vehicle, or a structure. [phx]Now the vehicle on the road blends in with it, so I think it’s a well-traveled highway, the vehicle on the

road blends in with it, both hot. Didn't initially look like it's moving, but now that stands out more, the contrast in the trees. At this angle it looks like a hostile vehicle. [Jade] There's something going on in the trees, you can tell. Which I didn't know before—I got task saturated trying to discern the car on the road in the sim. So having the visual picture first probably took my attention away from seeing anything else. I used the infrared images to help discern what was going on in the visual picture, instead of the other way around. So maybe the order in which they are presented might be a better—possible… "

Pilot 18 (Lt. Col., Male)—Fused imagery

- Target 1 (Cold woodchipper)
  - Time: 17.50
  - ID: Truck
  - Designation: Hostile
  - Confidence rating: 5
- Target 2 (Hot woodchipper)
  - Time: 4.94
  - ID: Truck
  - Designation: Hostile
  - Confidence rating: 5
- Target 3 (Humvee)
  - Time: MISSED
  - ID:
  - Designation:
  - Confidence rating:
- Target 4 (M5)
  - Time: 14.06
  - ID: APC
  - Designation: Hostile
  - Confidence rating: 3
- Question 1: What is your overall impression of the imagery system that you just used?
  - "Very good. I think it's very good. What I like about it, when you have the contrasting colors, it's very easy to tell red is red, and it jumps right out at you."
- Question 2: Did the way in which the images were presented help you to determine what the target was?
  - "Yes, very much so. When you cycle through it, it gives you more feedback, and a better process with which to make a decision. You have an initial opinion, and then with more data you refine the decision."
- Question 3: Would a system like this make your job in the cockpit easier?
  - "Very much so."
- Question 4: If you could change anything about the system, what would it be?
  - "I don't think there's anything much in the imaging…I guess if you're not used to looking for that particular image…training. More training. I just got one quick brief overview—if you were trained more, it's be more adherent, so maybe do that. "
- Question 5: How does this system compare to any automated targeting systems you may have used in the past?
  - "It's comparable, but it has those advantages. Color is good for people who have good color vision."
- Low-stress model validation
  - Cold Woodchipper
    - "[Jade] You have vehicles off the road there, they don't look very white in that shot. [Phx] They don't appear to be...the tires look like

they may have moved, there's some white in there, but it's hard to tell in that. Again, it looks like you have a background that's hard to pick up against. So contrast isn't very good. Again, this is the truck that I saw in the sim. But anything hot was gonna die, so he's dead."

- Hot Woodchipper
  - "[Jade] Ooh, we have some snow in the picture here, a lot of vehicles, obviously same vehicle again, there's other moving vehicles in the picture. [Phx] Now it's a different picture here, the other vehicles aren't in the picture. This one I'm trying to tell, you have a band of white throughout the picture there, so it makes it a little harder to pick up also, the tires show up very well though. It would be hard to tell what was in the trailer there, whether it was an anti-aircraft gun vs. a chipper-shredder, but now I know it's a chipper-shredder from the visual. I would think overall color is better than shades of gray. But I'm not sure what kind of contrast you're looking at when you have glare in the cockpit on those colors, so definitely be something to look at. But I think color is good."
- Humvee
  - "[Jade] Obviously the white jumps out at you, it shows you where the engine it hot, and there's some white in the crew compartment, so there might be persons inside of it. As far as identifying it, it's a flatbed, a truck, but you can tell there's not anybody, it's not carrying any troops in the bed. [Phx] A little better, obviously the truck was recently moving because the tires are hot, and the tracks. [Vis] OK, now I see a color picture, if you didh't know what it was you could identify markings, things like that. There's some kind of reflector there, that's why you're not seeing the back tire. It hides camouflage, and you couldn't see it with the infrared sensor, but obviously with the optical sensor you could tell exactly what it is."
- M5
  - "[Jade] This one, looking down at Area B, I can see the runway, I can see downtown Dayton, I can see the museum hangers right there. [Phx] Second picture a little bit more of a closeup image from the first one, I can see bright stuff between the trees there, you can't really make out what it *is*. Looking at the building there, that's the bottom of the hill and the intersection down there. Obviously identifying the white infrared tells you something is hot, but there's not enough visual acuity to tell exactly what that is on the infrared shot. Obviously I know the area. I like having the visual overlay—you can tell exactly what that is."

Pilot 19 (Maj., Male)—Fused imagery

- Target 1 (Cold woodchipper)
  - Time: 25.53
  - ID: Non military vehicle pulling machinery
  - Designation: Neutral
  - Confidence rating: 2
- Target 2 (Hot woodchipper)
  - Time: 7.47
  - ID: Truck carrying piece of heavy equipment again
  - Designation: Hostile
  - Confidence rating: 4
- Target 3 (Humvee)
  - Time: 3.31
  - ID: Humvee
  - Designation: Hostile
  - Confidence rating: 5
- Target 4 (M5)
  - Time: 11.4
  - ID: Troop transport
  - Designation: Hostile
  - Confidence rating: 4
- Question 1: What is your overall impression of the imagery system that you just used?
  - "Looks like a great idea, hopefully it will be able to work as shown there. One distraction would be the one example where the terrain masked the heat of the truck. I think that would be the exception to the rule, though—typically you wouldn't see the terrain as hot as the truck around it, unless it's neutral, which is the issue there, so in that instance it would work well."
- Question 2: Did the way in which the images were presented help you to determine what the target was?
  - "Yes—that was a good capability of flipping between the different options."
- Question 3: Would a system like this make your job in the cockpit easier?
  - "Yes"
- Question 4: If you could change anything about the system, what would it be?
  - "If it were possible to array the actual picture with the infrared as a 4th option, where the picture of what it actually is is on top, and the infrared just subtly underneath it, if that's possible. The one that would have helped the most on would be the first one [M5] where it's a wider picture, and you can't really see what you're looking at, and you can say, 'Oh maybe that's a truck there, but I can't really see it, then you flip over to the infrared, and say it's definitely a hot threat,' that might help out a little bit."
- Question 5: How does this system compare to any automated targeting systems you may have used in the past?
  - "For the ones that we have, where we would target something, it's a lot better—it's a lot easier to switch over there and see what it was with the way it's set up, with the thumb switch."

- Low-stress model validation
  - Cold Woodchipper
    - "[Jade] A little bit harder to see here, I can differentiate the tires, the rear tires, you can tell that it's carrying something you can tell that it's two separate things, if not then it's hinged in the center. Looks like the truck pulling something in the center there. Then you switch over to the actual picture, and that's exactly what it looks like. It looks like a woodchipper. But at the same time, when you look at with the infrared, it looks like some kind of weaponry, when you look at the actual picture you can tell that it's not. These two [IR] not as good as the other one [hot WC] in terms of differentiating hot and cold. This more looks more like a black and white photo. Hard to tell anything different. It is changing… You can see the tires and everything, but this sequence doesn't tell me much, and I wouldn't get too much information from it"
  - Hot Woodchipper
    - "[Jade] Right here what I'm looking at are the wheels, showing that the wheels are hot. [Vis] In this one, the visual, I'm looking at it and I see it's a truck I can't tell what it's pulling, obviously, I can't tell what's behind that tree, but it looks like a vehicle of some sort as well. Then you go over here [Phx] and you can't really tell that either, it's meshed in with that, and that can provide some difficulty as well. Unless it's all one thing, but it doesn't really look like it is. Here, I can also use the whiteness that shows that it's hot to differentiate where the front of it is as opposed to the back, so that's the engine up there, and back here it's a little cooler, so that's the back part. I can tell that this whole thing is hot, but I can't tell what it is. It has an arm up there, so I'm thinking, 'Wow, that might be a gun,' but when I switch to the visual, it doesn't look like a gun at all. This one [Jade], basically the exact same thing, a little bit better differentiation between the tires, better pickup of the other two cars right there, again you can tell the front of them to tell which way they're going."
  - Humvee
    - "[Jade] With this one, using the IR, you can basically tell what it is. You can differentiate between the wheel, and the engine, and the back of it where it's not as hot. You can tell that there's something in front of it [FSA] that's not at all like the rest of it, so it's a separate thing. When you flip over to the actual picture of it, you can tell that it looks like a dry erase board or something. This clarifies what it is. [Phx] In this infrared, a lot more clear on the heat and the difference in the tire—you can also see the track a little bit better. The sign being move there shows the back wheel, and how it's not quite as hot as the front wheel. Probably the brakes are in the front, that could differentiate that. [Jade] This looks like it's been here a little bit longer, because it's a little cooler, they've also moved

the sign over to block the wheel. You've lost all sense of the tracks in this infrared as well, that's why I would say it's been there longer, but you can't see any tracks at all. [Phx] I don't know if you'd be able to see people in it or not the way the infrared picks up, but I can't see anybody in there. That would be an interesting question, to see if you could see that."

- M5
  - "[Jade] This is a good one. [Jade]You can really see a hot item right in the center there. Without the color…the color really, in this one actually, this is a little better than the color. With the color I remember there being a lot of red. This one, I think maybe the gray-white scale would actually assist, where with the other [targets], I think the red one was better. Looking at the picture [vis] you can see that there is something there, can't tell what it is, it looks like a big vehicle. Over here you can see a standard car, and it looks bigger than that, so that's why I chose a troop transport when I saw it. [Phx] This one is a little bit harder to tell. You can tell there's something hot in there, but you can't really tell what it is, for all you know it could be a fire or something. There's a couple of random hot spots as well that I can differentiate. Going back to the photo [vis], you can tell what it is you're looking at, so when you're looking at the two next to each other you can compare it and see. And once again, in this one [Jade] you can readily see the difference in the buildings and the trees with nice clarification of the vehicle that's hot. I like the way the infrareds can pick up more detail that you can't necessarily see to the eye, and possibly bring it to your attention. This one shows me something that's right there [a bright spot in Phx], so I can go back to the other picture [vis] and say, 'OK, did I miss something there?' Well, there's a piece of road right there, so it could be that or it could be something in the trees. It can't tell me what it is, but it can bring the threat to my attention, or tell me that there's a possibility of something being there. Which I wouldn't have known about before. Now I can say, 'That looks like a road, but I'll keep my eye on it just in case.' Now you go over to this one [Jade], and you can't see much in that spot, it's hidden, but you can see other things that you didn't notice before [in vis] or wouldn't have seen before [in vis]."

