Human-Robot Teaming

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ABSTRACT

This presentation will provide program information, goals and objectives of the Technology for Human-Robot Interactions in Soldier-Robot Teaming (HRI) Army Technology Objective (ATO). The intent of this program is to develop and demonstrate an intelligent scaleable interface for mounted and dismounted control of ground and air unmanned systems. Currently in the Army there are unique interfaces developed by engineers for each unmanned system fielded. This saddles the soldier with a training burden to learn specific interface operations prior to controlling the robot. By providing a consistent look and feel across various sized controlling devices, the training burden is reduced as well as the soldier's cognitive workload. Additionally, task analysis will be performed to identify workload barriers and bottlenecks, and intelligent agents will be developed and applied to reduce and/or automate the higher workload tasks. Lastly, this program will develop adaptive automation techniques to intelligently shed or introduce tasks at the appropriate time to the soldier to maintain optimal situational awareness and maximize the performance of the soldier-robot team.

Keywords: Interactions, teaming, soldier-machine, robot, scalable interface, intelligent agents, adaptive automation

1. INTRODUCTION

The Technologies for Human-Robot Interactions (HRI) in Soldier-Robot Teaming Army Technology Objective (ATO) (Fig 1) was established in 2004 and is a joint program between the Tank-Automotive Research, Development and Engineering Center (TARDEC) and the Army Research Laboratory's (ARL) Human Research and Engineering Directorate (HRED), both agencies under the Army Materiel Command's (AMC) Research, Development and Engineering Command (RDECOM). The main objective for the program is to provide intelligent, scalable mounted and dismounted control of ground and air unmanned systems. There are four pacing technologies for this program; extensive task decomposition and analysis to establish the workload of the soldier, intelligent agent development for offloading or automating soldier tasks for optimum workload, scalable interfaces for presenting all relevant information to the user regardless of his equipment configuration and mission, and recursive modeling to refine and validate models developed throughout the program. The ultimate goal is to reduce the controlling workload and training requirements of unmanned systems to permit the soldier to focus solely on his primary mission. Secondarily, how can a mounted or dismounted soldier properly interact with a robotic system in a seamless fashion so that it functions as another member of his team?

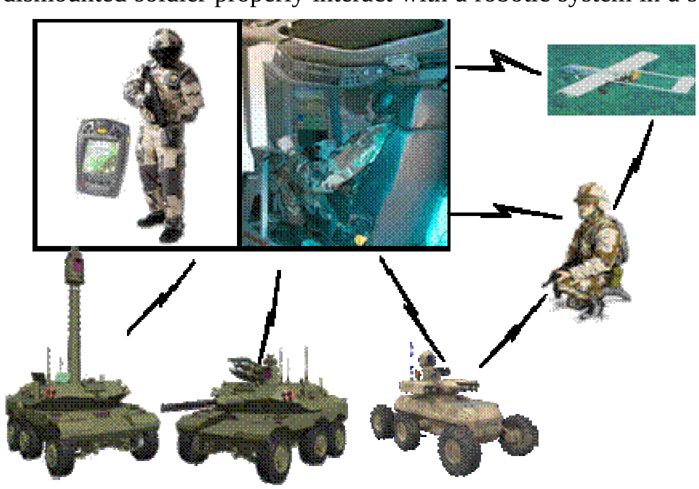

Figure 1: Technologies for Human-Robot Interactions (HRI) in Soldier-Robot Teaming Army Technology Objective (ATO)

The intent of this paper is to provide background information, a brief history outlining the establishment of the HRI ATO, and provide an overview of technologies, methodologies, approaches and support applications currently under investigation for use in this program.

Section two of this paper provides a program history detailing the current state of technologies in this area, the hurdles identified by the Army, and the methodology to be employed to overcome these barriers. This includes near term and long term objectives and potential transition opportunities for

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15. SUBJECT TERMS
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the Future Combat Systems (FCS) program and the Army weapon system community in general.

Section three of this report provides the systems engineering approach that the HRI program will utilize to solve human-robot teaming issues, scalability and adaptive automation to reduce soldier workload. This methodology identifies soldier requirements and delineates tasks, establishes relevant behaviors of the system, and feeds an end to end modeling system to test and validate component and system models.

Section four provides an assessment of current programs and technologies under investigation for incorporation or leveraging within the HRI ATO program. These programs are primarily comprised of Army ATO and Applied Technology Demonstration (ATD) programs; however relevant Army acquisition programs are also included. For each program, a program overview along with relevant technologies and potential application of those technologies within the HRI ATO program is summarized.

Section five of this report provides a technology assessment that presents an overview of applicable commercial and science and technology areas of interest to the HRI ATO program. The technologies presented within this section are anticipated to have a high degree of applicability to the HRI ATO and will be addressed and/or rationalized in some fashion within the resultant ATO products.

Section six of this report identifies specific conclusions as well as an approach for continued coordination and interchange of information and products between the HRI ATO and the FCS programs in accordance with TTA CT-18.

2. PROGRAM HISTORY

In 2002, the Army Science Board (Fig 2) conducted an Ad Hoc Study[1] on human robot interfaces. The study discussed the emergence of unmanned systems in the military, and identified some of the current shortfalls.

