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

Erik Blasch
Air Force Research Lab
2241 Avionics Cir, WPAFB, OH 45433 USA
Email: erik.blasch@sensors.wpafb.af.mil

Abstract – A human presented with a variety of displays is expected to fuse data to obtain 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.

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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 proposed such as Gibson’s work in ecological optics [1]. Gibson proposed 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 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.

In dynamic environments, man’s reliance on his sensory information fails for a couple of reasons: 1) sensory information is too rich to gather reliable data, 2) attention is focused on multiple tasks, and 3) complete information is not observable. For example, a pilot looking for ground moving targets is inundated with a vast amount of information, while flying the aircraft and looking for targets, and is only one observer of the complex battlefield, shown in Figure 1. In the first case, the human needs to augment his sensory capability by utilizing other sensory information such as radar. In the second case, the pilot’s attention is divided between target identification and successful control of the aircraft. In the third case, the pilot is a member of a competitive 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 aircraft or satellites. Additionally, a fusion interface design localizes his field of view, can augment his sensing capability, and provide information for flying the aircraft and identifying targets.

Focus on data and information fusion has relevance for cognitive interfaces. Data fusion integrates sensor signals, whereas information fusion processes signals for meaningful constructs. Researchers have effectively been working in data fusion (Waltz and Llinas [4], Varshney [5]), information fusion (Mahler [6]), and decision fusion (Dasarathy [7]). At the cognitive-fusion level [8], the human utilizes information to develop a parsimonious 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 also a fused action as shown in Figure 2. Cognitive fusion includes goals, decisions, and a fused action. Managing sensors for target identity is an example.

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 to employ ecological interfaces that afford functional abstraction. In addition, others have focused on design interfaces that effectively afford the user relevant information. Relevant information includes movement and color representations of targets. 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 synthetic aperture radar (SAR) and high range resolution (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 proposed a cognitive fusion algorithm for SAR and HRR processing and an adaptive action algorithm [22]. Blasch’s algorithms are 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.

Humans form hypotheses about the world and then seek information to confirm these hypotheses. One important issue is the processing of 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, Watamaniuk’s work in random dot displays is like the clutter in a SAR image [25]. We seek to utilize movement information for man-machine radar target identification.

For this paper, we 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 fusion ATR. Section 4 describes the interface and Section 5 discusses issues relevant for further discussion and research.

2. Ground Target Identification

When performing target identification, a pilot focuses on salient information, such as threats to survival and control of the aircraft. 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 sensor measurements. 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 tracking research [22].

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

An interface design can be an effective tool if the user trusts displayed information [17]; however, if the interaction is not mutual, either the human trusts the interface or neglects the interface completely. If the uncertainty is high and interface confidence 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 interface information. 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. An effective and efficient interface can aid target identification, 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 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 ATR speed and quality while the human can create and manage sets of information.

The cognitive information fusion concept is implemented in a computer interface which utilizes target sets, confidence values, and color-coding. The interface filters radar data, presents salient information, and captures incomplete knowledge. By using a hierarchical structure for information and data fusion, the human can bound the selection of fused information. Thus, high-level information and low-level data-fusion bound the information database. Further insights can be gained from the database through "belief filters"[4], which represent the current situational fused belief. A unique interface feature is the ability to display any information-fusion level to allow for multiresolution decision-making.

#### 3.1 Data Fusion

Time-critical scenarios, where multiple sensors can look at the environment, force the pilot to adaptively select sensors for target track updates as depicted in Figure 1. However, there is a tradeoff of sensing time and confidence. The difficulty is that only a few sensors can measure a target 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 interface must provide reliable, real-time feedback to support decision-making.

#### 3.2 Information Sets

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, 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 modify the initial idea for the ATR problem. We view incoming data in the automatic stage as a set of data since raw data gathered by the sensors is converted to facts, features, or information based on learned rules and phenomenology. The second difference is that the data association is resolved into information sets. Finally, a cognitive stage uses fused confidences based on the information sets to identify unknown target types.

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.

![Figure 5. The Cognitive HRR/SAR Control Hierarchy.](image)

3.3 Situation and Threat 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.

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 identify a target. For adaptive sensing actions, the interface presents target confidences to the user.

An action is information producing if it has a causal relationship. The target 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. 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 from a set of targets. A pilot cares only about the decision, not how it was derived. To calculate belief confidences, association of space-time event action probabilities is 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 spatial associations and temporal target state estimates.

4. Interface Design

While the interface is only one of many possibilities, 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 captures the movement of the target. The human has a 1-D sensor for audition, so audible information is available for target identity similar to radar 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 obtained, the relative size of the target, and whether the signal is above background noise.

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

### 4.2 Fused Information Sets

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 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 evidence, the correct target identity 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 both process confidences for suspected target identity and location that can be assessed through 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 left). The case of a
multiplatform scenario affords the user information from other aircraft, with their respective sensors. This spatial information is provided to the user and included in the calculation of the confidence measures. Additionally, the temporal information fusion is available from the target tracker (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 which targets to prune or add to the target set.

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 makes decisions serially. Likewise, the computer makes sequential decisions, albeit at a faster data rate than a human so as 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 designer’s 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 color space, help to clarify target confidences. Studies have shown that the human is adapted to processing $7 \pm 2$, pieces of information [4]. At all times, the interface seeks to take advantage of the limited numbers of information. For example, color separations was limited to 7 colors for processing.

Kuperman [17], used a SAR 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 image smoothing and size enhancements. 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 pilots for assessing ground moving targets. While many issues could serve to enhance the work, none should be ruled out. The research goal is to design effective and efficient interfaces that present a fusion of information from the computer for the human. The research goal is to integrate the two systems through the interface design.

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 motivate assembling an 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.

References


