Army Research Laboratory
Advanced Displays and Interactive Displays Fedlab
Technology Transitions
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ABSTRACT
The Advanced Displays and Interactive Displays Federated Laboratory (AD\&ID FedLab) is in its fourth year of a five year research project. Diverse areas of research such as spatio-temporal indexing for databases, intelligent information processing techniques such as sonification in the support of the display of courses of action, augmented reality, non-linear displays, tactile displays, gaze contingent displays, event related potentials and other cognitive engineering results are being readied for transition to various Army customers. In this paper we describe some of the research results along with their potential Army applications.

Keywords: Displays, cognitive engineering, sonification, speech recognition, liptracking, tactile displays, cognitive tunneling, exocentric displays, multimodal input.

1. INTRODUCTION
The Advanced Displays and Interactive Displays (AD\&ID) Consortium overall goal is to provide Army warfighters with innovative, cost effective solutions to information access, understanding and management for the Army of the future. Solutions must include providing the ability to assimilate and synthesize available information by the Commander and his staff. Users must also be able to make an assessment of the information’s quality and value; and, have the use of intelligent information filters and databases which permit the user to operate under conditions of uncertainty. And most importantly, information must be presented in a usable format to insure the consistency of battlefield understanding suitable to the user’s echelon. In order to achieve the overall goal it is necessary to explore advanced technical solutions that enhance the assimilation of information by the individual soldier as well as by the commander and his staff. The range of activities include:

1. establishing the groundwork required to support collaborative decision making, for both localized and physically dispersed groups;
2. the ability to “visualize” tactical goals, potential enemy courses of action and possible consequences of tactical actions in order to decide on an operational plan;
3. information scaling as a function of display size and information content;
4. 2D and 3D presentation of information; and
5. use of non-traditional interfaces such as natural language control, tactile displays, auditory, speech and gestures recognition.

A major research thrust of the AD\&ID program is the exploration of technology solutions to cognitive and perception-related aspects of human-computer interaction, in order to make good use of the software and displays that drastically improve the interface between Army users and their information systems. This critical link cannot be ignored because proper development will enable the Army to fully leverage its tremendous investments in information systems and hardware for the current and future Digitization of the Battlefield. For example, high performance display devices are being developed by industry, which have the potential to provide the solutions to many requirements for information assimilation on the battlefield. At the same time, information systems are being developed with the ability to acquire, process, and distribute more information than any user can handle. These systems need to allow individuals to fully utilize their capabilities to process information through multiple sensory channels without suffering from information overload. Under the AD\&ID program models, algorithms, advanced human-factors design principles and user interface techniques are being developed to provide users at the Division level and below with appropriate shared views of the battlefield regardless of the display system utilized. Current commercial business and office interface paradigms are typically ineffective and unsuitable for the Army’s
high stress environments. The presentation systems being developed for the Army must facilitate the conversion of data and information into usable knowledge.

The Advanced Displays and Interactive Displays Consortium (AD&ID) is composed of members selected for their recognized leadership in the technical areas established for this consortium. Industry partners include Rockwell through its Science Center (RSC), and Rockwell-Collins Inc. (RCI), Sytronics, Inc., and MCNC, Inc. The University partners are the University of Illinois at Urbana-Champaign (UIUC) and the North Carolina Agricultural & Technical (NCAT) University. As the lead organization, Rockwell brings a wide range of experience in the management of complex R&D programs at its Science Center, and through its Collins division, systems integration experience along with the design and development of displays for both military and commercial aircraft. UIUC) has a strong background in human-factors research, and in particular the Beckman Institute has a primary program in Human-Computer Intelligent Interaction (HCII). NCAT is the leading Human-factors University among the Historically Black Colleges and Universities (HBCUs). Sytronics is a small business with a strong background in human-factors research. MCNC, Inc. is a private, nonprofit corporation that provides advanced resources in electronic and information technologies to support education and industry and to enhance technology-based economic development in North Carolina.

One of the fundamental advantages of the FedLab concept is the quantity and quality of the resources that the members can share with ARL in accomplishing the research plan. Scientists and engineers from industrial partners, which are leaders in the commercial and defense sector product development, bring their knowledge of system and production issues and associated technology bottlenecks. University researchers bring their commitment to cutting-edge research and parallel involvement with other major research efforts funded by government and industry. ARL researchers bring their unique combination of research skills and specific focus on Army problems. In July, 1998 ARL received the Vice Presidents Golden Hammer award for Reinventing Government for the FedLab concept.