Pilot 20 (Maj., Male)—Fused imagery

- Target 1 (Cold woodchipper)
    - Time: 20.24
    - ID: Pickup
    - Designation: Neutral
    - Confidence rating: 4
- Target 2 (Hot woodchipper)
    - Time: 20.44
    - ID: Same truck
    - Designation: Hostile
    - Confidence rating: 5
- Target 3 (Humvee)
    - Time:11.78
    - ID: Humvee
    - Designation: Hostile
    - Confidence rating: 5
- Target 4 (M5)
    - Time: 16.96
    - ID: Vehicle—maybe a truck
    - Designation: Hostile
    - Confidence rating: 5
- Question 1: What is your overall impression of the imagery system that you just used?
    - "I would say it has a lot of potential. Having the color codes is nice. I understand that you have limitations on fidelity, and being able to tweak it. But being able to go from an IR image to an optical image, to an IR image and being able to cycle through that real time, it's very helpful."
- Question 2: Did the way in which the images were presented help you to determine what the target was?
    - "Yes, the only that I think would have helped on at least one of them, is I wish I could have gained down, just played with the gain of the IR image to try to really discern if the truck was really hotter than the background. Because there was one where the road leading to the truck was red, and truck was red, the background was blue, but if I could have just gained that down to discern the difference between the road or the truck, to see if the truck was actually more hot relatively speaking than the road."
- Question 3: Would a system like this make your job in the cockpit easier?
    - "Yes"
- Question 4: If you could change anything about the system, what would it be?
    - "I'm sure if you had something like this you'd also be able to zoom in. To be able to change the field of view, to expand the field of view would have been helpful on the second target [M5]."
- Question 5: How does this system compare to any automated targeting systems you may have used in the past?
    - "Good. I don't know if anything I've used is actually considered automated. But it's better than anything I've…it has the potential to be better than

anything I've used. I mean, if you've got 256 levels or 512 levels of grayscale, then you can get a better image than the 4 levels I saw. So it goes back to increasing the fidelity of the picture. But it's really good to be able to go back and forth between optical and IR."

- Low-stress model validation
  - Cold Woodchipper
    - "Looking at the optical [vis] image, there's a road intersection, on the far side of the road intersection, I would expect to see a vehicle, and what looks like a woodchipper, and then flipping over to the IR [Jade], given the time of day, in the previous photo, the foliage is probably cold, so I would expect the vehicle, if it was running, to be much hotter than the background, and if it was wasn't running, to be not as white-hot as the background. So looking at that, it looks to me that it probably isn't running because there's not a lot of contrast between the vehicle and the background, the woodchipper and the background if they were just running that. [Flips to Phx] Yeah [confirms]."
  - Hot Woodchipper
    - "Same issues on finding the target area, multiple cars in the area, and then an intersection . [Jade] Here it looks like the target area is much hotter than the background, so it's much more white than the background. The cars that are running are also showing the same—tires being hot, engine compartment being hot. [Confirms in Phx]"
  - Humvee
    - "If I had an optical [vis] image, I would probably start there. Understanding that camouflage and concealment could be easier to spoof, but I would start there, and then I would go from there to matching up what I saw in either my target photos that I'm stepping out to go fly with that is old, or to compare between the optical image and the IR picture. [Jade] So right away, I get the contrast of this door that is leaned up against the Humvee, I can confirm that it looks like some kind of panel with a low IR reflectivity leaning up against the Humvee. I would expect that to show up really well. There are the different paint schemes, and possibly the time of day, and all the crossover things associated with it, thermal crossover. But I would expect to see some contrast, and that would really force that picture in my mind. [Phx] Here, this is great, if you could actually see this kind of IR detail, where you can make out the different paint scheme, I've never seen that kind of detail before. That would be great. And it looks like the panel moved in that picture, it got moved away from the tire/"
  - M5
    - "[Vis] OK, big to small, funneling features, I see there's something out in the open, which, my initial reaction would be it's probably not a hostile, because it's probably not sitting out in the open, but that's not what I would expect them to do, so that would catch my eye. I

also see this curved road in the foreground that curves around, that could lead me to my target area, and then you can see the road in the IR picture [Jade], matching that up [to the visual]. [Phx]Up here, the same funneling features, the short grass is cold, assuming this is white-hot, and then over here, once again, the same kind of funneling features to that open area. There's something white-hot—that car is definitely hot compared to the background"

Pilot 16 (Maj., Male)—Fused imagery

- Target 1 (Cold woodchipper)
    - Time: 7.22
    - ID: White pickup truck
    - Designation: Neutral
    - Confidence rating: 4
- Target 2 (Hot woodchipper)
    - Time: 14.59
    - ID: Pickup truck
    - Designation: Hostile
    - Confidence rating: 3
- Target 3 (Humvee)
    - Time: 8.01
    - ID: Humvee
    - Designation: Hostile
    - Confidence rating: 4
- Target 4 (M5)
    - Time: 16.88
    - ID: Unable to ID
    - Designation: Neutral
    - Confidence rating: 2
- Question 1: What is your overall impression of the imagery system that you just used?
    - "I thought it was better with color than it would be with just black and white. The color adds to it. There should be some more training and see some more images. With the one I was kind of low confidence on, it was a red background, and the truck was red, so I didn't know if it was gained down from the background or if it was a hostile vehicle. Obviously, that's important, because just because a vehicle has driven through a hot area, doesn't make it hostile. But I'd have to see the images, get some more experience with that."
- Question 2: Did the way in which the images were presented help you to determine what the target was?
    - "I didn't get much difference in the 2 IR images. Didn't seem like I had…where it's pretty obvious in white-hot, when you go white-hot, black-hot, white-hot, black-hot in a targeting pod, it provides a good contrast to kind of help you refine some targeting stuff, but I didn't see much difference in the two color…again, it's probably a lack of familiarity with the… And the optical/EO image is fine—it's nice to have."
- Question 3: Would a system like this make your job in the cockpit easier?
    - "Yes."
- Question 4: If you could change anything about the system, what would it be?
    - "It would be nice to be able to zoom in and out, instead of being stuck with the one image. And then, again, if it was…if the 2 IR images were more different. I don't know how you would make it more different, but to be able to break out things in the background."

- Question 5: How does this system compare to any automated targeting systems you may have used in the past?
    - "Better, but it's a simulation. I mean, I couldn't slough the image, I couldn't zoom in, zoom out. My experience is conventional target pods, so I haven't done much with this. The color, I think, adds a nice element to it."
- Low-stress model validation
    - Cold Woodchipper
        - "[Vis] Obviously the EO doesn't provide me with much other than that there's a vehicle there. [Jade] Here I see that it [truck] is relatively the same temperature as the road, which I imagine is cool, so it's leading me to believe that this is a cool target. [Phx] Not real distinct in either of those images. That's a friendly pickup truck-woodchipper guy."
    - Hot Woodchipper
        - "[Vis—looks at briefly and goes on to IR]. [Phx] Now I start to see some more contrast, but I get kind of confused—the snow in the background or whatever that is in that cool area definitely contrasted with the road. [Jade] And this helps a lot here, because I can see this vehicle [on the road] is white hot in the brakes and the engine compartment, which leads me to believe that this one [pickup truck and woodchipper] is also warmer. Being able to compare this vehicle to this vehicle helps out. I'd drop a bomb on this guy."
    - Humvee
        - "[Vis—looks at briefly and goes on to IR]. [Phx] I start to pick up the engine compartment, and the wheel is standing out. [Jade] Again, it appears that there is significant contrast between him and the background, so I like the fact that it's different than the cool background. [Phx] The tire tracks help out here. So this guy's gonna get some triton all over him, I guess."
    - M5
        - "[Vis] Well, I see here I get a vehicle [indicates M5]. [Jade] And here I get a good contrast, and I see the white hot sticking out of the cool woodline here in the tree area. [Phx] This doesn't provide me with much because it's kind of washed out by the runway and the road. [Jade] Here, this [M5] stands out more for me, more so than it did in my previous experience with this targeting system [in the sim]"

APPENDIX H: K-MEANS CLUSTERING ALGORITHM

```
function [mask] = kcluster(img, k)

% This function clusters an image (img) into k clusters, and returns the
% mask image.

img = rgb2gray(img);                    %change the image to grayscale
img = im2double(img);                   %change the image to double precision
[m,n] = size(img);                      %find the size of the image
img = img(:);                           %vectorize the image
[IDX,C, sumd, D] = kmeans(img, k);      %find the cluster centers

for i = 1:(m*n)                         %For each pixel in the image...
   ind = find(D(i, :) == min(D(i, :)));  %...find the cluster it belongs to...
   mask(i) = C(ind);                    %...and replace the image value with the cluster value.
end
 mask = reshape(mask, m, n);            %turn the vectorized mask back into an image
 imshow(mask);                          %show the mask image
```

APPENDIX I: LOW-STRESS MODEL VALIDATION RESULTS

The following tables show the complete statements given by modeling experts with regard to the low-stress image fusion operator function model shown in Figure 9.

Pilot #	Target #	Expert #1: Industry	Reason for Incompleteness
16	1	Complete	N/A
	2	Complete	N/A
	3	Incomplete	Change arc that says "All noticeable details gleaned from image" to read "features of interest (shape, color, contrast, size, location, environment, time of day, temperature) gleaned from image"
	4	Incomplete	Change arc that says "All noticeable details gleaned from image" to read "features of interest (shape, color, contrast, size, location, environment, time of day, temperature) gleaned from image"
17	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
18	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
19	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Incomplete	Change arc that says "All noticible details gleaned from image" to read "features of interest (shape, color, contrast, size, location, environment, time of day, temperature) gleaned from image"
20	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
21	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
	% Complete	87.5	

Pilot #	Target #	Expert #2: Government	Reason for Incompleteness
16	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
17	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
18	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
19	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
20	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
21	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
	% Complete	100	N/A

Pilot #	Target #	Expert #3: Government	Reason
16	1	Complete	N/A
	2	Incomplete	Need an arc that leads to "Identify MMOs" node directly from "Review visible image" without going through infrared
	3	Complete	N/A
	4	Complete	N/A
17	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Incomplete	Need an arc that leads to "Identify MMOs" node directly from "Review visible image" without going through infrared
18	1	Incomplete	Need an arc to directly link "Create mental image of the scene" and "Review IR image"
	2	Incomplete	Need an arc to directly link "Create mental image of the scene" and "Review IR image"
	3	Complete	N/A
	4	Complete	N/A
19	1	Incomplete	Need an arc to directly link "Create mental image of the scene" and "Review IR image"
	2	Complete	Need an arc to directly link "Create mental image of the scene" and "Review IR image"
	3	Complete	Need an arc to directly link "Create mental image of the scene" and "Review IR image"
	4	Incomplete	Need an arc to directly link "Create mental image of the scene" and "Review IR image"
20	1	Complete	N/A
	2	Incomplete	Need an arc to directly link "Create mental image of the scene" and "Review IR image"
	3	Complete	N/A
	4	Incomplete	Need an arc that leads to "Identify MMOs" node directly from "Review visible image" without going through infrared
21	1	Complete	N/A
	2	Complete	N/A
	3	Complete	N/A
	4	Complete	N/A
	% Complete	66.66666667	

APPENDIX J: HIGH-STRESS MODEL VALIDATION RESULTS

The following tables show the complete statements given by modeling experts with regard to the high-stress image fusion operator function model shown in Figure 10.

