Eyekon: Distributed Augmented Reality for Soldier Teams

TOPIC: Information Superiority/Information Operations
and Information Age Transformations

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Abstract

The battlefield is a place of violence ruled by uncertainty. Timely knowledge of what's happening around a soldier can mean the difference between life and death. The goals of an enhanced mobile infantry are becoming a reality due, in part, to the U.S. Army's 21st Century Land Warrior (LW) program. However, the current system does not provide a "head up" display capability like that provided by today's avionics. When the soldier employs the weapon, he should see objects easily distinguishable as friendly or not, as well as enemy locations. The Eyekon project is an intelligent agent-based decision support system hosted on the soldier's wearable computer. Eyekon will use the soldier's private network to provide a perspective view in the weapon sight. This will naturally draw the warrior to the most desirable target. There are many performance and human factors issues to address before the concept can be used in lethal situations.

> *If you load a mud foot down with a lot of gadgets that he has to watch, somebody a lot more simply equipped – say with a stone ax – will sneak up and bash his head in while he is trying to read a vernier."*
>
> --Robert Heinlein, Starship Troopers

Introduction

The battlefield is a place of violence, chaos, and ruled by uncertainty. Timely knowledge of a soldier's environment and precise team coordinate can mean the difference between life and death. The goals of an enhanced mobile infantry as expressed in Heinlein's timeless Starship Troopers is becoming a reality due, in part, to progress being made by the U.S. Army's 21st Century Land Warrior (LW) program. However, the current system does not provide a "head up" display like the capability that today's avionics provides to fighter pilots. What is desirable is not only that the soldier sees objects and positions, easily distinguishable as friendly or not, but also the means to designate new objects as possible threats and to coordinate the friendly team's actions in response to a dynamically changing situation.

This work is aimed at developing smart icons and designations that are superimposed on the live video from a soldier's weapon sight. 21st Century Systems, Inc.'s Eyekon is an intelligent agent-based decision support system hosted on the soldier's wearable computer. Eyekon will use networked position reports to provide a perspective view in the weapon sight. The system will naturally guide the warrior to the most desirable target. It will also provide a means for networked coordination of fires and team attacks on non-line-of-sight targets. Naturally, there are many performance and human factors issues to address before the concept can be used in lethal situations.

In order to provide the dismounted soldier with 21st Century battlefield dominance, weapon systems must be optimized not only to minimize the total weight carried by the soldier but also to minimize the cognitive overload. Too much data in his display and the soldier rapidly is overwhelmed with "numbers," not vital situational information. Like a fighter pilot's HUD that displays too much information, the battle is lost before it starts. Similarly, too much information in the augmented weapon sight and the soldier becomes a battle causality due to a missed threat. What if a soldier could point out an imminent threat by simply marking its position on the display? Then all networked team-members would have an advance warning and knowledge that will significantly improve the chances of mission success. Further, tactical plans can be adjusted to the present situation on the fly and coordinated with the team in real-time, all without making a sound or a move. A massed, coordinated attack on the enemy will multiply the effectiveness of a soldier many times over through the power of information.

These weapon systems are required to meet the tactical battlefield environmental characteristics including delivery by parachute while worn by the Soldier. They must be self-contained, man-packed, and battery-powered since maximum efficiency without outside help is a must. Required systems must not rely on any fixed infrastructure to meet the operational performance requirements.

The baseline implementation of Eyekon functions on a wearable computer host connected via a secure wireless network to local and remote databases and to real-time sensor streams (e.g. inertial attitude, GPS, IR). Software Agents perform network queries, monitor threat information, and provide in-situ alerts and recommendations to the soldier, based on the current mission and status information. The computing host provides a simple, yet powerful Augmented Reality (AR) overlay on weapon sight display or in a helmet-mounted eyepiece. The HUD-like display utilizes size and brightness for perspective and color and shape for threat information.