In particular, the study observed that, “the force will require and use unmanned systems in ways that involve close interaction. Further, because the technology required for full autonomy will not be available in the abbreviated time frame for the initiation of Army transformation, efforts should focus on controlled, semiautonomous operations. These two observations lead naturally to the question of how humans and unmanned systems interact. In this study, we focused primarily on the issues surrounding the interactions of humans with unmanned ground systems. The ground environment presents significant challenges to autonomous systems, in large part due to the navigation requirements created by the wide variability of the terrain, and the close proximity between the autonomous entities and humans in the environment. These challenges to automated systems operation make the task of effective human-robot interactions particularly important to mission success. Further, airborne vehicles alone cannot efficiently perform a large number of tasks that are important to the Army necessitating the use of unmanned ground vehicles.”

Figure 2: Army Science Board

During the information gathering phase, the study found reasons for optimism as well as areas of significant concern. Current Army programs had shown significant strides in the area of advanced perception relating to autonomous navigation, but that, “no existing programs systematically approach the challenges of interactions between humans and complex unmanned systems. Existing literature contains numerous examples that show that the lack of rigor in the design of interactions and interfaces between humans and complex systems can lead to catastrophic results (e.g., Three Mile Island, the USS Vincennes shoot-down of the Iran Air Airbus). If the human-robot interaction issue is not systematically addressed, we are concerned that similar catastrophic problems could arise in the application of robotic platforms in the Army. This, in turn, would result in severe setbacks to the induction of robotics into the force.”

The study concluded with three basic findings. “First, we recommend that the requirements community, led by TRADOC and the schools, establish an operational architecture for autonomous robots, and validate the architecture through an aggressive program of hands-on usage and experimentation with available robots in the field; (e.g., by the Army National Guard, by the Opposing Force (OPFOR) at the National Training Center). Second, we recommend the creation of a new systems-oriented program for the analysis, understanding, development, and improvement of human-robot interactions. We recommend that ARL, in cooperation with DARPA and other technology and system developers be the steward for such a program. This should facilitate technology insights and lessons learned from the field use of robots and the real time feedback establish the baseline for future developments; a process that should promote spiral development. Finally, we recommend that the Army insist that FCS Block 1 program have, at a minimum, follower robots with a significant level of autonomy and surveillance and reconnaissance robots that can operate in limited environments—capabilities that can developed by maturing the technology that exists today."

Based on Army Science Board recommendations and approval from ASAALT and TRADOC, TARDEC took the lead role to develop a systems engineering approach in solving soldier-robot interaction issues, teaming with ARL-HRED for support in human factors engineering concerns.

3. PROGRAM METHODOLOGY

TARDEC and ARL-HRED are teaming to solve human-robot interactions for mounted and dismounted control of ground and air unmanned systems. The approach to solving this problem utilizes an end-to-end systems engineering approach that starts with the identification of soldier requirements to conduct missions when teaming with unmanned systems. These requirements are defined in terms of the tasks to be performed, in turn leading to the identification of system behaviors. System behaviors are captured in an HRI knowledgebase in accordance with an intelligent system ontology, along with the technologies and capabilities associated with the domain of intelligent systems in which these behaviors will be deployed. To the extent possible, the behaviors defined within the knowledgebase will be specified independent of specific technologies or their allocation (i.e., hardware, architecture, or human operators). Once archived within the knowledgebase, relationships will be defined between behaviors and functional capabilities to support analysis and trade off of specific deployments. As depicted in Figure 3, candidate deployments can be evaluated early in the analysis process by modeling deployments from the knowledgebase in an intelligent systems behavior simulation. For this step, tasks are extracted from the knowledgebase and allocated to specific hardware and crewmember agent models, with the behavior simulator executing the deployment as a set of interacting agents. External inputs to the behavior simulation; representing platform subsystems, other vehicles, and dismounted soldiers is provided via constructive simulation tools. Once a deployment has been evaluated, portions of the knowledgebase may be provided to component vendors, representing a set of executable requirements to include the logical data model and interactions required with other subsystem components. As components are acquired, they are evolved and tested in an iterative fashion through various program phases to include system integration testing, and field experimentation. Results from each of these phases are fed back into the knowledgebase as applicable. The capturing of behaviors within the ontology is further defined within section 4.2.2 and the modeling approach to support deployment development and analysis is further defined in section 4.2.1. In parallel, technologies will be explored (see section 5) that will optimize the soldier's performance for given missions. For example, due to the fact that a dismounted soldier will have a reduced amount of display space as compared to a mounted counterpart, he/she might

