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Assembling a Distributed Fused Information-based Human-Computer Cognitive Decision Making Tool

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Abstract *– A human, presented with a variety of displays is expected to fuse data for knowledgeable information. An effective presentation of information would assist the human in fusing data. This paper describes a multisensor-multisource information decision making tool that was designed to augment human cognitive fusion.*

Keywords: Cognitive-Level Fusion, Belief Filtering, tracking and ATR.

1. Introduction

Many psychologists, engineers, and computer scientists design interfaces for man-machine systems. One of the inherent assumptions in these designs is that the human fuses information from a variety of displays. To understand human sensory processing, many theories have been purposed such as Gibson's work in *ecological* optics [1]. Gibson purposed that the environment affords the user with information and that ecological information contains structure. An affordance is information made available to the human, however, man's attention is needed to take advantage of the potential information. Neisser [2] described perception in the form of *schemas*, where a schema is a mental codification of experience that includes a particular organized way of cognitively perceiving and responding to a complex situation or set of stimuli. A schema includes an anticipatory sensory signal, plan of action, and manager of information flow. Recently, researchers have adapted Neisser's schema to include situated action *plans*. A third paradigm is that of information processing [3] that seeks to map man and machines together. The *information processing* theory models man as a symbol manipulator with filtering and memory processes.

Man is placed in situations where his reliance on his sensory information fails for a couple of reasons: 1) the sensory information is too rich to gather reliable data, 2) the person is in a situation in which attention is focused on another task, and 3) all information is not available for the human to observe. For example, a pilot looks for ground moving targets, where there is a vast amount of information that the he must attune to as shown in Figure 1. The pilot must fly the plane as well as look for targets and the human is only one observer of the complex battlefield. In the first case, the human needs to augment his sensory capability by utilizing other sensory information such as radar, where additional sensory information can be transformed and synthesized for parsimonious perception. In the second case, the pilot's attention is divided between ground target identification and successful control of the plane. One benefit, for interface design, is that to fly the plane, the pilot is monitoring his instruments which localizes his filed of view. An interface from the augmented sensing system presented on the same panel would be of benefit. The third case stems from the fact that the pilot is only one person in a dynamic situation. The pilot is a distributed battlefield processor; however, through communication links, the fusion of information over space can be resolved in a computer interface to afford the person with information from other locations, such as another plane or a satellite.

The focus on data and information fusion has relevance for cognitive interfaces. Data fusion is at the sensor-signal level, whereas information fusion is the processing of signals for meaningful constructs. At the cognitive-fusion level [4], the human utilizes

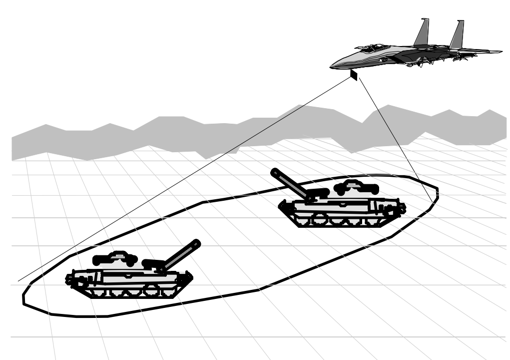

Figure 1. Target Sensor Management.

information to develop a fused perception of the world. Gathering information from an interface, the human must make an evaluation of the information and form not only a fused perception, but a fused action as shown in Figure 2. Researchers have effectively been working in data fusion (Waltz and Llinas [5], Varshney [6]), information fusion (Mahler [7]), and decision fusion (Dasarathy [8]). However, the integration of the fusion levels, requires human action where the human fuses goals and decisions, to form a *fused action*. Such an example includes managing sensors for target identity.