Pilot #	Target #	Expert #1: Industry	Reason for Incompleteness
1	1	Complete	
	2	Incomplete	Need a new subfunction to include filtering object of interest or features of interest (shape, color, contrast, size, location, environment, time of day, temperature) from all MMOs
	3	Complete	
	4	Complete	
2	1	Complete	
	2	Incomplete	Need a new subfunction to include filtering object of interest or features of interest (shape, color, contrast, size, location, environment, time of day, temperature) from all MMOs
	3	Complete	
	4	Complete	
3	1	Complete	
	2	Complete	
	3	Complete	
	4	Incomplete	Need a new subfunction to include filtering object of interest or features of interest (shape, color, contrast, size, location, environment, time of day, temperature) from all MMOs
4	1	Incomplete	Need a new subfunction to include filtering object of interest or features of interest (shape, color, contrast, size, location, environment, time of day, temperature) from all MMOs
	2	Complete	
	4	Complete	
5	1	Complete	
	2	Complete	
	3	Complete	
	4	Incomplete	Need a new subfunction to include filtering object of interest or features of interest (shape, color, contrast, size, location, environment, time of day, temperature) from all MMOs
6	1	Complete	
	2	Complete	
	3	Incomplete	Need a bi-directional arc to encompass second-guessing of designation after target has been selected
	4	Incomplete	Need a new subfunction to include filtering object of interest or features of interest (shape, color, contrast, size, location, environment, time of day, temperature) from all MMOs
	% Complete	69.56521739	

Pilot #	Target #	Expert #2: Government*	Reason
1	1	Complete	
	2	Incomplete	Need another node where the target of interest is being specified--identifying target from the clutter
	3	Complete	
	4	Incomplete	Need another node where the target of interest is being specified--identifying target from the clutter
2	1	Complete	
	2	Complete	
	3	Complete	
	4	Complete	
3	1	Complete	
	2	Complete	
	3	Complete	
	4	Complete	
4	1	Complete	
	2	Complete	
	4	Complete	
5	1	Complete	
	2	Incomplete	Need another node for registering images, both spatially and temporally, and need another node where the target of interest is being specified--identifying target from the clutter
	3	Complete	
	4	Incomplete	Need another node for establishing context of the scene
6	1	Complete	
	2	Incomplete	Need another node for establishing context of the scene
	3	Complete	
	4	Complete	
	% Complete	78.26086957	

Pilot #	Target #	Expert #3: Government*	Reason
1	1	Complete	
	2	Complete	
	3	Complete	
	4	Complete	
2	1	Complete	
	2	Complete	
	3	Complete	
	4	Complete	
3	1	Complete	
	2	Complete	
	3	Complete	
	4	Complete	
4	1	Complete	
	2	Complete	
	4	Complete	
5	1	Incomplete	Need to change arc leading from "Snapshot of visual image" to "identify color and physical features"
	2	Complete	
	3	Complete	
	4	Complete	
6	1	Complete	
	2	Complete	
	3	Complete	
	4	Complete	
	% Complete	95.65217391	

APPENDIX K: COPYRIGHT REPRODUCTION PERMISSIONS

Amanda Christine Muller a écrit :

> Dear Dr. Berger-Vachon,
>
> I would like to request permission to reporduce a figure from the 2002
> volume of /Advances in Modelling & Analysis B: Signals, Information,
> Patterns, Data Acquisition, Transmission, Processing, Classification
> /in my doctoral dissertation. The figure originally appeard in volume
> 45, issue 2, on page 222. It would be faithfully reproduced in my
> dissertation document, titled "Cognitively-Engineered Multisensor Data
> Fusion for Military Applications," with full credit given to the
> original authors (Li and Wang) and source journal. I look forward to
> your response.
>
> Thank you,
>
> Amanda Muller
>
>
>
> ---
> Amanda C. Muller
> Ph.D. Candidate
> Human-Computer Interaction Laboratory
> Wright State University
> (937)775-5153
> http://www.wright.edu/studentorgs/multisport
>
>
Dear Ms Muller,

OK, from us you can reproduce this figure.
I don't think the authors will mind
Good luck for your thesis discussion,
Sincerely,

C. Berger-Vachon

Human
Factors
and
Ergonomics
Society

August 18, 2005

Amanda C. Muller
Wright State University
Department of Biomedical, Industrial, and Human Factors Engineering
207 Russ Center
3640 Col. Glenn Hwy.
Dayton, OH 45435

Dear Ms. Muller:

Thank you for your request for permission to reproduce the following figure ("the Figure") from our publication, *Human Factors*:

Figure 3, p. 211. Cohen, M. S., Freeman, J. T., & Wolf, S. (1996). Metarecognition in time-stressed decision making: Recognizing, critiquing, and correcting. *Human Factors*, 38(2).

We are pleased to grant you a nonexclusive, nontransferable license to reprint the Figure in one edition of your doctoral dissertation, "Cognitively-Engineered Multisensor Data Fusion for Military Applications," on the following terms and conditions:

1. Acknowledgment of HFES copyright must appear in the work. The following wording is recommended:

Reprinted with permission from *Human Factors*, Vol. 38, No. 2, 1996. Copyright 1996 by the Human Factors and Ergonomics Society. All rights reserved.

2. This permission extends to only one edition of your dissertation. To reprint the Figure in future editions, derivative works, etc., will require separate permission.

Thank you for your interest in the Human Factors and Ergonomics Society.

Sincerely,

HUMAN FACTORS AND ERGONOMICS SOCIETY

Lois Smith
Communications Director

P.O. Box 1369
Santa Monica, CA
90406-1369 USA
TEL (310) 394-1811
FAX (310) 394-2410
info@hfes.org

From	annelise.mark.pejtersen@risoe.dk
Sent	Tuesday, October 11, 2005 2:38 pm
To	muller.4@wright.edu
Cc	
Bcc	
Subject	SV: Copywright permission request

Dear Amanda Muller,
That is OK with me-good luck with your dessertation and many greeting s to John Flach form me! I hope that he is doing well. I would like to see your thesis, when you have finished, since I am currently the chairman of a Committee sat down by the Danish Research Minister on Cognition and Robot Technology, and your topic seems to be relevant for that work.
I wish you good luck
Many kind regards
Annelise

Annelise Mark Pejtersen
Research Professor, Risø National Laboratory
Aff.professor at University of Washington, Seattle, USA
Chairman of the IFIP Technical Committee on Human-Computer Interaction
http://www.ifip-hci.org/
Head of Cognitive Systems Engineering Center
Systems Analysis Department
Risø National Laboratory, P.O 49 4000 Roskilde, Denmark
Tel: 45-46775149, Fax: 45-46775199
email: amp@risoe.dk
www.risoe.dk/sys
www.csecenter.dk

Fra: Amanda Christine Muller [mailto:muller.4@wright.edu]
Sendt: ti 11-10-2005 20:02
Til: annelise.mark.pejtersen@risoe.dk
Emne: Copywright permission request

Dr. Pejtersen,

I am a Ph.D. Student at Wright State University in Dayton, Ohio, USA. I am writing my dissertation on Cognitively-Engineered Multisensor Data Fusion for Military Applications. I would like to request your permission to include the decision ladder pictured on page 65 of your book, Cognitive Systems Engineering, in the background section of my dissertation. Of course, full credit would be you and your co-authors, and to the original publication. Thank you, and I look forward to your response.

Sincerely,

Amanda Muller

WRIGHT STATE
UNIVERSITY

Department of Biomedical, Industrial, and Human Factors Engineering
207 Russ Engineering Center
3640 Colonel Glenn Hwy.
Dayton, OH 45435-0001
(937) 775-5044
FAX (937) 775-7364
www.cs.wright.edu/bie

S. Narayanan, Ph.D., P.E.
Professor and Chair
(937) 775-5044
e-mail: s.narayanan@wright.edu

December 7, 2005

Amanda C. Muller
Wright State University
Department of Biomedical, Industrial, and Human Factors Engineering
207 Russ Center
3640 Col. Glenn Hwy.
Dayton, OH 45435

Dear Ms. Muller:

Thank you for your request for permission to reproduce the following figure from my article published in *Human Factors and Ergonomics in Manufacturing*:

> Figure 5, p. 220. Narayanan, S., Bailey, W., Tendulkar, J., Wilson, K., Daley, R., & Pilske, D. (1999). Modeling real-world information seeking in a corporate environment. *Human Factors and Ergonomics in Manufacturing*, 9(2).

I hereby grant you permission to reprint this figure in your doctoral dissertation, "Cognitively-Engineered Multisensor Data Fusion for Military Applications."

Sincerely

S. Narayanan, Ph.D., P.E.

APPENDIX L: SPIE PUBLICATION

The following paper was published in the Proceedings of SPIE, sponsored and published by SPIE—The International Society for Optical Engineering. It was presented at the SPIE Defense and Security Symposium in Orlando, Florida, on April 14, 2004. A travel grant was also awarded.

Kight, A.C. and S. Narayanan. 2004. Cognitive engineering in algorithm development for multisensor data fusion. *Proceedings of the SPIE: Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications 2004.* 5434:148-155.

Cognitive Engineering in Algorithm Development for Multisensor Data Fusion in Military Applications

Amanda C. Kight and S. Narayanan
Wright State University
Department of Biomedical, Industrial, and Human Factors Engineering
3640 Colonel Glenn Highway, Dayton, Ohio 45435

ABSTRACT

In battlefield situations, human operators are bombarded with substantial amounts of information and expected to make near-instantaneous decisions. The large amounts of information, coupled with short decision times and the need to reduce the potential of making incorrect decisions, create the possibility for information overload. This problem is especially prominent in military applications involving imagery from multiple sensors. Computer-based algorithms for fusing pertinent sets of imagery have proven somewhat useful for alleviating this problem. However, little research has been done on designing multisensor data fusion systems using principles of cognitive engineering, which involves the consideration of human cognition during the design process. The design of a sensor fusion system using principles from cognitive engineering would create a more natural relationship between human and machine, and would thus be extremely effective in reducing operator error in military situations. This paper explores the need for integrating human reasoning and cognition in algorithm development for multisensor fusion applications.