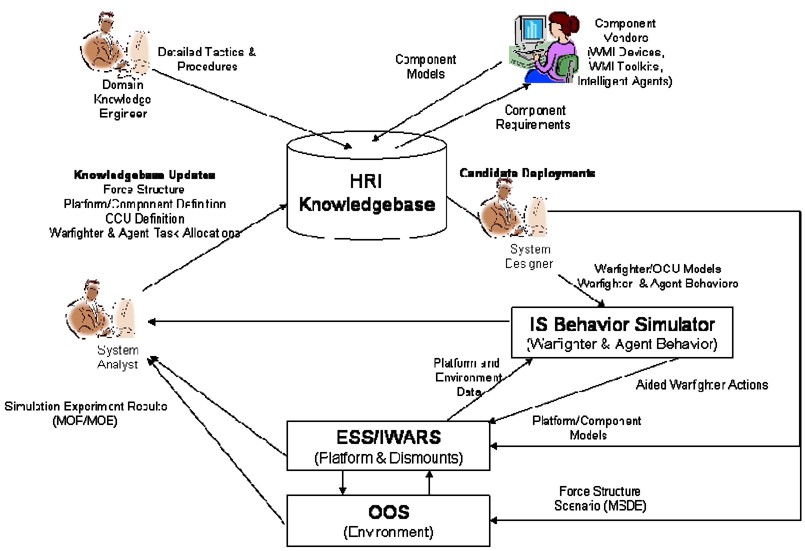

Figure 3: HRI Modeling Methodology

utilize technologies such as speech recognition or gesturing as an alternative input device to interface with the system. The end goal is to put the right equipment into the soldier's hands that best fit his/her overall mission requirements.

4. PROGRAM COMPONENTS

Four key components serve as the foundation for the HRI ATO systems engineering approach to human-robot interactions: Architecture, modeling and simulation, interface scalability, and intelligent agents/adaptive automation. These items were provided to PM-UA as part of a Technology Transition Agreement[2] that was delivered in November of 2004 and will refine deliverables through FY08. Each component is detailed in the sections that follow, including applicable technologies and methodologies under development/refinement within the DoD and commercial world that have bearing on HRI ATO program requirements.

4.1. Architecture

In order to ensure the integration of HRI components and HRI product compatibility to Army weapon systems, the HRI program will define a reference architecture, supporting product definition, development, integration, and test. The reference architecture will be defined utilizing a systems engineering process to analyze and capture HRI system requirements, future force Army mounted and dismounted system requirements, Army force operational requirements (supporting derivation of vehicle tasks and vehicle/crew behaviors), Army technical architectural requirements, and intelligent system architecture discipline requirements.

HRI system architecture requirements will be derived from a varying set of sources to include:

- HRI target platform requirements with respect to scalable interface configurations and platforms defining scalability and extensibility;
- HRI technology (e.g., crew control and operator interface technologies, decision aiding, sensors, common Warfighter-Machine Interface (WMI)) requirements compiled via program and technology assessments;
- HRI program transition requirements supporting the future force to include FCS, Future Force Warrior (FFW) and HRI technology spiral integration into Stryker and current force systems; and
- Force structure system requirements, defining the tactical operational behavior of the robotic and host platforms within platoon configurations; and Joint architecture requirements as they relate to architecture standards and interfaces, defined within the Joint Technical Architecture and Joint Technical Architecture – Army.

Following the establishment of the HRI system architecture requirements, a reference system architecture design will be initiated to establish a logical model of architecture components, attributes, and interfaces to facilitate the creation and integration of system, subsystem, and component models supporting HRI virtual and physical integration. Primary inputs to the HRI system architecture design include the review and synthesis of: Army weapon system architecture initiatives to include the Joint Technical Architecture and Joint Technical Architecture – Army, the Weapon System Common Operating Environment and the FCS System of System Common Operating Environment;
TARDEC Intelligent Systems architecture initiatives, to include the Vetronics Reference Architecture, embedded simulation architecture, Vetronics Technology Integration crewstation and system architecture, WMI guidelines and common WMI specifications; and the TARDEC Intelligent Ground Vehicle (IGV) taxonomy (see section 4.2.2.3). The system architecture design will utilize the IGV taxonomy as a basis to capture and decompose vehicle tasks to tactical behaviors and subsystem/system components that execute those behaviors. In this context the term "component" implies subsystems, architecture, intelligent agents, or scalable interface operators. Components will be identified in accordance with the HRI architecture requirements and a functional classification and decomposition approach will be employed to derive a reference architecture model identifying components, component interfaces, component attributes, and component relationships and dependencies. Component attributes will be defined to not only capture operational characteristics, but to capture architecture physical and usability aspects as well (e.g., weight, cost, volume, lifespan, mean time between failure).

The reference architecture will be specified using the Unified Modeling Language (UML) and Ontology Web Language (OWL) and will capture system-wide design decisions, architecture context, system components, concept of execution, and interface design.

4.2. Modeling and Recursive Simulation

The following section describes various HRI ATO modeling and simulation methodologies and tools supporting component, constructive, and virtual modeling and simulation to be applied in the definition and development of HRI subsystems and systems.

4.2.1. End to End Modeling Approach

The HRI ATO will employ a model-based development process facilitating the initial realization of system/subsystems as computer models that are iteratively refined and validated through simulated tests. For each iteration, the fidelity of the model and the simulated test will be increased until it can be demonstrated that the modeled design meets all of the system requirements for the intended environment. At that point a physical system can be realized from the model definition in a laboratory prototype form. The physically realized prototype system can be iteratively tested in the simulated environment until it demonstrates the ability to meet all allocated system requirements, at which point the system can be realized in a form suitable for its intended environment and tested in the field though user experimentation. This process, currently being matured within TARDEC is known as the end to end modeling process.