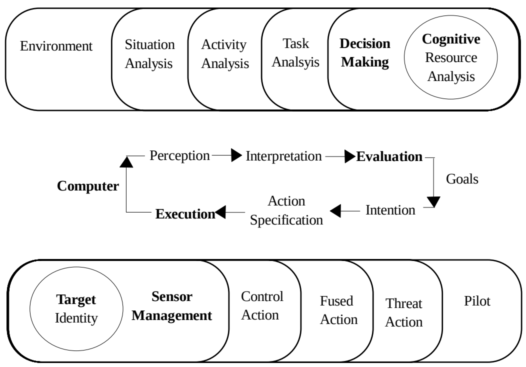

Figure 2. Fused Ecological Information perceptual evaluation and action execution..

Cognitive psychologists, such as Rasmussen [9, 10] and Flach [11], have been addressing issues for designing interfaces to augment complex decision making. Bennet and Nagy [12,13,14], have design concepts to enhance user performance and minimize human errors. Their approach is ecological interfaces that afford functional abstraction. In addition, others have focused on design interfaces that effectively afford the user relevant information. Such issues are movement and color representations of the real world. We seek to address human motion processing to augment these displays for spatial and temporal fusion [15]. Finally, the role of information accumulation is also one of uncertainty reduction. Researchers such as Bisantz and Llinas [16,17] are investigating uncertainty minimization through trust in automation.

Cognition for moving ground targets from SAR and HRR sensors has been a topic of recent discussion. Kuperman[18,19,20] is assessing crew aiding systems for subjective assessment of SAR imagery, which includes cognitive fusion [21]. Blasch [4] has purposed a cognitive fusion algorithm for SAR and HRR processing and an adaptive action algorithm [22]. The algorithm is based on the multiple levels of fusion including data, information, and cognitive level fusion. The integration of computer and human fusion is a new field and a topic of research interest. Such an example is the complex problem of fusing radar information, such as synthetic aperture radar (SAR) and high range resolution (HRR), that requires a knowledge of multiple fusion levels.

Humans form hypotheses about the world and then seek information to confirm the hypotheses. One of the important issues is the processing by which people are attuned to is moving information. Watamaniuk [23] has shown that people process a local and global speed signal and has used to the information to guide the presentation of moving information [24]. Additionally, Wamataniuk's work in random dot displays is like the clutter in the SAR image [25]. We seek to utilize these concept in target detection presentation of radar information.

For this paper, we are seek to assemble an interface that fuses SAR and HRR information, integrates multisource spatial and temporal information, and affords the user with an ecological perception of the battlefield for distributed cognitive decision making of ground moving targets. Section 2 formulates the ground target identification problem and Section 3 details issues in cognitive ATR. Section 4 presents the interface and Section 5 discusses issues relevant for further discussion and research.

2. Ground Target Identification

When performing a mission, a pilot focuses on salient information, such as threats to survival the same time he is to control the plane. Threats are difficult to measure because they are situation dependent and require reactive navigation [22]. While navigating a scenario, a pilot seeks to increase target-identity confidence by fusing and anticipating sensor measurements. Given a sensor suite, the pilot must adaptively view the correct sensor to discern the target of interest. In the multisensor/multitarget scenario, the pilot desires information that affords the best set of information to identify targets.

Recursive decision making under uncertainty is prominent in sensor fusion strategies. Sensor fusion includes automatic signal filtering, measurement association, target threat estimation, and cognitive sense prediction. Figure 3 shows a cognitive fusion model, based on the JDL levels of fusion, in which kinematic data is processed for situational and threat information. After fusion of data for information, a sensor manager, such as a human, must take a plan of action to choose the next set of sensors. A target recognition and tracking plan includes a domain representation, a dynamic environment understanding with risks and uncertainties, and acknowledgement of situation complexity arising from many possible sensor actions and outcomes. Such recognition problems have been studied for engineering and cognitive and tracking research which include learning and reasoning strategies [22].