2. COGNITIVE ENGINEERING APPLICATIONS

The Cognitive Engineering Applications research projects are related to understanding and demonstrating how computer technology can facilitate the cognitive functioning of military personnel in their professional activities. One of the research areas with immediate Army application is the Intelligent Information processing for Visualization project, in this project research is being undertaken to generate, evaluate, and display courses of action (COAs) for both friendly and enemy forces. The goal of this research is to speed up the process of turning a commander’s intent w.r.t. the battlespace into a set of potential COAs that can be analyzed collaboratively, and from which intelligence collection plans may be generated and monitored as the battle progresses. Of course, as information is collected from the various collection assets the assumptions about the enemy’s plans may change and force a replanning cycle. This *generate*, *evaluate*, and *monitor* loop is embodied in the applications Fox-GA, Owl, and Raven (and its collaborative counterpart Co-Raven). There are a number of other research projects that are developing technology to support these tasks, examples of these include technology for indexing spatio-temporal data-base objects, and sonification support for the display of the Bayesian Belief Networks (BBNs) that are the basis for the Raven applications.
1. Intelligent Information processing for Visualization

Fox, Owl and the Ravens

Fox-GA is a decision support tool that has been designed to assist military planners to rapidly generate and evaluate a variety of coarse grained high-quality friendly courses of action (FCOAs). Its goal is to develop a set of potentially desirable FCOAs for presentation to the battle staff. As described in [1] the relation of Fox to the battle staff is that of an architect that makes numerous plans that he or she then shows for customer approval. Fox-GA’s genetic algorithm allows the system to search through a large space of possible FCOAs in order to show the user the a small number of possible courses of action that are found to be the fittest according to a utility function. Part of the transition effort that is underway in the FedLab is the generalization of this approach by associate partner Charles River Associates of Cambridge, MA.

In order to evaluate the effectiveness of Fox-GA as an intelligent decision aid in the future Army Tactical Operation Centers (TOCs) the program was taken to Ft. Leavenworth, KS. Eleven Army officers used a traditional paper-based briefing and the Fox-GA COA generator to determine a course of action in three different combat scenarios. Presentation of the Fox-GA COAs was made with either a two-dimensional (2-D) interface based on the ARL Combat Information Processor (CIP) or the three-dimensional (3-D) interface provided by the National Center for Supercomputer Applications’ Battleview system. Preliminary findings reported in [2] indicate that Fox-GA significantly increased the number of alternatives considered (2-3 times greater) over the paper-based briefing, and that the 2-D presentation of information was both the preferred and best performing situation.

The second stage in the evaluation cycle of the COAs is the Owl application [3] that is being developed at the Palo Alto Laboratory of the Rockwell Science Center. The function of Owl is to try and display the inherent uncertainty in the various courses of action generated by Fox-GA. The reasons for this uncertainty are manyfold, but include: 1) imprecise or missing information about enemy strengths, placement, or intent due to limitations of intelligence gathering assets (precision, coverage, availability), 2) erroneous assumptions or interpretations regarding enemy actions, 3) outdated information due to limited time persistence of acquired data, 4) probabilistic nature of battle events (e.g. targeting, accuracy). The approach that Owl takes in dealing with this uncertainty is to show the total distribution of all the events rather than make arbitrary choices concerning probabilistic events as in many traditional simulations, the total distribution of all the events is displayed so that important information such as the distribution of results is available. This is important as a large variance means that the outcome of the particular battle under analysis is largely left to chance. It is also possible to perform a sensitivity analysis by running the stochastic simulation once for each random variable being assessed. In each run, all random variables except for the one assessed are set to their mean values, whereas the assessed variable is varied according to its predefined probability distribution, and the variables are then ranked according to the magnitude of the standard deviation that they contribute to the outcome. The COAs selected by Owl can be used as input to other tools such as CECOM’s CADET [4] (for order of battle generation) or for RAVEN, described below.

The last stage of the chain is the Raven application and its collaborative counterpart Co-Raven, in these systems the Priority Intelligence Requests (PIRs) concerning the location of resources at a number of Lines of Defensible Terrain (LDTs), these LDTs are further subdivided into Named Areas of Interest (NAIs) and each NAI is broken down into evidence nodes, representing the classes of resources that may be identified as present or absent at that site. The function of Raven is to use
Bayesian Belief Networks (BBNs) to manage the flow information as it accumulates at the leaf nodes (from incoming salute reports) and percolates up the evidence network to the PIRs at the root nodes.