The end to end modeling process maps to the general systems engineering design process, aligning methodologies and tools to assist in early and frequent up front modeling in the requirements definition process through preliminary and detailed design. The modeling through these phases of a system's lifecycle will be iterative and it is highly desirable to select tools and methodologies that facilitate a continuous transition as the models increase in fidelity. It is envisioned that modeling phases within the end to end modeling process will produce correlated constructive, component, virtual, and physical models to include scalable interface models, host vehicle models into which scalable interfaces will be integrated, and robotic vehicle models that will be controlled by scalable interfaces that control robotic assets, whether they are configured within a vehicle crewstation, dismounted handheld device, or mixed. Models developed early on in the requirements and design phase will be archived such they may serve as a reusable model base for programs with similar requirements.

The HRI program is currently defining the phases of the end to end modeling approach to be employed within the program, the relevant tools and methodologies, and the desired mapping of the end to end modeling approach to the systems engineering design process. Some of the tools and methodologies under investigation are described in subsequent sections of this report.

4.2.2. Constructive Modeling

A number of constructive modeling tools and methodologies will be examined for inclusion in the HRI ATO. This will include stochastic tools such as CASTFOREM and COMBAT XXI, component models developed by MathWorks, MATLAB, SimuLink, and AutoCAD, behavior modeling tools such as OWL-S, cognitive modeling tools like ACT-R, IMPRINT and SOAR.

Stochastic modeling tools like CASTFORUM and Combat XXI will be employed within the end to end modeling process to model initial vehicle level requirements with respect to required system capabilities. Once established, these requirements will be flowed through the end to end modeling process to support the derivation of human robotic interfaces and evaluate human robotic interface deployments.

The HRI program will develop stand alone and integrated constructive component models, representative of common scalable interface architecture system/subsystem and application components. Component models used to support virtual integration and test will focus on analysis, and support dynamic simulation of key integration parameters such as power loading, data bus loading, processor/memory loading, thermal loading, space claim, interface compatibility, and operator workload. Embedded simulation models will be developed to focus on operational performance analysis and will support dynamic simulation of component operation in a distributed simulation environment. These models will also have access to simulation scenario and ground truth information in order that they can simulate the operational behavior of complex automated systems. In addition to scalable interface models, the HRI program is also developing Manned Ground Vehicle (MGV), Unmanned Ground Vehicle (UGV) and Unmanned Air Vehicle (UAV) component models to support simulation, integration, and validation of scalable interface concepts prior to build and field test.

The HRI ATO program is defining, employing, and refining an IGV ontological modeling technique to specify systems of systems behavioral views for both manned and unmanned ground vehicles. The IGV ontology models a group of vehicles (e.g., a Unit of Action) as a hierarchy of interconnected intelligent agents that spans each of the command echelons (i.e., company commander, platoon leader, section leader) as well as the vehicle architecture (i.e., major, vehicle systems, subsystems, and components). The behavior of each agent is specified as a set of services defined using the OWL-S web service ontology developed by DARPA. OWL-S also provides the language to map services to intelligent agents and describe interactions between services. Although work has already started on the development of the IGV ontology many more missions must be modeled to support the HRI project. A functional decomposition of anticipated missions of UGV and UAV equipped units will be conducted using the 4D/RCS methodology to identify the essential tactical behaviors of each vehicle (manned or unmanned) in the unit and the interactions between each vehicle in the unit. This decomposition will begin with the analysis of Army reference materials defining missions, tactics, techniques and procedures. The functional decomposition will also include the identification of the tasks that must be conducted within each vehicle to control each level of equipment to accomplish the tactical behaviors. The IGV behavior models will be developed using open source tools such as Protégé-2000. As HRI technology concepts mature, IGV behaviors will be allocated to human operators or computer automation in separate IGV deployment models to reflect candidate system design concepts. Representations of vehicles within the ontological model will be kept consistent with an HRI reference architecture model to support the allocation of tasks to agents that correspond to physical entities in the HRI architecture. IGV behavioral models will serve as a knowledge base for tactical behaviors which will also be used as a reference sources for the design of subsystem models, constructive operators, or decision aiding approaches such as intelligent agents.

The HRI program will provide a means to model the cognitive behavior required to conduct ground combat vehicle operations. These models will be developed to capture the intelligence required to control and interact with robotic systems. This modeling activity will support simulation integration to analyze automation requirements and to trade-off deployments/conceptualizations prior to physical hardware design and development. Three cognitive modeling technologies currently under investigation and/or development within TARDEC to support the HRI program are ACT-R, IMPRINT, and SOAR.

Adaptive Character of Thought – Rational (ACT-R) specifies a cognitive architecture that can be utilized to model a wide range of human cognition and is targeted at the atomic level of thought (cognitive, perceptual, and motor). For the HRI program, TARDEC is analyzing the benefits and potential of employing the ACT-R modeling technique to characterize cognitive behavior and is also analyzing data resulting from the IMPRINT/ACT-R integration experiments conducted by the ARL-HRED.