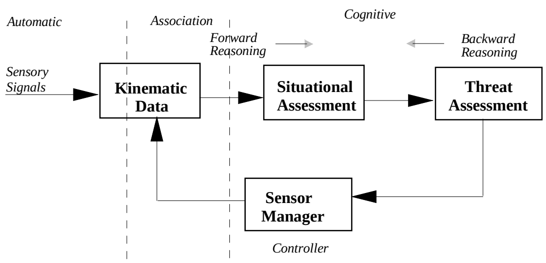

Figure 3. Sensor Fusion.

A method for automated sensor fusion and selecting sensor action plans would assist pilots in time-critical target tracking, identification, and threat assessment [4]. For instance, tracking a moving object includes *searching* the measurements, *predicting* the pertinent information, while *extracting* information and *matching* the sensed information with the expected information. Performing such a task requires measurement *action selection* to minimize the number of measurements and optimize the target identity. Roboticists, who are researching man-machine systems, have developed algorithms for planning [26, 27], perceptions [28], and assessing goals [29].

Automation can be an effective tool if the user trusts the system [17]; however, if the interaction is not mutual, either the human trusts the interface or neglects the interface completely. If the uncertainty is high which implies the confidence in the system is low, the human chooses not to use interface such as in the case where a human turns off the display and visually looks for a target on the ground. If the pilot must maintain a high altitude, visual scanning is not possible. The pilot must put full faith in the information presented in the interface. We seek to augment the human-machine fusion by operating in the domain of the human, such as presentation of sets of information with confidence values related to the uncertainty in the measurement system. Automation can be an effective and efficient interface for target identity, but presenting fused information is not well understood.

3. Cognitive ATR Decision Making

Gibson referred to the cockpit environment as affording information to the user. While the environment is man-made, we can take advantage of the interface design so as to afford the user with fused information for decision making. Decision-making processes require the management and processing of vast amounts of information. The human mind unfortunately is limited in its capabilities to manage, recall, and sort information. However, computers are adept in data collection, manipulation, and fusion tasks. One advantage of humans is fusing information for decision making by bounding sets of information. Computers can support the human decision making process by presenting sets of information to enhance the ATR speed and quality with which sets are created and managed while the human can determine the order in which information is fused and processed.

The *cognitive information fusion* concept is implemented in a computer interface which utilizes confidence value sets much like a human does. The interface filters and presents salient information to the user as well as captures incomplete knowledge. Any component of an information set can be selected as the focus of attention which bounds the view of the world. By using a hierarchical structure to information and data fusion, the world remains unbounded as any fused set of information can be selected. The database of information is viewed through information-fusion nodes in a tree structure to address various higher-level information and lower-level data-fusion relationships. Further insights can be gained from the database through "*belief filters*"[4] at each node which find the common fused-set in any list of information. A unique feature of the program is the ability to display any information-fusion levels to allow for multiresolution decision-making concepts.

3.1 Data Fusion

Time-critical scenarios, where multiple sensors can look at the environment, forces the pilot to adaptively select sensors for threat and track updates as depicted in Figure 1. However, there is a tradeoff of sensing time and threat confidence. The difficulty is that only a few sensors can measure a target threat before an updated track is needed. Hence, to save time, certain sensor measurements may be ineffective for target recognition, or lack information-producing actions and track updates. The ability for the interface system to provide reliable feedback is to do it in a

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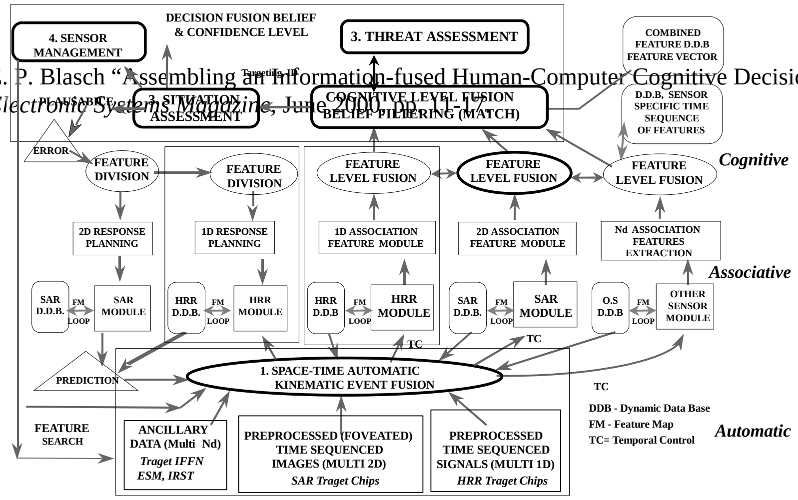