![Bayesian Belief Networks processing incoming salute reports](image)

**Figure: Bayesian Belief Networks processing incoming salute reports**

**Sonification of BBNs**

The human ear is very sensitive to small changes in input quality, so rather than have the PIRs at the root nodes of the BBNs notify according to some threshold value, the PIRs can be associated with a musical signal that is part of an ensemble that is designed to be auditioned together. For example, each LDT being monitored on the battlefield is associated with an audio mix (e.g. pitched instruments for one LDT, non-pitched instruments for another) that is composed of a unique auditory signature for each NAI. The audibility of each signature is determined according to the probability at the corresponding BBN node[5].

In order to reflect the hierarchical organization of the PIR tree, amplitude variation is managed in two layers. At the LDT level, amplitude is set for the corresponding signatures, according to the probability of resources at each LDT. This macroscopic adjustment determines the dynamic range of amplitudes controlled by each NAI. The increase and decrease of probability at the LDT level acts as a normalization of signatures that are responding to the probability fluctuations. After normalizing at the LDT level, the individual signatures are scaled according to their NAI nodes. The result is that as information comes in the form of Salute Reports the quality and audibility of the components of the sound mix change, providing eyes-free monitoring of the battlefield situation.

### 3. PERCEPTION-BASED DISPLAY FORMATS

#### 1. Bimodal Speech Recognition

Traditional acoustic-based automatic speech recognition (ASR) systems perform reasonably well when supplied with adequate training data and when the target environment is quiet, or matched to those in which the training data was collected. Various strategies based on statistical methods or modeling of the human auditory system have been tried to improve the accuracy of speech recognition in high-noise environments, another approach is to augment the acoustic recognition with dynamic visual features such as the position of the jaw, tongue and lips. The latter is motivated by the ability of the hearing-impaired to understand speech by reading lips.

Previous work has applied algorithms to video images of lip features that were collected offline. The bimodal recognition system described herein is distinguished by the fact that it uses robust lip localization and tracking techniques to perform real-time extraction of lip contours which are combined with acoustic features using Entropic’s HTK toolkit for handling hidden Markov models (HMMs). The first step in the recognition process is to localize the lips. This is done by downsampling the image (typically by a factor of 8), on the basis of hue a maximal connected component is extracted in order to localize the lip position, then hue and intensity information are used to match a contour to the lip boundary. Lip features are extracted from this contour and fed into the HMM. Initial results [6] have shown the utility of this approach by demonstrating lip-reading capabilities from a small CCD camera mounted on an adjustable headset.
2. Tactile Displays

A tactile interface between the soldier and the combined military communication and information systems can provide a useful tool for future military operations, especially those of the SUO/SAS variety. One of the advantages of tactile displays is that they augment traditional visual and auditory sensory channels, or may replace them in situations where those displays would either be obtrusive or open the soldier to detection by enemy forces, e.g. night battles or when noise would compromise the soldiers position. Two different experiments were performed using five vibrotactile stimulators. In the first experiment the subjects were asked to identify which stimulator was activated by pressing the corresponding button on a five button response keypad. The other experiment used the five stimulators mounted at 0°, 45°, 90°, 135° and 180° (angles referenced to the right arm), with the directional commands created by the actuation of a single stimulator or paired stimulators to indicate an azimuth between the two sources. Using combinations of weak and strong signals the azimuth resolution was reduced to 11° a significant improvement over current existing systems which use a large number of devices. Initial results [7] indicate that visual prompting is still more accurate than tactile prompting, but this will be explored further in 1999 when the stimulator array will be added to the Digitally Aided Soldier for Human Engineering Research (DASHER) in order to perform a land navigation experiment.

3. Augmented Reality

Augmented reality, where an artificial environment is superimposed over a real image, has found many uses in indoor environments for in-building navigation, “x-ray vision” and various maintenance applications. Registering the real-world
scene with the virtual world can be accomplished using a magnetic tracking system such as the Flock-of-Birds™ by Ascension Technologies™ to determine the position and orientation of the sensor. In addition, markers of different shapes and/or colors can be used as reference points for a tracking system. In the outdoor scenario, a GPS unit and a magnetic compass can obtain position and azimuth. However, the errors associated with these sensors (from 5° to 30° for the magnetic compass) are too high for accurate registration.