Improved Performance Research Integration Tool (IMPRINT) models are used to constructively simulate cognitive behaviors. IMPRINT is dynamic, stochastic discrete event network modeling tool that assesses the interaction of soldier and system performance throughout the system lifecycle. In order to support virtual test of scalable interface concepts, the HRI program will define a set of IMPRINT models, to include tasks identified in the MGV behavioral models. These IMPRINT models will include predefined external stimuli to enable the simulation of the model in predefined HRI test vignettes. Initial models will be modified to define the specific allocation of tasks to operators/automation; representing the specific interactions between the HRI scalable interface and operator in accordance with the specific WMI technologies defined in the scalable interface concept. Multiple versions of these IMPRINT models can be created with the task execution times and workload adjusted to reflect specific applications of HRI technologies. Each version can be evaluated for a set of test scenarios and the results compared to assist in the selection of the most promising HRI configuration. As new IMPRINT models are developed, they will be archived within a model repository for possible reuse by the Government or other scalable interface contractors.

State Operator and Result (Soar) is a general cognitive architecture, developed by the University of Michigan that has been employed in the development of systems that exhibit intelligent behavior across a wide array of domains to include artificial intelligence and cognitive science   Soar addresses two primary aspects of cognitive architecture: 1) a fixed set of mechanisms and structures that process content to produce behavior and 2) the theory, or point of view, about what cognitive behaviors have in common. For the HRI program, TARDEC is analyzing the application of the Soar architecture for cognitive modeling and for translation of cognitive behaviors to decision aiding agents to control autonomous unmanned assets.

4.2.3. Vehicle Performance Modeling

For the past several years, TARDEC has been working towards the evolution of a constructive modeling technique to represent and integrate human operators within high fidelity M&S environments. This technique to define high-resolution constructive models of a ground combat vehicle and its crew has been termed Vehicle Level Human Performance Modeling (VLHPM). The VLHPM supports the prediction of crewmember performance given a specific vehicle system configuration (e.g., specific mobility, lethality, surveillance, and survivability subsystems) and a specific set of warfighter-machine interface technologies (e.g., multifunction displays, voice control, heads up displays). The VLHPM is capable of operating in a distributed simulation environment using HLA protocols to enable the creation of complex battlefield environments to fully exercise the crew models. The VLHPM supports optimization of operator task allocations and warfighter-machine interface designs prior to development of more expensive man-in-the-loop crew station simulators. The architecture of the VLHPM is comprised of a vehicle model integrated to a human performance model.

The vehicle model is implemented utilizing the TARDEC Embedded Simulation System (ESS), which is a configurable, high-resolution simulator of FCS combat vehicle organizations designed to support constructive, and human-in-the-loop (HITL) real-time (wall-clock) mock battle simulation experiments. The ESS provides a configurable vehicle model, which in turn provides detailed simulations of subsystems such as mobility, lethality, survivability, sensing, and communications. It can be employed to model and simulate either manned or unmanned ground and air vehicles, has Semi Automated Forces (SAF) capability, and is DIS/HLA compliant. The ESS models the latest FCS concept vehicle designs (MGV, UGV, UAV and Unattended Ground Sensors (UGS)) and will be altered to accommodate program needs.

4.2.4. Virtual System Integration Laboratory (VSIL)

The TARDEC VSIL is a constructive simulation environment designed to facilitate vetronics systems engineering of intelligent ground vehicle systems. The VSIL defines a logical model with an associated configurable simulation object base that can be employed within a constructive simulation at various levels of fidelity to rationalize and evaluate system/subsystem deployments prior to final allocation and hardware acquisition. VSIL deployments support analysis, allocation, and tradeoff within key areas of the intelligent ground vehicle domain to include: Vetronics (data control and distribution, computing/knowledge resources, controls and displays, power management and distribution), intelligent agents (human/machine), physical allocation (power, weight, volume, thermal, and other environmental), workload allocation (human/machine), and planning and preparation.
The three primary VSIL interfaces are the repository interface; the simulation execution environment interface; and the performance, analysis, and measurement interface. Through these interfaces, VSIL model developers and VSIL system deployment developers can create, execute, analyze, and archive VSIL system models. The repository interface provides for the import/export of repository models and the configuration of models into system/subsystem deployments. In addition, this interface can be utilized to create test scenarios that define external stimuli representing battlefield events. The simulation execution environment interface governs simulation startup/initialization, shutdown, and execution control. Finally, the performance, analysis, and measurement interface provides a means to analyze simulation performance through the measurement of system measures of performance and measures of effectiveness based on attributes defined in the VSIL reference model architecture.

Within the HRI ATO program, the VSIL will be used to evaluate specific deployments of scalable interface components during the preliminary and detailed design of a scalable interface. Each evaluation will provide data on the compatibility of the selected scalable interface components with each other and with the vetronics systems defined for the host vehicle. The evaluation will identify vetronics resource shortfalls that could occur at any time during a mission (e.g., insufficient battery power to sustain a remotely deployed scalable interface during extend periods of silent watch). The evaluation will also provide an insight to the operator work load during different phases of system operation. Use of the VSIL facilitates the conduction of trade-offs to refine deployment concepts and as deployment concepts mature from preliminary design through detailed design, component models with increasing levels of fidelity can be used to support detailed analysis in accordance with the increasing levels of fidelity in the design definition.