The Eyekon built-in decision aids provide the individual soldier more in-depth situational awareness via decision graphics (e.g., rated targets by most dangerous, steering arrow, ROE issues, team status). A steering arrow points to next priority target, if outside of view, then the arrow points in the direction of the acute angle and the arrow length is proportional to angle magnitude. Rules of Engagement (ROE) guidance can help the soldier in situations where responses are escalating. Team status provides the team's real-time situation, e.g. rounds remaining, water, casualties. An extended version of Eyekon provides support at the team level. Given projected computing performance capabilities, processing speed, memory capacity, and network bandwidth; Eyekon would support a new type of team interaction: self-organizing behavior. The Army unit with Eyekon divides recon and target tasks as a self-organizing team. It is very robust because the enemy cannot "take out" the leader. The Team is very adaptable and responsive to changing battlefield conditions. It swarms the battlefield and instantly responds to the unfolding event, in part due to the capability of Eyekon In-the-situation awareness.

The applicability of the Eyekon technology to non-combatant and operations other than war (OOW) is especially attractive. Eyekon's AR interface, combined with its agent-based decision aids, has the potential to revolutionize law enforcement, fire and disaster management, maintenance operations, and intelligence gathering. The team-based coordination and (re)planning functions can reduce execution time and increase effectiveness, thus providing savings in terms of reduced manning, increased productivity, and reduced exposure to hazards.

Augmented Reality

Augmented reality (AR) technology provides the user with superimposed information that can be seen in the real world; we supplement it. Ideally, it would seem to the user that the real and virtual objects coexist. Alignment of the superimposed information is critical. Just a few pixels off and the "augmentation" becomes a nuisance. Add latency and confusion results for the user. What is AR good for? Basically, applications of this technology use the virtual objects to aid the user's understanding of his environment. AR improves the perception of the natural world by adding to our senses via computer-generated information visual graphics, sounds, smells or tactical sensations. Televised football games use SporTVision's first-down line superimposed over the game scene to increase the viewing audience awareness.

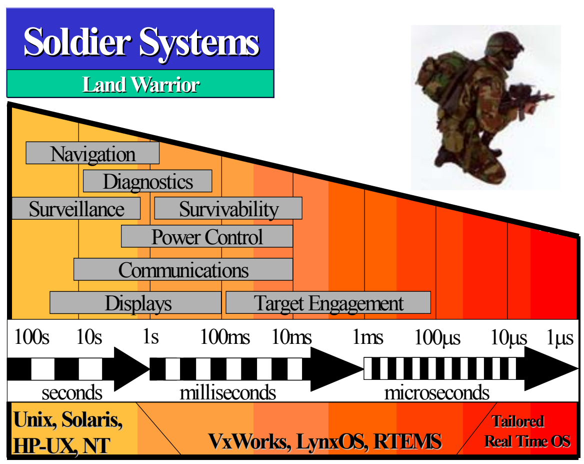

Fig.1. Requirements for Soldier Systems

Eyekon involves the design of a user interface and is a subset of AR of visual enhancements applied to the Land Warrior concept. Our concept is aimed not at the current configuration (LW System 1.0) but next version since it would be too costly to add a requirement into the current design and there are limitations in the weapon sight capability. Our study configuration is evolving to meet the domain requirements (Figure 1). The computer output is directed to either the weapon sight or helmet mounted eyepiece. The eyepiece can be used as a situation map display or as the weapon sight when the weapon is held off shoulder; say when the weapon is pointed around the corner of a building.

The decision support design will leverage the graphical user interface development methodology from projects involving USA, USAF and USN along with our real-time Assistive Agent development environment (AEDGE™) to provide real-time software for a "heads-up" weapon aiming application. With proper Land Warrior visualization and host environment requirements for specific Soldier's needs, appropriate planning for software development for the Eyekon concept and prototype will commence. Eyekon concept features are:

> **Superimpose situation icons on a dismounted Soldier's weapon sight*
> **Improve situation awareness by rating threats in a perspective view*

**Maximize responsiveness and minimize weight and power requirements*

The technical objective to investigate the applicability of software components that overlay smart icons, named Eyekon, to the dismounted soldier's individual weapon sight. Eyekon provides objects for the graphical user interface of friendly and enemy positions in the weapon sight when the dismounted Soldier employs the weapon. Eyekon is an intelligent agent-based decision support system hosted on a wearable computer with an available database and updates via radio links. The output of Eyekon is fed directly to the soldier's display. Display examples are a hands-free device (HFD), weapon-aiming devices that could be installed on the existing M16 rifle, the M4 carbine, the future Objective Individual Combat Weapon (OICW), or helmet-mounted display (HMD). Eyekon would support not only weapon aiming but also would display combat identification of friendly soldier's response to interrogation devices, help direct fires by highlighting target areas, or augment the direct view using a see-through HMD. The developed software components must conform to the Joint Technical Architecture-Army. This is a vital requirement for enhancing concepts such as interoperability, cost avoidance, and force multiplier due to fielded asset commonality.