1. INTRODUCTION

Battlefields are by their very nature dynamic and chaotic. In such conditions, human operators are bombarded with substantial amounts of information and expected to make near-instantaneous decisions. Particularly with the advent of modern information networks, the pace of war has significantly increased, forcing human operators to make decisions within increasingly small windows of opportunity. The large amounts of information, coupled with short decision times and the need to reduce the potential of making incorrect decisions, create the potential for information overload.

This problem of information overload is especially prominent in military applications involving imagery from multiple sensors. As the amount and complexity of image information grows, decisions based on multisensor imagery become more difficult, error-prone, and time consuming.

Computer-based algorithms for fusing pertinent sets of imagery have proven useful for alleviating this problem (Li & Wang, 2002). Fusing the images from the different sensors, while enhancing the supplemental information contained in the images, can serve to decrease the operator's workload and improve overall performance by making targets more visible (Fay et al., 2001).

The concept of cognitive engineering has become prominent in the design of human-computer systems in recent years. Cognitive engineering involves the consideration of human cognition in system design to allow the user a more natural experience in dealing with the machine. The design of a sensor fusion system using principles from cognitive engineering would thus be extremely effective in reducing operator error in military situations.

2. MULTISENSOR DATA FUSION

Multisensor data fusion is used in numerous applications to combine data obtained by different sensors. In military applications, multisensor data fusion techniques can be employed to reduce information overload for pilots and battlefield commanders who must make near-instantaneous decisions based on large amounts of varied information. In battlefield situations, excessive mental stress can reduce even the most highly-trained professionals to amateur status (Ardey, 1998). Fused data of target-recognition sensors allows assessment of a situation at higher levels, greatly reducing the amount of information presented to the decision maker (Grossman, 1998). If this reduced information is presented correctly, there is great potential to reduce the stress on the decision maker.

The fusion process may take place at several different levels. The lowest is data-level fusion (Figure 1a), where the raw data from each sensor are combined and interpretation follows (Li & Wang, 2002; Nejatali & Ciric, 1998). This fusion method retains most of the data, but is often computationally costly. It also requires that all sensors measure the same physical phenomenon, such as visual or acoustic events (Li & Wang, 2002).

Feature level fusion (Figure 1b) seems to be the most popular method for fusing multisensor data (Basir & Shen, 1996; Byrd et al., 1998; Crowley, 1993; Fay et al., 2001; Inguva & Garrison, 1998; Nejatali & Ciric, 1998; Peli et al., 1999; Wan & Fraser, 1999). Feature vectors are extracted from the observed data, and these vectors are combined into a single feature vector, which is subsequently interpreted (Li & Wang, 2002). Feature level fusion is less computationally expensive than data level fusion, but results in the loss of some data due to the generation of the feature vector from the raw data.

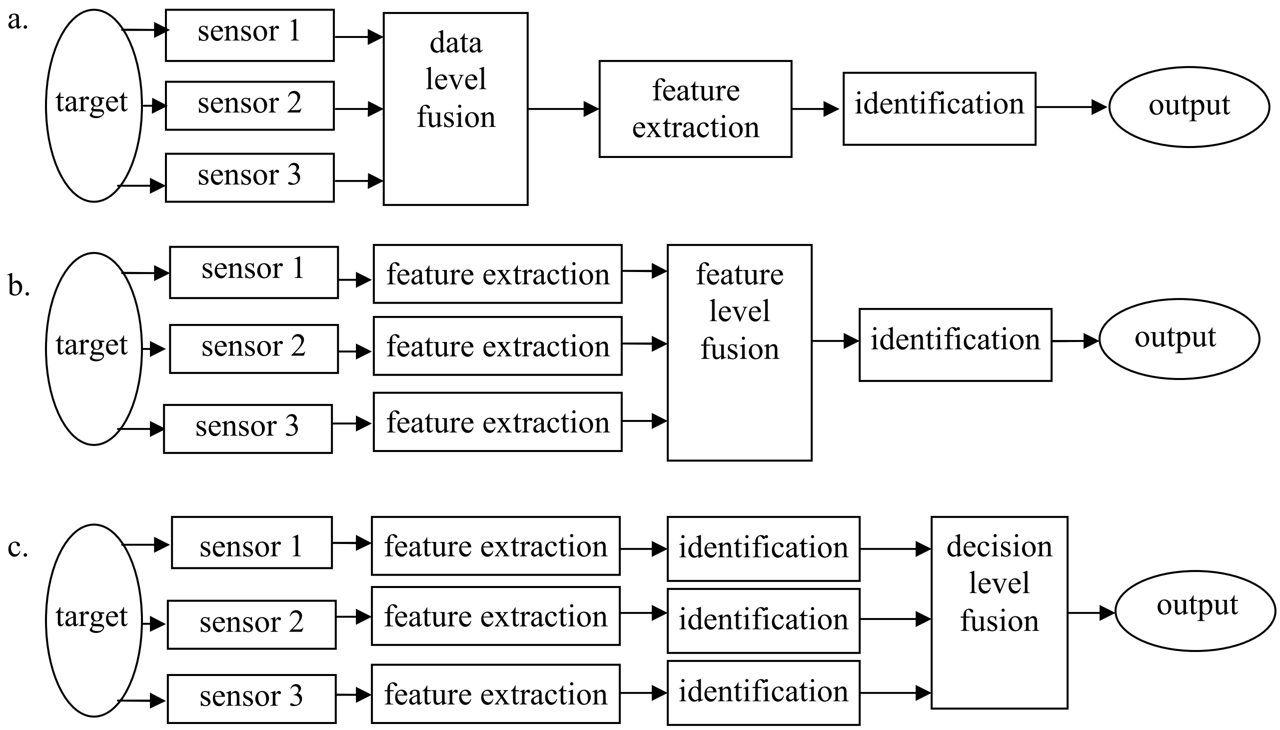


Figure 1: Schematic diagrams of the three basic types of multisensor data fusion: data level fusion (a), feature level fusion (b), and decision level fusion (c)(Li & Wang, 2002).

The highest-level method is decision level fusion (Figure 1c), in which a decision is made based on the output of each sensor using pattern recognition algorithms, and these decisions are combined into a single decision. This method results in the largest amount of data loss, but requires the smallest amount of data storage (Li & Wang, 2002).

Within these levels exist numerous algorithms for fusing data from multiple sensors. The simplest method is majority voting, used in classification applications; the correct class is the one most chosen by the different classifying sensors (Li & Wang, 2002). Weighted averaging is slightly more computationally complex—in this method, the weighted average of information from a redundant group of sensors is calculated, and the average is used as the fused value (Grossman, 1998; Li & Wang, 2002; Zhou & Leung, 1997). The difficulty lies in selecting the appropriate weights.

If sensors are mutually independent, Bayesian methods may be used to fuse their outputs. These methods use standard Bayesian statistics to compute the likelihood of a fused decision based on the prior probabilities. The Bayes formula for sensor fusion is:

$$P(H_j \mid E) = \frac{\prod_i P(E_i \mid H_j) P(H_j)}{\sum_j \left\{ \left[\prod_i P(E_i \mid H_j) \right] P(H_j) \right\}}$$

where $P(H_j|E)$ is the a posteriori probability of hypothesis H_j being true given sensor evidence E_j, $P(H_j)$ is the a priori probability of hypothesis H_j being true, and $P(E_i|H_j)$ is the probability of observing sensor evidence E_j given that hypothesis H_j is true (Grossman, 1998). The problems with this method include the necessity of mutual sensor independence, and the required knowledge of a priori and conditional probabilities (Grossman, 1998; Li & Wang, 2002). Advantages include relative insensitivity to noise and unbiased results based only on the data and prior information (Inguva & Garrison, 1998).

Kalman filtering is another method for data fusion, which provides optimal estimation of data by using recursive evaluation, an internal model of system dynamics, and a dynamic weighting of incoming state estimates of the system (Crowley, 1993; Grossman, 1998). The state estimates are formed using the state equation, which relates *s(k+1)* (the state vector at time *k+1*), , to *s(k)* (the state vector at time *k*) , by the following equation:

$$s(k+1) = \phi_k s(k) + w(k)$$

where ϕ_k is the state transition matrix and *w(k)* is noise (Grossman, 1998). The measurement model then relates the observation or measurement *x* to the state vector with the following equation:

$$x(k) = H_k s(k) + n(k)$$

where H_k is the measurement matrix and *n(k)* is the measurement noise with covariance R_k. The simplest solution is given by the vector estimator equation:

$$\hat{s}(k) = \phi\hat{s}(k-1) + R_k\left[x(k) - H\phi\hat{s}(k-1)\right]$$ (Grossman, 1998)

The Kalman filtering method has numerous limitations. Most notably, the observed evidence used for input to the state equations may be uncertain, incorrect, or incomplete (Grossman, 1998). Also, the model used for the above equations is driven by known inputs and zero-mean white Gaussian noise with known covariance (Crowley, 1993; Grossman, 1998). Different (non-Gaussian) noise mechanisms and unknown inputs render the method of Kalman filtering useless.

Numerous other methods including the Dempster-Shafer theory (Grossman, 1998; Li & Wang, 2002), fuzzy logic (Li & Wang, 2002), and minimum entropy (Basir & Shen, 1996; Zhou & Leung, 1997) have been proposed. Each of the aforementioned fusion methods has unique strengths and weaknesses specific to its application.

Research into fusion of laser radar and forward-looking infrared (FLIR) sensors began as early as 1987(Tong et al., 1987). These sensors are currently central to military sensors research. Early fusion algorithms involved segmentation of man-made targets from natural backgrounds, using range changes in laser radar data for segmentation, and large changes in infrared data for enhancement(Tong et al., 1987). While these algorithms provided some improvement over the individual sensor data alone, the resultant images were still unclear and did not lend themselves well to quick interpretation. Aggarwal and Chu(Aggarwal & Chu, 1993) continued research on fusion of data from these sensors using a segmentation and weighted-averaging approach. Again, however, the resulting images were not able to be easily and quickly interpreted.

3. COGNITIVE PROCESSES IN COMPLEX SYSTEMS

Cognitive engineering is a relatively new concept involving the development of computational tools to be used as *instruments* by competent practitioners for effecting results, rather than as *prostheses* for replacing human inadequacy (Hutchins, 1996; Roth et al., 1988). Cognitive systems form a partnership where computation is guided with cognitive insight, and cognition is, in turn, stimulated by feedback from computed results (Das, 2000). In high-stress situations, it is vitally important that systems being operated are designed according to cognitive principles(Ardey, 1998). In order to develop a cognitive system, the cognitive engineer must investigate problems such as what information to present, how to present it, and when to present it (Hollnagel, 1988).