Figure 5. The Cognitive HRR/SAR Control Hierarchy.

real-time fashion to provide support for decision making.

3.2 Sets of Information

Fitts and Posner presented a way for humans to learn new tasks [30]. They presented three stages of development as cognitive, association, and automatic. In the case in which a human is presented with a new and complex problem, they first use declarative knowledge in acquiring new facts to understand the *cognitive* problem. In the *association* stage, evidence is accumulated to prune or eliminate extraneous facts. Additionally in this stage of conflict resolution, facts are matched in order to develop relationships between the targets. Finally, in the third and final stage, the association rules are used to *automatically* perform the task. Like Fitts and Posner, we chose to employ these stages, as shown in Figure 5. We have many modifications to the initial idea. For the ATR problem, we feel that the incoming data is actually in the automatic stage since raw information gathered by the sensors is converted to facts or features based on learned rules and phenomenology. The second difference is that the association of data is resolved into information components. Finally a cognitive stage is used to identify unknown target types or for the problem at hand, the identification of unknown people.

The adaptive action algorithm [22] learns useful sequential sensor actions that achieve the desired confidence level and presents to the track algorithm the next-state sensor measurement actions. The action confidence level determines the amount of clutter measurements. The tracking system processes the clutter for target recognition and chooses to move forward, avoid threats, or seek mission targets which is displayed in the interface. The scenario is similar to one in which a pilot monitors multiple target perspectives and selects the set of sensor actions that confirms threat beliefs.

3.3 Information Fusion

Situational information fusion requires a learned set of adaptive actions producing a goal-directed behavior. The problem is complicated due to target-threat importance, measurement uncertainty, and order of actions. The mission specific goal is to get to a desired target while avoiding threatening targets. Since the threatening targets are random, off-line learning will not help; however, some time is available for coordinating a set of next-state sensor measurements to discern threats which is a human-machine cooperation task.

3.4 Situation and Threat Assessment

The adaptive action algorithm fuses sensor and dynamic information such as target maneuverability. The system reasons over possible sensing actions for threat assessment. Actions are prioritized based on target of lethality or desirability. Using the action plan, the pilot reasons over track updates to avoid threatening targets. For adaptive sensing actions, the algorithm stops in time and presents target confidences to the user.

An action is *information producing* if it has a causal relationship. The threat update increases confidence when a causal relationship occurs. For instance, a causal relationship exists for sequential processing of the identity and its threat, but not the reverse. Updating the threat belief with only the threat measurement results in a minimally reinforced belief and single look ahead. To conduct the analysis, the person must carry out sensing plans that are adaptable to the sensed information. Although the pilot does not process probability measurements, he does compare relative probabilities as confidences compared to other target identities. A pilot cares only about the decision, not how it was derived. To calculate *belief confidences,* in the association of the space-time event action probabilities are fused. The *belief association probability* summation is used to develop confidences in sensed information. Once the belief is updated, a confidence level is presented based on the fusion of space-time association target state estimates.

4. Interface Design

While the interface is only one of many possibilites, it serves as a model from which the fusion community can discuss issues in presenting fused information for decision making.

4.1 Data Fusion

From the onset, it was decided that the signal-level information would be difficult for the human to process, but the person would want access to the data. For instance, HRR information is a 1-D signal that that captures the movement of the target. The human has a 1-D sensor for audition, so audible information is availble for target identity simialr to doppler processing. Additionally, by presenting the 1D signal, (shown in Figure 6, top right) fusion of visible information can verify if the correct signal is obatined, the relative size of the target, and whether the signal is above backgorund noise.