The Eyekon concept is comprised of a baseline set of display symbols and an optional set of functions that enhance the display. The use of the options depends the reported usefulness through customer feedback. The proposed implementation minimizes cognitive workload and requires minimal training.

The baseline implementation of Eyekon functions using a wearable computer host and using existing data, network queries, and computing host provide perspective-view icons overlaid on weapon sight display. We will use size and brightness for perspective. The decision aid provides the individual soldier a more in-depth situational awareness with decision graphics (e.g., rated targets by most dangerous, steering arrow, ROE issues, team status). Steering arrow points to next priority target or, if outside of view, then the arrow points in direction of acute angle and the arrow length is proportional to angle magnitude. Rules of Engagement (ROE) can help soldier in situations where escalation responses are changing. Team status provides what the team's real-time situation (e.g., rounds remaining, water, casualties). An extended version is to provide support at the team level. Given slated computing performance capabilities (processing speed, memory capacity, and network bandwidth), Eyekon would support a new type of team interaction: self-organizing behavior. See for example, the article from US Army War College [3]. The Team with the slated field capability and Eyekon Option 2 divides recon and target areas as a self-organizing team. It is very robust because the enemy cannot "take out" the leader. The Team is very adapt-able and responsive to changing battlefield conditions. It swarms the battlefield and instantly responds to the unfolding events, in part due to the capability of Eyekon In-the-situation awareness.

Technical Approach

The technical approach is to investigate and to analyze dismounted soldier interface requirements that increase situation awareness from present practice. It will determine a set of system visualization requirements and metrics, to perform a functional analysis and develop a software plan, to adapt 21st Century System's AEDGE™ software and to host it on a soldier's wearable system. The "heads-up" situation awareness is first defined as when the soldier shoulders the weapon and looks though the weapon aiming sight; a HFD. Alternate "heads-up" are: (1) being able to use the weapon sight off the weapon, such as to look around a building corner without being exposed, (2) a helmet-mounted display (HMD) consisting an eye-piece that fits over one eye (not see-through), and (3) a HMD with see-through eyepiece. User interface requirements and related resource requirements investigation areas that will be addressed, for day, twilight or night operations are: (1) Heading of the using Soldier, (2) Position of all friendly units and Soldiers, (3) Enemy threat locations, if available by Army digital Tactical Internet, (4) Weapons orientation of friendly Soldiers, (5) Identification of individual Soldier and aggregate units and (6) Ready status of individual Soldiers in terms of ammunition, water and health.

Data requirements via situational reports fed continuously by the Soldiers will also be investigated. The automated reports and Eyekon data provide the situational awareness of the team to a Soldier without having the entire unit stop and take a formal report and expose themselves to enemy counter-attack by losing momentum. In addition, for military operations in urban terrain (MOUT) or possibly close-quarters battle (CQB) where non-combatants are in the are of operations ("no-shoot" targets mixed with known threats), the study will investigate display requirements to depict friendly locations even if behind a wall in building or in a cave by superimposing an Eyekon over their relative positions through the weapons sight.

Another requirement is that Eyekon must perform in the host environment, that is, be rugged to handle the warrior mission. Host system processing, networking and data storage characteristics are continuing to advance. Wearable system technology advances continue in many application areas such as for U.S. Army and USSOCOM projects. Industries always want worker's productivity to increase. Wearable computers, combined with wireless technology, allow art dealers to examine artifacts on location and instantly compare with electronic library high-resolution photographs. Another area is working in tight quarters, such as in commercial aerospace application where a flight-line technician has direct access to all technical orders while working in the cramped areas (e.g., electronics bay of the aircraft). The point-of-departure Eyekon concept is shown in Figure 2. As concept matures, the baseline is expected to change. The point-of-departure provides a reference with which to compare candidate concepts. Data is provided to Eyekon via the soldier's database. Eyekon provides an overlay of friendly and enemy icons positioned on the weapon sight video. Position accuracy is dependent on database data accuracy. Agents maintain Eyekon updates as weapon sight is moved through angles. It is comprised of a baseline set and an optional set of functions. The use of the options depends the reported usefulness through customer feedback.