The power of a cognitive system lies in its ability to increase the human decision maker's adaptability to the kinds of problems that could arise in the pursuit of the overall project goals (Roth et al., 1988). The overarching purpose of such a system is to improve the quality of information available to the user, and to provide the needed information in a format that best supports the user under dynamic decision making conditions (Hollnagel, 1988; Hutchins, 1996).

Most operator errors in traditional human-machine systems are the result of a mismatch between the properties of the human and machine. These mismatches are often the result of the designer's failure the explicitly address the demands the system places on the human, a deficit in so-called "cognitive coupling" (Hollnagel & Woods, 1999; Reason, 1988; Woods, 1986). Traditional (non-cognitive) human-machine systems often place emphasis on user acceptance of the machine's given solution, often resulting in situations where the user either always rejects the machine's output because he feels it is unreliable, or always accepts it because he feels the cost of error in overriding the machine is too high(Woods, 1986). Cognitive engineering takes into account that human and machine elements contain partial and overlapping expertise that, if properly integrated, can result in better joint system performance than is possible by either element alone (Woods, 1986). Active human participation in the entire problem solving process has been found to lead to more successful and timely solutions(Roth et al., 1988).

Model-based decision support is a branch of cognitive engineering that has been studied extensively in recent years (Brodie & Hayes, 2002; P. M. Jones & Mitchell, 2002; Narayanan et al., 2002; Parasuraman et al., 2002; Sheridan, 2002). Design of a model-based decision support system generally consists of task analysis, function allocation, and interface design.

Course of action (COA) planning is a component of task analysis that involves outlining possible plans of action for the human-computer system given different situations (Brodie & Hayes, 2002). For example, the system may need to offer the user different options for processing images of different objects. In conjunction with COA planning, protocol analysis should be established. This consists of observing experts performing an activity similar to that to be accomplished with the human-computer system, and creating a model of an "ideal" user. This allows identification of user needs (Brodie & Hayes, 2002). Following this procedure, functions should be allocated to the machine to best address user needs and to help compensate for user inadequacies (Brodie & Hayes, 2002; Hollnagel, 1988; Hollnagel & Woods, 1999). The user interface should then be designed to allow the human user to interact with the system in an intuitive manner, based on the allocated functions (Brodie & Hayes, 2002; Guida & Lamperti, 2000).

The concept of trust between human and machine is critical in the design of decision support systems, including those utilizing multisensor data fusion (Muir, 1988). The user must be able interact with the system in such a way that he is able to understand the process by which the system aids the decision, and is therefore able to trust the system's output. Attempts to remove the user completely from the problem solving loop cause complacency, and can often increase the user's burden in some situations by asking him to handle more difficult cases without the benefit of experience on simpler cases (Roth et al., 1988). On the other hand, allowing the user to make all decisions with little no help from the system defeats the purpose of the decision aid, causing information overload on a regular basis.

Trust in the decision aid is particularly important in battlefield situations. Errors in target recognition may cause destruction of friendly targets or death of allies. If the user does not trust the decision aid completely, fear of such errors will most likely cause him to ignore the system output in the high-stress situations when it is needed the most.

The basic rule behind the design of cognitive systems is that a top-down approach should be used—that is, the machine must be designed with the human end user's cognitive processes in mind, rather than trying to mold the end user to fit the machine. Thus, the designer must have a realistic view of how the human user functions cognitively (Hollnagel & Woods, 1999).

Cognitive system design is thus a problem-driven approach rather than a technology-driven approach (Woods, 1986). When tools dominate the design, the designer runs a strong risk of solving the wrong type of problem (Woods, 1986). The human cognition aspect of the design must be considered throughout the design process (Roth et al., 1988).

The user interface in a human-machine system is an important cognitive link between elements (Tauber, 1985). Poor interface design usually results in human performance problems (Hollnagel & Woods, 1999). Overall, it must be easy for the user to specify what he wants from the machine, and to interpret the solutions the machine offers (Hollnagel, 1988). Hutchins (1996) stipulates that graphic presentations should be used over text-based formats because they reduce the amount of mental computation needed to perform the tasks, and they allow users to spend less time searching for needed information.

When a cognitive system has been successfully designed, the operator will develop an internal model that describes the operation and function of the machine. This model will be based on training, experience, instruction, and the nature of the interface (Hollnagel & Woods, 1999). The cognitive system will provide a mechanism for integrating all the control resources, including people, facilities, instrumentation, and training into a single integrated system (Hollnagel & Woods, 1999).

Following the design and implementation of a cognitive system, it is imperative that the system be evaluated, since it is the actual, rather than the anticipated consequences of the design that are important (Hollnagel, 1988; Hollnagel & Woods, 1999; Piccini, 2002). Simulation and testing with human operators is an important means to identifying flaws in the cognitive system design (Martel, 1996; Reason, 1988).

4. PROPOSED RESEARCH IN COGNITIVELY-DESIGNED MULTISENSOR DATA FUSION SYSTEMS

These insufficiencies in previous research on cognitively-designed multisensor data fusion beg future study. The authors plan to develop fusion algorithms for FLIR and synthetic aperture laser radar sensors for specific military targets. The major research questions to be addressed are:

1. What multisensor fusion techniques can be applied to 2D and 3D active and passive sensors?
2. At what level (data, feature, decision) should the fusion be performed?
3. What new, more efficient techniques can be developed?
4. How can fused images be cognitively coupled with their users for optimum performance in high-stress battlefield situations?
5. How can the user be modeled to support interface design?
6. How can a multisensor data fusion system involving humans be evaluated to ensure it is functioning as it should?

To address these questions, the methodology displayed in Figure 2 will be employed. Current and retired fighter pilots will be interviewed to determine their needs in a fusion system. Established fusion methodologies will be evaluated based on these requirements, and new, more favorable techniques will be developed according to these user needs and to known cognitive design specifications. Current methodologies for flight-simulator an battlefield-simulator testing will be reviewed and employed to establish a model of the user and design an appropriate cognitive interface. Empirical evaluation of the finished design will be conducted, allowing the pilots to provide feedback on the efficacy of the system. Their interactions with the system will be observed to ensure that the cognitive coupling objectives have been fulfilled. The resulting system should allow pilots and battlefield commanders in high-stress situations to make quick decisions based on information from multiple sensors.

5. CONCLUSION

Review of the aspects of cognitive design of human decision aids illuminates the need for such methods in the design of multisensor data fusion systems, particularly those used in high-stress battlefield conditions. Taking into account the cognitive processes of pilots and battlefield commanders when designing such systems should allow more natural and efficient image interpretation scenarios. The proposed research addresses these issues, and should result in a more successful multisensor data fusion system.

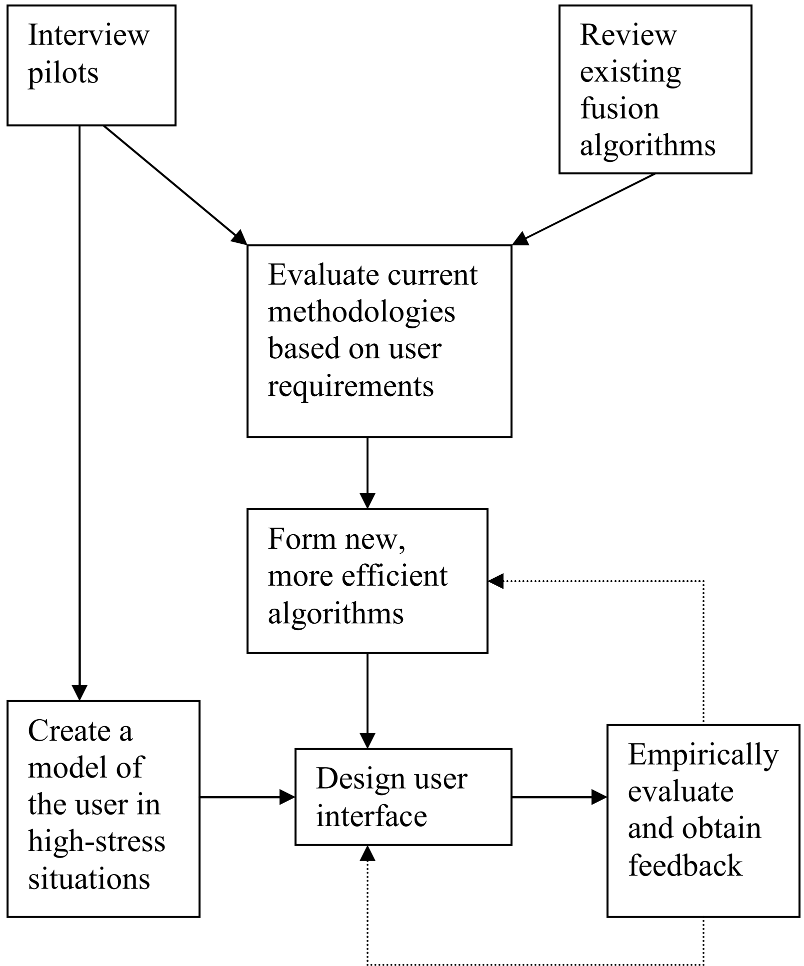


Figure 2: Design methodology. Dashed lines indicate feedback loops.

REFERENCES

1. S. Li and Y. Wang, "Multisensor data fusion and its applications," Advances in Modelling & Analysis B: Signals, Information, Patterns, Data Acquisition, Transmission, Processing, Classification **45**(2), 19-37 (2002).
2. D. A. Fay, J. G. Verly, M. I. Braun, C. Frost, J. P. Racamato, and A. M. Waxman, "Fusion of multi-sensor passive and active 3D imagery," presented at the Enhanced and Synthetic Vision 2001, Orlando, FL, April 16-17, 2001, 2001.
3. G. F. Ardey, "Fusion and Display of Data According to the Design Philosophy of Intuitive Use," presented at the Sensor Data Fusion and Integration of the Human Element, Ottawa, Ont., Canada, 14-17 Sept. 1998, 1998.
4. P. Grossman, "Multisensor data fusion," GEC Journal of Technology **15**(1), 27-37 (1998).
5. A. Nejatali and I. R. Ciric, "Novel image fusion methodology using fuzzy set theory," Optical Engineering **32**(2), 485-491 (1998).
6. K. Byrd, B. Smith, D. Allen, N. Morris, C. Bjork, and K. Deal-Giblin, "Intelligent processing techniques for sensor fusion," presented at the Sensor Fusion: Architectures, Algorithms, and Applications II, Orlando, FL, April 16-17, 1998, 1998.