4.2.5. Physical Simulation

Physical simulation will be utilized within the HRI program as a step within the end to end modeling process to validate operator HMI performance prior to vehicle field testing. Physical simulation is conducted within the TARDEC Ground Vehicle Simulation Facility by integrating the scalable interface and operator into a motion based simulator and executing tactical operational scenarios requiring operator interaction. Operator performance and condition will be evaluated to validate the effectiveness of the scalable interface under test. Deficiencies will be documented and addressed via redesign at the appropriate predecessor phase within the end to end modeling cycle.

The HRI program is coordinating with the High-Fidelity Ground Platform & Terrain Mechanics Modeling ATO, a collaborative effort among TARDEC, ERDC and ARL, to leverage their high fidelity models of FCS ground platforms and their corresponding terrain to conduct assessments of mobility, durability, mission module, and moving vehicle operations.

4.3. Decision Aiding

While the concept of decision aiding has been in existence for several years, the manner in which decision aids are best suited to support crew operators and the manner in which decision aiding architectures should be developed to support ease of integration for disparate vendor solutions and technology has not been adequately addressed (Fig 4).

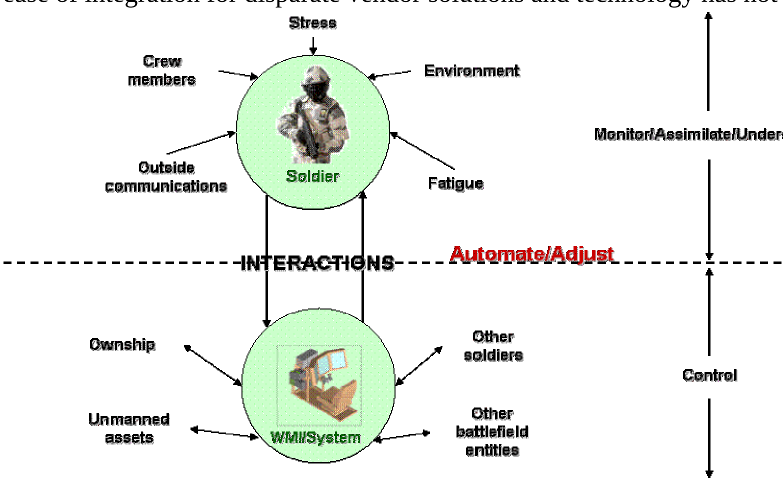

Figure 4: Adaptive Automation

Areas that need to be further explored and matured include:

- Levels of autonomy. Typically levels of autonomy will minimally include no autonomy (decision aide may be aware such that it could react to a change in state, but is completely passive), semi-autonomous (decision aide is in the loop and performs some functionality, operator provides final authority for any mission critical function), and fully-autonomous (decision aide is fully engaged and performing tasks typically assigned to a crewmember).
- Decision aiding architecture. Both the FCS program and science and technology programs have been experimenting with designing decision aiding architectures. In order to be successful, a decision aiding architecture will require the ability to adapt over time and architecture terms, behaviors, and components need to be defined that will facilitate the ability to integrate advancements in decision aide technologies over time. One key area is the definition of the system knowledge base and the manner in which decision aids, planners, and system components will interface to enhance and utilize elements of the knowledge base.
- Commercial infrastructure. Commercial knowledge architecture infrastructure is rapidly developing to include knowledge management, semantic networks, intelligent agents, and web based service architectures. The FCS program has been analyzing the manner in which commercial tools, techniques, and paradigms might best map to support system of system agent relationships and interactions. As methodologies are defined to decompose tasks and behaviors, tools need to be defined to capture operational and system level architecture data and facilitate the analysis, automation, modeling and simulation, and eventual development and integration of intelligent agents. Commercial tools in the areas of ontology, modeling and simulation, and web services need to be analyzed against these requirements.
- Extended application. Following the establishment of decision aiding architecture, extended applications need to be analyzed and developed to determine the best way in which decision aids can support improvements in the operator's ability to perform his mission with respect to human robotic interaction and teaming. One example area is in task sharing/shedding, which would combine sensors integrated to the decision aiding

system to monitor crew condition and/or loading and to adapt to either take on priority tasks or share the workload (i.e., perform as an autonomous interactive crewmember).

4.4. Common WMI

This section addresses activities under investigation within the HRI ATO to standardize WMI and WMI components within the target platform scalable interface domain. The approach under investigation addresses the architectural and requirements basis for WMI commonality such that a common WMI can be defined that is not only configurable and extensible, but is also reconfigurable and adaptable to support system upgradeability and interchangeability of robotic assets and mission packages.