For a stationary target, the radar information is targets from which the human can detect targets (shown in Figure 6, top middle). Thus, the human acts as a sensor mananger to select targets, from a pushbutton interface, and regions of interst to focus the radar sensor for data collection (shown in Figure 6, top).

4.2 Sets of Information for Fusion Analysis

Information fusion is a result of the data and signal analysis. The SAR and HRR data types are fused by the computer or by the human. Since the human tries to compare the data with learned perceptions of targets, he is performing a search, predict, extract, and match for targets. For instance, in the battlefield, certain types of targets are assumed to be moving together like tanks. The human must parsimoniously limit the matching of targets from a set of hypothesized targets. Likewise, the interface

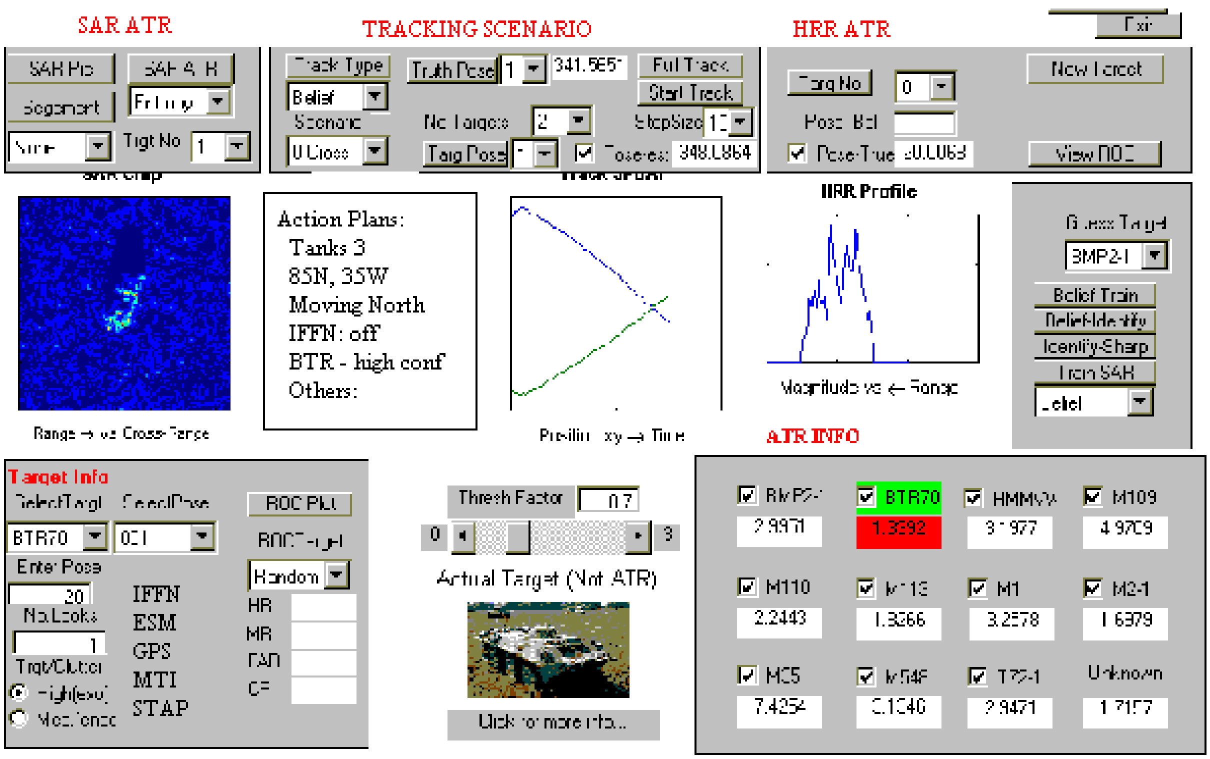

Figure 6. Initial Interface Design for Integration Fusion of Information.