In a hybrid registration scheme described by Behringer [8] a GPS and magnetic compass was used to provide coarse azimuth and inclination, while accurate registration is achieved by extracting an horizon silhouette from a terrain database, and matching this with an image boundary from the external CCD camera as shown below. There are obvious Army applications in the ability to overlay information from intelligence assets onto the external scene (to provide the capability to look through an intervening mountain and “see” friendly or enemy units).

![Figure: An Artificial Horizon Silhouette Registered to the Actual Horizon](image)

### 4. Searching and Comprehending the Visual Environment

The ground soldier of the future will be assisted by electronic information delivered to them in the field. The technology used to display this information will have critical effects on its comprehension and registration by the intended user. A comparison was made in [9] between target detection using a head-mounted display (HMD) and a hand-held display. Some of the results from this study are that cueing aided the detection of cued objects, but at the cost of successful detection of uncued objects, especially in the case when the subjects were using an HMD. In similar experiments in an immersive environment [10] a similar “tunneling” effect occurred w.r.t. information that was initially presented in the forward view. The conclusion was therefore that some kind of exocentric (“tethered”) displays was more appropriate for the display of 3-D information to military personnel.

### 4. SOLDIER CENTERED COMPUTER INTERFACE

The role of this part of the research effort is to support the integration of both the hardware and software pieces described above and begin the transition of the technology to potential Army customers such as CECOM or other RDECS and the Battlelabs. An important part of the plans for successful transition are the validation experiments that are planned for the coming year in the Integration Support Lab (ISL). Another example of the successful combination of FedLab technology is the experimental test-bed that is being developed at the Rockwell Science Center in Thousand Oaks, CA. The purpose of this test-bed is to experiment with combining control modalities for networks of wireless microsensors.
1. Integration Support Laboratory

Figure: The Integration Support Lab and a Depiction of the Multimodal Fusion Architecture that Supports the Integration Efforts.

The Integration Support Laboratory is a facility located in the Beckman Institute of the University of Illinois at Urbana-Champaign. Here technology from the FedLab is combined under the goals of validating the synergies of multimodal interactions. We have developed a Multimodal Fusion Architecture that provides the software support for integrating input and output devices that have very different update rates for their data (~20 Hz for visual displays, 44KHz for high-quality audio. In addition, the MFA provides a model for navigating virtual environments that decouples the display of the virtual world from the input and output modalities[11].

2. Handheld Displays for Sensor Networks

Figure: A Depiction of a Handheld Display for a Microsensor Network in a MOUT scenario, and the Control of a Large Display with an HPC.

There are three Consortia that are conducting research under the FedLab cooperative agreement model the Displays Fedlab of which the authors are members, along with FedLabs devoted to Telecommunications and Advanced Sensors. In the intersection of these two FedLabs is research that is being undertaken at Rockwell Science Center and UCLA on wireless microsensors. In the displays FedLab we have supported these efforts with a preliminary task analysis for the different classes of users of these sensor networks. These initial analyses have in turn led to the preliminary design of a user interface for monitoring and controlling the sensor network[12].

A team at Rockwell Science Center in Thousand Oaks, CA has taken a metaphor from a commercial videogame to control a large format display. Two handheld PCs (HPCs) communicate with a PC hosting the wargaming application over a Proxim RangeLAN™, the application is under voice and stylus command, but in addition to this the wargame is displayed on the HPC (at lower resolution). In addition to providing an overview of the battle area, the large screen display, which has a much smaller focus area, can be directed to move to the area of the battlefield selected on the HPC. This will not only provide...
a test bed for the integration with the wireless microsensors, but will also allow the validation of results from the high-resolution displays of the NCSA.

5. CONCLUSION

The work of the AD&ID FedLab has begun to shift from that of almost pure research to a new phase of transition where the goal is to take validated technology from the researchers to Army customers for further development. Some of the technology pieces such as those dealing with course of action analysis and intelligence collection have begun to be transitioned because of their closeness to existing tasks. Some of the more speculative research such as that dealing with the control of wireless sensor networks is beginning to make its way into prototype applications, from whence it is hoped that it will find a home within the Army of the future.

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7. REFERENCES