7. O. A. Basir and H. C. Shen, "Modeling and fusing uncertain multi-sensory data," Journal of Robotic Systems **13**(2), 95-109 (1996).
8. T. Peli, M. Young, R. Knox, K. Ellis, and F. Bennett, "Feature level sensor fusion," presented at the Sensor Fusion: Architectures, Algorithms, and Applications III, Orlando, FL, April 7-9, 1999, 1999.
9. R. Inguva and G. Garrison, "Fusion of LWIR sensor data by Bayesian methods," presented at the Sensor Fusion: Architectures, Algorithms, and Applications II, Orlando, FL, April 16-17, 1998, 1998.
10. J. L. Crowley, "Principles and Techniques for Sensor Data Fusion," in *Multisensor Fusion for Computer Vision*, J. K. Aggarwal, ed. (Springer-Verlag, New York, 1993), pp. 15-36.
11. W. Wan and D. Fraser, "Multisource data fusion with multiple self-organizing maps," IEEE Transactions on Geoscience and Remote Sensing **37**(3), 1344-1349 (1999).
12. Y. Zhou and H. Leung, "Minimum entropy approach for multisensor data fusion," presented at the Proceedings of the IEEE Signal Processing Workshop on Higher-Order Statistics, Banff, Alta., Canada, July 21-23 1997, 1997.
13. C. W. Tong, S. K. Rogers, J. P. Mills, and M. K. Kabrisky, "Multisensor data fusion of laser radar and forward looking infrared (FLIR) for target segmentation and enhancement," presented at the Infrared Sensors and Sensor Fusion., Orlando, FL, May 19-21 1987, 1987.
14. J. K. Aggarwal and C.-C. Chu, "The Issues, Analysis, and Interpretation of Multi-Sensor Images," in *Multisensor Fusion for Computer Vision*, J. K. Aggarwal, ed. (Springer-Verlag, New York, 1993), pp. 38-62.
15. E. M. Roth, K. B. Bennett, and D. D. Woods, "Human interaction with an "intelligent" machine," in *Cognitive Engineering in Complex Dynamic Worlds*, E. Hollnagel, G. Mancini, and D. D. Woods, eds. (Academic Press Limited, San Diego, 1988), pp. 23-51.
16. S. G. Hutchins, "Principles for Intelligent Decision Aiding," in *Human Interaction with Complex Systems: Conceptual Principles and Design Practice*`, C. A. Ntuen and E. H. Park, eds. (Kluwer Academic Publishers, Boston, 1996), pp. 103-131.
17. B. Das, "Cognition friendly interaction," presented at the Unsolved Problems of Noise and Fluctuations. UPoN'99: Second International Conference, Adelaide, SA, Australia, July 12-15, 1999, 2000.
18. E. Hollnagel, "Information and resoning in intelligent decision supposrt systems," in *Cognitive Engineering in Complex Dynamic Worlds*, E. Hollnagel, G. Mancini, and D. D. Woods, eds. (Academic Press Limited, San Diego, 1988), pp. 215-228.
19. E. Hollnagel and D. D. Woods, "Cognitive systems engineering: new wine in new bottles," International Journal of Human-Computer Studies **51**(2), 339-356 (1999).
20. J. Reason, "Cognitive aids in process environments: prostheses or tools?," in *Cognitive Engineering in Complex Dynamic Worlds*, E. Hollnagel, G. Mancini, and D. D. Woods, eds. (Academic Press Limited, San Diego, 1988), pp. 7-14.
21. D. D. Woods, "Cognitive technologies: The design of joint human-machine cognitive systems," The AI Magazine, Winter, 1986, 1986, pp. 86-92.
22. P. M. Jones and C. M. Mitchell, "Model-based cognitive engineering in complex systems--Part I," IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans) **32**(1), 2-4 (2002).
23. R. Parasuraman, T. B. Sheridan, and C. D. Wickens, "A model for types and levels of human interaction with automation," IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans) **30**(1), 286-297 (2002).
24. T. B. Sheridan, "Some musings on four ways humans couple: implications for systems design," IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans) **32**(1), 5-10 (2002).
25. S. Narayanan, W. Bailey, J. Tendulkar, R. Daley, D. B. Pliske, and K. Wilson, "Design of model-based interfaces for a real world information system," IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans) **32**(1), 11-24 (2002).
26. C. B. Brodie and C. C. Hayes, "DAISY: A decision support design methodology for complex, experience-centered domains," IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans). **32**(1), 50-71 (2002).
27. G. Guida and G. Lamperti, "AMMETH: a methodology for requirements analysis of advanced human-system interfaces," IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans) **30**(3), 298-321 (2000).

28. B. M. Muir, "Trust between humans and machines, and the design of decision aids," in *Cognitive Engineering in Complex Dynamic Worlds*, E. Hollnagel, G. Mancini, and D. D. Woods, eds. (Academic Press Limited, San Diego, 1988), pp. 71-83.
29. M. J. Tauber, "Top down design of human-computer systems from the demands of human cognition to the virtual machine-an interdisciplinary approach to model interfaces in human-computer interaction," presented at the IEEE Workshop on Languages for Automation: Cognitive Aspects in Information Processing, Palma de Mallorca, Spain, June 28-29 1985, 1985.
30. M. Piccini, "Human factors in the design of supervisory control systems and human-machine interfaces for highly automated complex systems," Cognition, Technology & Work **4**(4), 256-271 (2002).
31. R. J. Martel, "HCI Architecting for System Reliability," in *Human Interaction with Complex Systems: Conceptual Principles and Design Practice*`, C. A. Ntuen and E. H. Park, eds. (Kluwer Academic Publishers, Boston, 1996), pp. 13-23.

REFERENCES

Aggarwal, J. K., & Chu, C.-C. (1993). The Issues, Analysis, and Interpretation of Multi-Sensor Images. In J. K. Aggarwal (Ed.), *Multisensor Fusion for Computer Vision* (pp. 38-62). New York: Springer-Verlag.

Archer, S., Warwick, W., & Oster, A. (2000). Current efforts to model human decision making in a military environment. In M. J. Chinni (Ed.), *Military, Government, and Aerospace Simulation* (3 ed., Vol. 32, pp. 151-155): The Society for Computer Simulation International.

Ardey, G. F. (1998, 14-17 Sept. 1998). *Fusion and Display of Data According to the Design Philosophy of Intuitive Use.* Paper presented at the Sensor Data Fusion and Integration of the Human Element, Ottawa, Ont., Canada.

Basir, O. A., & Shen, H. C. (1996). Modeling and fusing uncertain multi-sensory data. *Journal of Robotic Systems, 13*(2), 95-109.

Beach, L. R. (1993). Broadening the Definition of Decision Making: The Role of Prechoice Screening of Options. *Psychological Science, 4*(4), 215-220.

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review, 94*(2), 115-147.

Billings, C. E. (1997). *Aviation automation: The search for a human-centered approach*. Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Bisantz, A. M., & Seong, Y. (2001). Assessment of operator trust in and utilization of automated decision-aids under different framing conditions. *International Journal of Industrial Ergonomics, 28*, 85-97.

Brodie, C. B., & Hayes, C. C. (2002). DAISY: A decision support design methodology for complex, experience-centered domains. *IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans). 32*(1), 50-71.

Brown, W. M., & Songer, C. W. (1989). A prospectus for automatic target recognition. *IEEE Transactions on Aerospace and Electronic Systems, 25*(3), 401-410.

Buchanan, B. G., & Shortliffe, E. H. (1984). *Rule-Based Expert Systems: The MYCIN experiments of the Stanford Heuristic Programming Project*. Menlo Park, CA: Addison-Wesley Publishing Company.

Byrd, K., Smith, B., Allen, D., Morris, N., Bjork, C., & Deal-Giblin, K. (1998, April 16-17, 1998). *Intelligent processing techniques for sensor fusion.* Paper presented at the Sensor Fusion: Architectures, Algorithms, and Applications II, Orlando, FL.

Carolan, T. F., & Scott-Nash, S. (2000). An application of human performance modeling to system design. In M. J. Chinni (Ed.), *Military, Government, and Aerospace Simulation* (Vol. 32, pp. 63-68). San Diego: The Society for Computer Simulation International.

Cohen, M. S., Freeman, J. T., & Wolf, S. (1996). Metarecognition in time-stressed decision making: Recognizing, critiquing, and correcting. *Human Factors, 38*(2), 206-219.

Cohen, M. S., Thompson, B., & Freeman, J. T. (1997). *Cognitive Aspects of Automated Target Recognition Interface Design: And Experimental Analysis*. Arlington, VA: Cognitive Technologies, Inc.

Crowley, J. L. (1993). Principles and Techniques for Sensor Data Fusion. In J. K. Aggarwal (Ed.), *Multisensor Fusion for Computer Vision* (pp. 15-36). New York: Springer-Verlag.

Cummings, M., & Guerlain, S. (2005). The decision ladder as an automation planning tool. *Cognition, Technology, and Work, In Review*.

Daniel, M. M., & Willsky, A. S. (1997). A multiresolution methodology for signal-level fusion and data assimilation with applications to remote sensing. *Proceedings of the IEEE, 85*(1), 164-180.

Das, B. (2000, July 12-15, 1999). *Cognition friendly interaction.* Paper presented at the Unsolved Problems of Noise and Fluctuations. UPoN'99: Second International Conference, Adelaide, SA, Australia.

Dasarathy, B. (2004). *Multi-Sensor, Multi-Source Information Fusion: Architectures, Algorithms, and Applications* (No. SC149). Orlando: SPIE.

Dave, R., Ganapathy, S., Fendley, M., & Narayanan, S. (2004). A knowledge-based system to model human supervisory control in dynamic planning. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 12*(Suppl. October 2004), 1-14.

Eggleston, R. G., Young, M. J., & Whitaker, R. D. (2000). *Work-centered Support System technology: a new interface client technology for the battlespace infosphere.* Paper presented at the Proceedings of the IEEE 2000 National Aerospace and Electronics Conference. NAECON 2000. Engineering Tomorrow, Dayton, OH.

Ewert, B. (2005). Simulating flight stress for scientists. In A. Muller (Ed.) (pp. Interview). Dayton, OH.

Fay, D., Verly, J. G., Braun, M. I., Frost, C., Racamato, J. P., & Waxman, A. M. (2001, April 16-17, 2001). *Fusion of multi-sensor passive and active 3D imagery.* Paper presented at the Enhanced and Synthetic Vision 2001, Orlando, FL.

Fay, D., Waxman, A. M., Aguilar, M., Ireland, D. B., Racamato, J. P., Ross, W. D., et al. (2000, 10-13 July 2000). *Fusion of multi-sensor imagery for night vision: color visualization, target learning and search.* Paper presented at the Third International Conference on Information Fusion, Paris, France.