4.4.1. WMI Guidelines

A primary base component, supporting the standardization of a common WMI is the establishment of a set of guidelines governing WMI methodology and principles within the domain. The HRI ATO will analyze requirements to develop a consistent set of guidelines that can be interpreted within an interface to support common look, feel, and scalability. The HMI guidelines will address the following areas of scalable interface design: configurability, display layout, data logging, operator login, status, and modes of operation. Configurability addresses dynamic reconfigurability of controller and robot interfaces providing the ability to upload platform configuration specific data for display. Platform specific data could include mission package configuration, mission package controls and status, as well as robotic platform specific controls and status. Display layout addresses the manner in which a screen can be physically and/or virtually addressed supporting the placement of controls and status indicators. General terms and methods applicable across interfaces would be defined in an abstract manner such that they could be mapped accordingly within a physical interface design, for example warning, caution, and alert (WCA) levels and help. To the degree applicable, static display areas will be defined for the display of critical data such as status and WCA's. Data logging addresses the type of data that may be logged for training, validation, and/or analysis purposes. Logged data could include WCA, audio, images, and session data. Operator login addresses the manner in which an operator gains access to the WMI, systems controlled by the interface, and the role access of the operator within a session. Status addresses the manner in which operator critical status information is defined and accessed. Critical status information could include robotic vehicle status, mission status, vehicle orientation, communication link status, and battery levels. Modes of operation address controller modes of operation and the interface behavior within each respective mode. Example modes could include setup (configuration, diagnostics, log/other status), pre/post operational (mission planning and mission analysis), operational (tactical operations), sleep (reserve), and training (embedded training, mission playback and analysis).

4.4.2. Description Techniques

Description techniques provide a mechanism to define scalable interface graphical objects and the manner in which these objects are defined for interchange, display, and behavior within a system. For the HRI program, description techniques are being analyzed such that a device/graphics independent hierarchical WMI object classification can be defined where lower level (detailed) objects can be specified to inherit and extend parent attributes. For each graphical object, behavior (attributes, controls, and status), graphical realization (physical and graphical configurations), application interface (methods and effects), and interchange (XML specification of representation/classification) will be defined. Within the HRI program these graphical classifications will be utilized to specify and interchange human-machine interface between robotic vehicles and controllers supporting discover and reconfiguration of robotic systems. In addition, the employment of description techniques would facilitate role based scalable interface development in that a controller targeted to serve a specific purpose; e.g., diagnostics or palette loading/unloading would process only the essential XML tag controls required for the mission at hand, while ignoring non-essential XML tag controls.

4.4.3. WMI Scalability

The HRI program is investigating various methods to address WMI scalability to include graphical/physical scalability as well as configuration and prioritization of interface information. With respect to graphical/physical scalability, alternate representations or scaling of graphical controls could be defined/standardized within the description technique (e.g., graphical control visualization for a large scale, medium scale, or small scale display). With respect to configuration and prioritization of scalable interface information, techniques are being analyzed to encode information priority within XML schemas such that a WMI can display information in priority order in accordance with available display area.

4.4.4. WMI Portability

The HRI program is analyzing methods to port WMI's across platforms to include the analysis of description techniques that define WMI's in a device, graphical, and operating system independent manner. Portability analysis will also investigate graphical interchange techniques and device/programming language independent representation of graphical control methods.

5. TECHNOLOGIES UNDER INVESTIGATION

In addition to the methodologies employed above for executing the program, the HRI ATO will explore various current and emerging technologies as well as commercial operator device interfacing techniques for potential inclusion. Many of these are currently being investigated with respect to the level of applicability and the manner in which they would facilitate operator workload in either a positive or negative regard.

5.1. Head Mounted Display (HMD)

An HMD is a headset used mostly with virtual reality systems. An HMD can be a monocle, a pair of goggles, or a full helmet. In front of each eye is a tiny monitor. Some project the data to a piece of glass, allowing the data to be overlaid to the real world view. In addition, most HMD's include a head tracker so that the system can respond to head movements.

5.2. Head Tracker

A head tracker is a device used to detect the movement and position of the users head. There are five types of head trackers in use today: mechanical, optical, magnetic, acoustic, and inertial. Each uses a different approach to collecting the head position data, and each has advantages and disadvantages that must be weighed against specific mission requirements.

5.3. Displays

Most WMI displays in currently fielded ground combat vehicles are based on Active Matrix Liquid Crystal Display (AMLCD) color flat panel technology. These devices can display at least 512 unique colors. This is a requirement in order to display color maps and enhance the effectiveness of the user. Typically these currently fielded WMI displays are commercial or industrial quality from offshore sources that have been ruggedized by a 3rd party or vehicle system integrator. Ruggedization might include enhanced packaging for high shock and vibration environments, internal heaters to extend low temperature operation, added protection for the display glass itself, operation from 28V vehicle power, and/or the replacement of commercial connectors with higher reliability military equivalents. The WMI displays themselves are typically augmented with one or more operator input device such as a touch screen, pointing device, or bezel mounted switches.

Recently the trend has been to migrate toward an "all digital" interface between the display and the computer system. Early systems used an analog component type interface. This signal had to be digitized at the display since an AMLCD is inherently a digital device. An "all digital" interface improves display quality and supports higher display resolutions with more colors. There have been issues with display obsolescence and maintaining adequate supply for production and spares. The commercial AMLCD market is primarily driven by Laptop computers since they consume most of the displays. If a certain size or resolution display that is used on a military vehicle falls out of favor commercially, then supply problems for the military can arise. This fact is leading a push to choose a new technology to replace the current AMLCD displays. There has been a push in flexible display technology that may provide unique solutions for dismounted soldiers, and will be monitored.