displayed as a SAR image (shown in Figure 6, top left). The SAR image is cluttered, however, the user can choose a region of the image to process. Typically, a moving target indicator MTI provides access to all the targets in the field of view, however, the human must determine which target is of interest. In the case of multiple targets, tracking information can provide visual cues as to the position of the processes sets of information and presents confidence values (shown in Figure 6, lower right). The control of target set sizes is done by choosing a minimum set of target types to analyze. Initially the belief in all targets is possible, but through accumulated sensed information evidence the target increases. This is done interactively between the human and the interface through set management. Additionally, targets that are not plausible are pruned from the plausible set. The difference between the believable targets and the plausibility of targets can be used as a confidence measure (shown in Figure 6, lower right). Thus, the human and the interface are both processing confidences in the suspected targets for each location and analyze receiver operator curves, (shown in Figure 6, lower left).

4.3 Cognitive and Decision Fusion

Since the pilot is only one of many in the battlefield, additional information is processed to determine the targets (shown in Figure 6, lower center). The case of a multiplatform scenario affords the user information from other planes, with their respective sensors. This spatial information is provided to the user and processed in the confidence measures if available. Additionally, the temporal fusion of information is available from the tracking information (shown in Figure 6, top center).

At the cognitive fusion level, additional information is needed such as Identification of Friend, Foe, or Neutral (IFFN) target affiliation (shown in Figure 6, middle center). Decision fusion is one in which the interface helps select the targets of interest. When suggested targets are assessed, the human confirms that certain targets should be pruned from the set of information.

4.4 Fused Action

The purpose of the paper is to discuss issues in human-computer interface fusion; however, for the sensor management case, the human serially makes decisions. Likewise, the computer makes sequential decisions, albeit at a faster data rate than human capabilities to appear to be processing in parallel. Cognitive fusion can be called parallel processing, however, we do not discuss the issue, since the interface is limited to sequential decisions. Since the human can only take one action, it should be a fused action based on the information and decision chosen.

4.5 Initial Human-Computer Interface Issues

The analysis of the interface is the result of one human assessing the information and is subject to the designers preferences. Color, motion, and size are all cues that augment the perception of the targets. Tracking and motion cues help to direct attention to the targets of interest. Additionally, colors, well separated in the CIE diagram, help to clarify target confidences. Studies have shown that the human is adapted to processing 7 ± 2, pieces of information [1]. At all times, the interface seeks to take advantage of the limited numbers of information. Likewise, the separation of colors was limited to 7 colors for processing.

Kuperman [17], used the NIRS rating system and found that operators preferred image enhancements to the SAR imagery which consisted of reducing the image sizes by statistical means and a fuzzy set enhancement of the image. In the interface design, we use SAR image enhancement by segmenting the MTI plot with multiple targets, to that of a single target with some smoothing and size enhancement of the image. It was found that the human was better at identifying the target when size was increased and performed slightly better with the smoothed image, rather than the raw data alone.

5. Discussion and Conclusions

The interface design is the initiation of work in augmenting image analysts and pilot for assessing ground moving targets. While many issues could serve to enhance the work, none should be ruled out. The goal of the research is to design effective and efficient interfaces that produce a fusion of information from the computer for the human. The link is the interface between the two systems.

Many issues will need to be tested to determine the validity of the design. Hence, assembling the interface, as opposed to the successful analysis of the design is the key to the work. Research in engineering data, information fusion, and decision fusion were used to develop the signal-processing and research in psychology and perception motivated the display design. Cognitively, engineering and psychology provide motivation for assembling the interface to afford the user with effective and efficient ways for target identification for cases in which a purely visual analysis is not available, such as a high altitude aircraft with radar sensors.

The author invites any comments and suggestion from which to spawn a new field of research in human-computer evaluation and execution fusion interface designs.

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