A point-of-departure for the Eyekon baseline is to develop symbols using data from the soldier's (e.g. Land Warrior) database. Determine the soldier kinematics such as present position, heading and rate of change, weapon pointing (compass, tilt and rate of change) and possibly head pointing and then determine kill box for the weapon's range and kinematic state. Agents will query database and tactical network for target position reports of friendly, enemy & neutral in or near the kill box and develop standard object display icons for position reports and track. An intelligent agent will adjust the standard icons for perspective view objects (smart icons). The perspective view is based on identity and distance. The icon's display attributes such as color, brightness and size will also be adjusted for time of day to account for vision changes due to daylight, twilight, or darkness. It will also adjust weapon sight display based on sight magnification, heading, tilt, and angular rates. It will register for weapon sight and movement, and then display icons.

The established Land Warrior program provides guidance for assessment (via criteria weighting) or the override of the assessment function. The assessment determines most dangerous threats based upon threat vulnerability. The vulnerability calculation determines LOS distance and the threat's weapon type using probability of hit and probability of kill values from the LW database. It adjusts the perspective view of the icons based on assessed threat values, ROE and current level of escalation. It will provide a steering arrow that will point to the next priority target(s). That is, if next target is inside the current field of view (FOV), then arrow points to maximum threat icon. However, if next target is outside of current FOV, then arrow points in shortest direction (left or right) and the arrow length is proportional to angular magnitude. A control deadband would remove pointing ambiguity if the enemy were directly behind. Eyekon decision aids will take advantage of the fact that the team is networked via a tactical network. The networked team is technically capable of being a team that is self-organizing and non-hierarchical. An example in the literature is New York City. The populace is feed every day. Yet, no one is in charge of feeding the inhabitants. No one organization is responsible for ordering, scheduling, delivering, or expediting food. It works through self-organizing commerce. This is not the current way that the U.S. Army, or any army or any national military

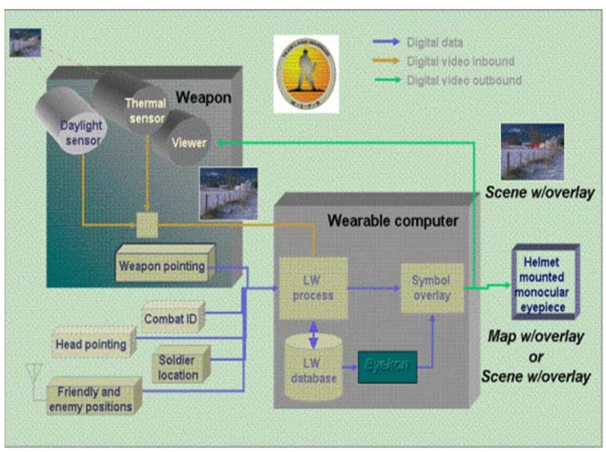

Fig.2. Eyekon Concept

organization works today. As the thrust for information access is pushed down to lower and lower echelon levels, ultimately every soldier will be able to access any information available at any time. This widespread access has the potential for new, unheard-of organization schemes to emerge. See, for example, The Real Military Revolution [3]. The Team with this capability and Eyekon Option 2 divide up recon and target areas as a self-organizing team. It is very robust because the enemy cannot "take out" the leader. The Team is very adaptable and responsive to changing battlefield conditions. It swarms the battlefield.

The concept for a set of point-of departure (POD) symbols will be reviewed with subject matter experts and trades against the POD set will be made. A follow-on study, using subject matter experts, will consist of a cognitive task analysis (CTA) performed by a cognitive psychologist. The CTA study will consider individual and team interactions. Metrics will be used to quantify symbol layout, selections, and symbol attributes. Though initial work is focused on the individual and the individual's interface, team interactions will become more important as use of the tactical intranet increases. The friendly situation is shown in the lower right portion of the weapon sight.