5.4. 3D Audio

A three-dimensional audio (3D Audio) system allows for the placement of sound cues in three-dimensional space. These sounds are produced using traditional stereo speakers. This is accomplished by dynamically analyzing the sound coming from the speakers and sending feedback to the sound system so that it can readjust the sound. Sounds are usually placed using a graphical user interface (GUI) provided with the 3D Audio system. Those systems that do not provide a GUI often provide an Application Programmer's Interface (API) to utilize the 3D Audio capabilities. Once a sound is placed in the 3D world, its position is produced based on the user's orientation and head-related transfer function (HRTF). Head trackers are used by most 3D Audio systems to obtain user orientation information. These head trackers are commonly linked to 3D Audio systems using serial, USB, or Ethernet connections. HRTF's are generated based on the user's head size. The number of HRTF's provided with a 3D audio system varies. Some systems provide a way to generate new HRTF's using additional hardware or make different HRTF's available via the company's website.

5.5. Speech Recognition

Speech Recognition deals with designing computer systems that can recognize spoken words. Note that speech recognition implies only that the computer can take dictation, not that it understands what is being said. The most powerful systems can recognize thousands of words; however, they generally require an extended training session during which the computer system becomes accustomed to a particular voice and accent. Speech recognition can aid in simple tasks such as data entry and menu navigation. More complicated tasks such as directly controlling one or more remote assets can be accomplished, but the effectiveness of this application has yet to be determined. Voice quality may change under adverse conditions with high noise and vibrations. This will cause the accuracy of the speech recognition system to degrade. Adding Active Noise Reduction (ANR) to the speech recognition system would be one way to counteract this condition.

5.6. Controls

Most scalable interfaces are targeted to various platform hardware configurations, largely due to vendor specific requirements as well as user community and/or program end application requirements. Fielded scalable interfaces tend to be packaged as a display and associated physical input controls (e.g., switches, dials, knobs, and joysticks). The displays may provide for user input via a touch screen, allowing for graphical user input as well. The use of control devices are generally based on the capability it will provide. Axis devices, such as levers, pedals, and joysticks, are predominately used to control movement tasks. Buttons and switches can also be used to control mobility, but may not provide the sensitivity needed for fine control. Buttons and switches, whether physical or graphical, are more often used to control states and modes of the asset. One emerging trend in scalable interface design is the use of Personal Digital Assistants (PDA). These hand-held devices provide a touch screen that can display video, a thumb pad, and four of more physical buttons. They can provide limited asset control as compared to a full scalable interface, but they can provide enough functionality to control simple mobility.

5.7. Haptic & Tactile

Haptic and tactile devices make use of the sense of touch. Tactile is a specific type of haptic device that uses pressure or vibration stimulators that interact with the skin. An example of a haptic device is the "vibrate" function found on most pagers and cell phones. Haptic devices of the greatest potential interest to the U.S. Army include tactile displays that provide information through the use through some type of sensor emplaced on the skin or in arrays on a vest. Because skin-emplaced sensors can signal events, tactile displays can be used to provide information when visual or audio cues may not be available. Tactile display information includes warnings and alarms, navigation and guidance cues, system location, and malfunction information, and threat warnings.

5.8. Biometric

Biometric technologies are chiefly for security purposes, allowing the proper level of interaction via authentification with the system and accords the user required access levels. Examples of this are fingerprint/thumbprint signatures, retinal scans, face and voice recognition. This technology is useful in presenting the user with proper data upon accessing the system, and will be explored for utility in human-robot applications.

5.9. Gesture

Gesturing is a promising technology for intuitively interfacing with computer systems, and is especially useful where silent operations are desired or where space is limited (ex. keyboard stowage and power requirements). This technology will be evaluated as a potential candidate in optimizing human interfacing with given mounted and dismounted controller devices.

5.10. Face Recognition

Face recognition is a technology that can be used for security purposes, but can also be utilized for interpreting user intent. Under this category, lip reading and eye tracking are also included. These technologies will be explored for potential application in the HRI ATO, but have not been analyzed in depth.

5.11. Human Feedback/Stress Monitors

In order to properly analyze human workload levels, non-intrusive technologies are necessary to assess whether the soldier is overloaded and must shed tasks or have specific tasks automated. Current human feedback and stress monitoring devices are being assessed for this requirement, and will be explored in detail to determine effectiveness in assessing soldier health and workload.

6. CONCLUSION

The HRI ATO has established a systems engineering approach and modeling methodology for addressing the barriers identified by the Army Science Board. This approach, when combined with the proper mix of technologies scaled for mounted and dismounted control and utilization of recursive testing to validate the models developed, will yield optimum results for mounted and dismounted, ground and air soldier-robot teams. The end goal is reduced training for the soldier across varying missions, reduced overall workload in performing these missions, and specifically reducing the robot controlling portion of the mission to allow the soldier to concentrate on his primary mission…defending our nation.

REFERENCES

1. Army Science Board Ad Hoc Study on Human Robot Interface Issues, September, 2002.
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