Fitts, P. M. (1951). *Human Engineering for an Effective Air-Navigation and Traffic-Control System*. Washington, D.C.: Air Navigation Development Board.

Grossman, P. (1998). Multisensor data fusion. *GEC Journal of Technology, 15*(1), 27-37.

Guida, G., & Lamperti, G. (2000). AMMETH: a methodology for requirements analysis of advanced human-system interfaces. *IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans), 30*(3), 298-321.

Hollnagel, E. (1988). Information and resoning in intelligent decision supposrt systems. In E. Hollnagel, G. Mancini & D. D. Woods (Eds.), *Cognitive Engineering in Complex Dynamic Worlds* (pp. 215-228). San Diego: Academic Press Limited.

Hollnagel, E., & Woods, D. D. (1999). Cognitive systems engineering: new wine in new bottles. *International Journal of Human-Computer Studies, 51*(2), 339-356.

Hutchins, S. G. (1996). Principles for intelligent decision aiding. In C. A. Ntuen & E. H. Park (Eds.), *Human Interaction with Complex Systems: Conceptual Principles and Design Practice`* (pp. 103-131). Boston: Kluwer Academic Publishers.
Huttenlocher, D. P., & Ullman, S. (1990). Recognizing solid objects by alignment with an image. *International Journal of Computer Vision, 5*(2), 195-212.
Inguva, R., & Garrison, G. (1998, April 16-17, 1998). *Fusion of LWIR sensor data by Bayesian methods.* Paper presented at the Sensor Fusion: Architectures, Algorithms, and Applications II, Orlando, FL.
Isberg, B., Thorstensen, O., & Jorulf, H. (2004). Validation of diagnostic imaging based on repeat examinations. An image interpretation model. *Acta Radiologica, 45*(5), 540-546.
Jones, B. J. (1995). Variability and universality in human image processing. In F. T. Marchese (Ed.), *Understanding Images: Finding Meaning in Visual Imagery* (pp. 197-241). New York: Springer-Verlag New York Inc.
Jones, P. M., & Mitchell, C. M. (2002). Model-based cognitive engineering in complex systems--Part I. *IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans), 32*(1), 2-4.
Klein, G. (1998). *Sources of Power: How People Make Decisions*. Cambridge, MA: The MIT Press.
Krebs, W. K., & Sinai, M. J. (2002). Psychophysical assessments of image-sensor fused imagery. *Human Factors, 44*(2), 257-271.
Kuperman, G. G. (1997). *Human system interface (HSI) issues in assisted target recognition.* Paper presented at the Aerospace and Electronics Conference.
Kustra, T. W. (2000). *A Methodology to Develop Interactive Decision Support Systems for Complex United States Air Force Logistics Planning.* Wright State University, Dayton.
Lee, J. D., & Sanquist, T. F. (2000). Augmenting the operator function model with cognitive operations: Assessing the cognitive demands of technological innovation in ship navigation. *IEEE Transactions on Systems, Man, and Cybernetics--Part A: Systems and Humans, 30*(3), 273-285.
Li, S., & Wang, Y. (2002). Multisensor data fusion and its applications. *Advances in Modelling & Analysis B: Signals, Information, Patterns, Data Acquisition, Transmission, Processing, Classification, 45*(2), 19-37.
Llinas, J., Acharya, R., & Ke, C.-C. (1998). *Fusion based methods for target identification in the absence of quantitative classifier confidence* (No. CMIF-6-98). Buffalo: Center for Multisource Information Fusion.
Malone, T. B., & Heasly, C. C. (2003). Function allocation: Policy, practice, procedures, and process. *Naval Engineers Journal, 115*(2), 49-59.
Martel, R. J. (1996). HCI Architecting for System Reliability. In C. A. Ntuen & E. H. Park (Eds.), *Human Interaction with Complex Systems: Conceptual Principles and Design Practice`* (pp. 13-23). Boston: Kluwer Academic Publishers.
McNeese, M. D., Bautsch, H. S., & Narayanan, S. (1999). A framework for cognitive field studies. *International Journal of Cognitive Ergonomics, 3*(4), 307-331.
Mitchell, C. M. (1987). GT-MSOCC: A domain for research on human-computer interaction and decision aiding in supervisory control systems. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-17*(4), 553-572.

Mitchie, A., Laganiere, R., & Henderson, T. (1993). Multisensor Information Integration for Object Identification. In J. K. Aggarwal (Ed.), *Multisensor Fusion for Computer Vision* (pp. 255-276). New York: Springer-Verlag.

Muir, B. M. (1988). Trust between humans and machines, and the design of decision aids. In E. Hollnagel, G. Mancini & D. D. Woods (Eds.), *Cognitive Engineering in Complex Dynamic Worlds* (pp. 71-83). San Diego: Academic Press Limited.

Naikar, N., & Saunders, A. (2003). Crossing the boundaries of safe operationL An approach for training technical skills in error management. *Cognition, Technology, and Work, 5*(3), 171-180.

Narayanan, S., Bailey, W., Tendulkar, J., Daley, R., Pliske, D. B., & Wilson, K. (2002). Design of model-based interfaces for a real world information system. *IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans), 32*(1), 11-24.

Narayanan, S., Bailey, W., Tendulkar, J., Wilson, K., Daley, R., & Pilske, D. (1999). Modeling real-world information seeking in a corporate environment. *Human Factors and Ergonomics in Manufacturing, 9*(2), 203-229.

Narayanan, S., Ruff, H. A., Edala, N. R., Geist, J. A., Patchigolla, K. K., Draper, M., et al. (2000). Human-integrated supervisory control of uninhabited combat aerial vehicles. *Journal of Robotics ab\nd Mechatronics, 12*(6), 628-639.

Nejatali, A., & Ciric, I. R. (1998). Novel image fusion methodology using fuzzy set theory. *Optical Engineering, 32*(2), 485-491.

Nulty, W. G., & Ratliff, H. D. (1991). Interactive Optimization Methodology for Fleet Scheduling. *Naval Research Logistics, 38*, 669-677.

Parasuraman, R., Sheridan, T. B. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans), 30*(3), 286-297.

Peli, T., Young, M., Knox, R., Ellis, K., & Bennett, F. (1999, April 7-9, 1999). *Feature level sensor fusion.* Paper presented at the Sensor Fusion: Architectures, Algorithms, and Applications III, Orlando, FL.

Piccini, M. (2002). Human factors in the design of supervisory control systems and human-machine interfaces for highly automated complex systems. *Cognition, Technology & Work, 4*(4), 256-271.

Rasche, C., & Koch, C. (2002). Recognizing the gist of a visual scene: possible perceptual and neural mechanisms. *Neurocomputing, 44-46*(3), 979-984.

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (1994). *Cognitive Systems Engineering*. New York: John Wiley & Sons, Inc.

Reason, J. (1988). Cognitive aids in process environments: prostheses or tools? In E. Hollnagel, G. Mancini & D. D. Woods (Eds.), *Cognitive Engineering in Complex Dynamic Worlds* (pp. 7-14). San Diego: Academic Press Limited.

Roth, E. M., Bennett, K. B., & Woods, D. D. (1988). Human interaction with an "intelligent" machine. In E. Hollnagel, G. Mancini & D. D. Woods (Eds.), *Cognitive Engineering in Complex Dynamic Worlds* (pp. 23-51). San Diego: Academic Press Limited.

Ruff, H. A., Narayanan, S., & Draper, M. (2002). Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles. *Presence, 11*(4), 335-351.

Sarter, N. B., & Schroeder, B. (2001). Supporting Decision Making and Action Selection under Time Pressure and Uncertainty: The Case of In-Flight Icing. *Human Factors, 43*(4), 573-584.
Scott, S. D., Lesh, N., & Klau, G. W. (2002, 20-25 April 2002). *Investigating human-computer optimization.* Paper presented at the Proceedings of CHI2002. ACM SIGCHI(Special Interest Group on Computer-Human Interaction). Minneapolis, MN.
Sheridan, T. B. (2002). Some musings on four ways humans couple: implications for systems design. *IEEE Transactions on Systems, Man & Cybernetics, Part A (Systems & Humans), 32*(1), 5-10.
Sims, S. R. F., & Phillips, M. A. (1997). Target signature consistency of image data fusion alternatives. *Optical Engineering, 36*(3), 743-754.
Smith, M. I., Ball, A. N., & Hooper, D. (2002, 1-2 April 2002). *Real-time image fusion: a vision aid for helicopter pilotage.* Paper presented at the Enhanced and Synthetic Vision 2002, Orlando, FL, USA.
Smith, M. I., & Heather, J. P. (2005). *Review of image fusion technology in 2005.* Paper presented at the Thermosense XXVII.
Sokolowski, J. A. (2000). Replacing rule-based models with neural networks for human decision modeling in military simulations. In M. J. Chinni (Ed.), *Military, Government, and Aerospace Simulation* (Vol. 32, pp. 131-135). San Diego: The Society for Computer Simulation International.
Sokolowski, J. A. (2003). Enhanced Decision Modeling Using Multiagent System Simulation. *Simulation, 79*(4), 232-242.
Tauber, M. J. (1985, June 28-29 1985). *Top down design of human-computer systems from the demands of human cognition to the virtual machine-an interdisciplinary approach to model interfaces in human-computer interaction.* Paper presented at the IEEE Workshop on Languages for Automation: Cognitive Aspects in Information Processing, Palma de Mallorca, Spain.
The Data Fusion Server. (2004). *The JDL Definition of Information Fusion*. Retrieved July 13, 2004, from http://www.data-fusion.org/article.php?sid=70
Toet, A., & Franken, E. M. (2003). Perceptual evaluation of different image fusion schemes. *Displays, 24*(1), 25-37.
Toet, A., IJspeert, J. K., Waxman, A. M., & Aguilar, M. (1997, 21-22 April 1997). *Fusion of visible and thermal imagery improves situational awareness.* Paper presented at the Enhanced and Synthetic Vision 1997, Orlando, FL, USA.
Toet, A., & Walraven, J. (1996). New false color mapping for image fusion. *Optical Engineering, 35*(3), 650-658.
Tong, C. W., Rogers, S. K., Mills, J. P., & Kabrisky, M. K. (1987, May 19-21 1987). *Multisensor data fusion of laser radar and forward looking infrared (FLIR) for target segmentation and enhancement.* Paper presented at the Infrared Sensors and Sensor Fusion., Orlando, FL.
Umeda, K., Ikushima, K., & Arai, T. (1996, April 22-28, 1996). *Fusion of range image and intensity image for 3D shape recognition.* Paper presented at the IEEE International Conference on Robotics and Automation, Minneapolis, Minnesota.
Wan, W., & Fraser, D. (1999). Multisource data fusion with multiple self-organizing maps. *IEEE Transactions on Geoscience and Remote Sensing, 37*(3), 1344-1349.

Waxman, A. M., Gove, A. N., Fay, D. A., Racamato, J. P., Carrick, J. E., Seibert, M. C., et al. (1997). Color night vision: opponent processing in the fusion of visible and IR imagery. *Neural Networks, 10*(1), 1-6.
Winograd, T., & Flores, T. (1986). *Understand Computers and Cognition: A New Foundation for Design*. Norwood, NJ: Ablex Publishing Corporation.
Woods, D. D. (1986, Winter, 1986). Cognitive technologies: The design of joint human-machine cognitive systems. *The AI Magazine, 6,* 86-92.
Yoshida, K., Yokobayashi, E., Kawase, K., & Tanabe, F. (1995, 9-14 July 1995). *Computer simulation system of cognitive man-machine interaction in accidental situation of nuclear power plant.* Paper presented at the Symbiosis of Human and Artifact. Future Computing and Design for Human-Computer Interaction, Tokyo, Japan.
Zhou, Y., & Leung, H. (1997, July 21-23 1997). *Minimum entropy approach for multisensor data fusion.* Paper presented at the Proceedings of the IEEE Signal Processing Workshop on Higher-Order Statistics, Banff, Alta., Canada.
Zhou, Y., & Leung, H. (1998, April 16-17, 1998). *A maximum likelihood approach for multisensor data fusion applications.* Paper presented at the Sensor Fusion: Architectures, Algorithms, and Applications II, Orlando, FL.

VITA

EDUCATION

Wright State University, Dayton, OH
Doctor of Philosophy in Engineering, expected completion March, 2006.
Dissertation title: "Cognitively-Engineered Multisensor Data Fusion Systems for Military Applications." GPA: 4.0/4.0.

Worcester Polytechnic Institute, Worcester, MA
Master of Science in Biomedical Engineering, May, 2002.
Thesis title: "Optimization of a Technique for Phosphorescence Lifetime Imaging of Oxygen Tension in the Mouse Retina." GPA: 3.9/4.0.

Bachelor of Science in Biomedical Engineering With High Distinction, May, 2001.
Thesis title: "Biomechanical Properties of Normal and Smoke-Damaged Tracheal Tissue." GPA: 3.8/4.0.

PROFESSIONAL EXPERIENCE

Contractor, Air Force Research Laboratory, Sensors Directorate, Electro-Optics Research Branch, Dayton, OH, September 2003-March 2006. Secured $36,495 annual contract via the Anteon Corporation for conducting research in multisensor data fusion systems for military applications. Developed a new technique for using human subjects and cognitive engineering to model how humans make decisions based on multisensory imagery. Supervisors: Matthew Dierking and S. Narayanan.

Research Assistant, Wright State University, Dayton, OH September 2002-March 2006. Led a team to conduct an evaluation of distance education in Human Factors Engineering at Wright State University. Evaluated existing methods for analyzing data related to Air Force sortie generation logistics. Managed laboratory scheduling for ten students. Provided technical writing and editing services for students and professors. Supervisor: S. Narayanan.

Consultant, Lexis-Nexis, Dayton, OH, August-December 2004. Developed test plan for algorithm assessment and usability evaluation in a new information retrieval system. Served as lead technical writer for the project. Supervisor: Richard Miller.

Research Assistant, Imaging Research Center at The Children's Hospital Research Foundation, Cincinnati, OH, June 2002-June 2003. Developed methods for using magnetic resonance imagery to study the effects of juvenile rheumatoid arthritis on articular cartilage. Advisor: Bernard J. Dardzinski.

Research Assistant, Worcester Polytechnic Institute Department of Biomedical Engineering, Worcester, MA, January 2000-May 2001. Developed protocols for optical phosphorescence lifetime imaging in mouse models. Advisor: Ross D. Shonat.

Peer Learning Assistant, Worcester Polytechnic Institute Department of Biomedical Engineering, Worcester, MA, August 1999-October 2000. Aided students with homework, test review, and laboratory experiments in an Experimental Physiology course. Advisor: Ross D. Shonat.

Summer Intern, Boston Scientific Corporation, Natick, MA, June-August 2000. Developed methods for improving arterial stents using polymer-based drug-delivery coatings. Advisor: Robert Herrmann.

HONORS

Dayton Area Graduate Studies Institute Competitive Tuition Scholarship, 2002-2006. Full-tuition scholarship with assistantship.

Tau Beta Pi Engineering Honor Society, 2000-present. Member, vice-president, and advisor.

NASA Microbes in Space Workshop, July, 2005. One of three students from the state of Ohio selected to attend a space flight design workshop. Worked on a multidisciplinary team to develop a new bioassay for the International Space Station.

Wright State University Graduate Student Excellence Award, 2005. Presented to the outstanding student in each of Wright State University's graduate programs. Criteria for selection include superior academic achievement, noteworthy thesis work, and potential for significant contributions in the field.

Seth Bonder Scholarship for Applied Operations Research in Military Applications, 2004. One $5000 scholarship awarded each year by the Institute for Operations Research and the Management Sciences to a promising young researcher involved in the development and application of process modeling and operations research analyses to military issues.

SPIE Student Travel Grant, 2004. Funds for travel to the SPIE Defense and Security Symposium.

Sigma Xi Graduate Research Award, 2002. Awarded for outstanding research by a masters-level student at Worcester Polytechnic Institute.

Alfred R. and Janet H. Potvin Award, 2002. Presented to the outstanding graduate student in biomedical engineering at Worcester Polytechnic Institute.

National Eye Institute Travel Fellowship, 2002. Funds for travel to the Association for Research in Vision and Ophthalmology Annual Meeting.

Stephen Salisbury Prize, 2001. Presented to the most meritorious seniors at Worcester Polytechnic Institute.

Provost's Major Qualifying Project Award, 2001. Presented to the most outstanding senior project in each academic department at Worcester Polytechnic Institute.

National Science Foundation Young Scholar, 1993-1997.

PROFESSIONAL SOCIETIES

NSPE—National Society of Professional Engineers, 2005-Present.

IEEE—Institute of Electrical and Electronics Engineers, 2004-Present.

INFORMS—Institute for Operations Research and Management Science, 2004-Present.

SPIE—The International Society for Optical Engineering, 2003-Present.

PRESENTATIONS

"A Model of Human Interpretation of Multisensory Images for Military Applications," INFORMS Annual Meeting, San Francisco, CA, November 13, 2005.

"The Dempster-Shafer Theory," guest lecture for Wright State University course number HFE 890: Model-Based Decision Aiding, September 15, 2004.

"Cognitive Engineering in Algorithm Development for Multisensor Data Fusion," SPIE Defense and Security Symposium 2004, Orlando, FL, April 14, 2004.

REFEREED PUBLICATIONS

Muller, A.C., S. Ganapathy, M. E. Fendley, and S. Narayanan. 2006. Effectiveness of Distance Education in a Graduate Human Factors Engineering Curriculum. *WSEAS Transactions on Advances in Engineering Education* 2(3): 148-154.

Kustra, T.W., S. Ganapathy, **A.C. Muller**, and S. Narayanan. 2005. Decision support system for logistics systems analysis using image theory and work domain analysis. *Journal of Defense Modeling and Simulation* 2(2):.71-85.

Kight, A.C., B.J. Dardzinski, T. Laor, and T.B. Graham. 2004. The effect of juvenile rheumatoid arthritis on T2 maps of femoral weight-bearing articular cartilage. *Arthritis and Rheumatism* 50(3):901-904.

Shonat, R.D. and **A.C. Kight**. 2003. Oxygen tension imaging in the mouse retina. *Annals of Biomedical Engineering* 31(9):1084-1096 *(cover photograph).* Also selected for the Virtual Journal of Biological Physics Research 6(5), September 1, 2003.

ABSTRACTS

Kight, A.C. and R.D. Shonat. 2002. Imaging of oxygen tension in the mouse retina. *Association for Research in Vision and Ophthalmology (ARVO) 2002 Annual Meeting,* Ft. Lauderdale, FL. Abstract Program Planner accessed at www.arvo.org, Abstract #2577.

Shonat R.D. and **A.C. Kight.** 2001. Frequency domain imaging of oxygen tension in the mouse retina. *Proceedings of the International Society on Oxygen Transport to Tissue 29th Annual Meeting*, Philadelphia, PA, p. 86.

CONFERENCE PROCEEDINGS

Muller, A.C., S. Ganapathy, M. Fendley, and S. Narayanan. 2005. Comparison of In-Class versus Distance Learning Approaches in a Graduate Engineering Program. *Proceedings of the 1st WSEAS/IASME International Conference on Educational Technologies*. (In Press).

Kight, A.C. and S. Narayanan. 2004. Cognitive engineering in algorithm development for multisensor data fusion. *Proceedings of the SPIE: Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications 2004.* 5434:148-155.

Shonat, R.D. and **A.C. Kight**. 2003. Frequency domain imaging of oxygen tension in the mouse retina. Preliminary Instrumentation Development. *Advances in Experimental Medicine and Biology* 510:243-247.

OTHER PUBLICATIONS

Kight, A.C. 2002. *Optimization of a Technique for Phosphorescence Lifetime Imaging of Oxygen Tension in the Mouse Retina.* Electronic Thesis Document number etd-0430102-115119, Worcester Polytechnic Institute, Worcester, MA.

SERVICE

INFORMS Annual Meeting, San Francisco, CA, November 13, 2005. Served as chair for a conference session on "Sensor and Search Problems for Military Applications."

Raider Multisport Club, Dayton, OH, January 2005–March 2006. Served as secretary/treasurer and webmaster for a club dedicated to triathlons, duathlons, and adventure races in the Wright State University Community.

Wright State University Trebuchet Competition, Dayton, OH, February 2005–February 2006. Served as Assistant Director of Purchasing for a competition aimed at sparking the interest of high school students in engineering and design.

National Forensic League and Ohio High School Speech League, Ohio statewide, December 1997-present. Served as a judge for high school speech competitions.

Aerospace Adventures, Dayton, OH, July 2003-July 2005. Assisted with a program at the Vectren-Dayton Air Show to educate children about aerospace science and engineering.

Camp REACH, Worcester, MA, August, 2002. Served as a counselor at a two-week residential camp for seventh-grade girls aimed at developing their interests in science and engineering.

ADDITIONAL QUALIFICATIONS

Secret Clearance, United States Department of Defense.

Engineer Intern, National Society of Professional Engineers. Status awarded April, 2004.