For the baseline, a requirements analysis will develop the top-level functions for the Eyekon concept and be presented as a functional flow diagram. The functions are shown in Figure 3.

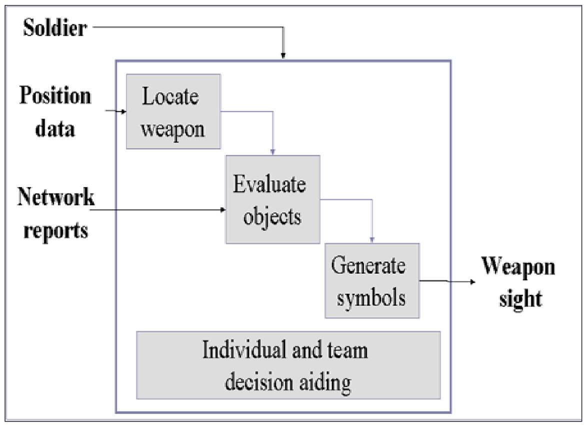

Fig.3. Eyekon Functionality

It defines four functions. The first function is "Locate weapon" and sets the stage for the display of the area sector – just where is the soldier in the area and where is the weapon (sight) pointing and how is it changing. As depicted at the top in the figure the soldier, interacting with Eyekon functions, may change criteria weightings if the database information accuracy changes or if the weapon that the sight is attached changes. Implementation depends upon selection of options. With the soldier and weapon position now known, Eyekon might send out queries on the LW network for situation reports within the weapon range. Periodic report updates and aperiodic queries feed Eyekon object evaluation. Tactical database objects are identified as friend, foe, neutral or unknown and located within the FOV. The decision aiding then scales according to leader criteria and threat level.

Application of AEDGE™

We take a pragmatic approach to intelligent agents, as we apply our experience delivering agent technology to other domains (team decision support, software systems synthesis). Our agents are autonomously running software components, which monitor, analyze, and advise human users. Such agents will add great utility to the platoon. Agents provide choices and evaluate the performance of users "on the fly" to give valuable feedback to the participants. We propose two classes of agents in our tool suite.

Agent Types

The first class is comprised of *human-assistant* agents. A human assistant agent provides concrete advice to humans who are participating in the session. Such assistant agents could be useful both in the learning process as well as in the content development and evaluation processes. If a trainee is making an incorrect choice at a critical point in the exercise on which the correctness of the rest is dependent, an agent can provide a second chance or additional clues for the concrete situation, thus highly increasing the educational value for the trainee. Human assistant agents both react to human requests and provide advice without being prompted for it, if, they determine that help and guidance is needed. Human assistant agents are one of the contributions of this work.

Coordinators and arbitrators of distributed decisions populate the second class of agents. Even when individual agent and human decisions are based on team-level, global knowledge (which may or may not be the case, depending on the nature of a decision or knowledge available to a human or an agent), it is normal to expect conflicts and also temporal discrepancies. Agents of the third kind try alleviating such conflicts, advising agents and humans (including, agents of the second kind) how to adjust these decisions and re-enter a more stable situation, while still not sacrificing their (conflicting) objectives. Examples of conflicts include multiple users requesting modification of a single simulation object (e.g. a route way point or an infiltration zone) at the same time, or a user attempting to switch the nature or the pace of an exercise while in a team mode with other participants. Agents of the third kind too are a major contribution of this work.

The need for a standardized common infrastructure has lead 21CSI to design an environment where both agents and simulated entities (or representations of real-world assets) are represented as first-class objects capable of interacting with each other. 21CSI's extensible multi-component Decision Support Systems (DSS) architecture, known as AEDGE™, is a standardized Commercial Off the Shelf (COTS), DII COE compliant agent architecture that enables complex DSS to be developed as an expansion of the AEDGE™ core functionality.

The Eyekon-AEDGE™ study interface is shown in Figure 4. The developer is provided a set of overlay controls, the circle "A", and a set of scenario controls, "B". The picture is a video capture of an experimental site. The overlay controls direct either video feed to the screen or brings up a 2D map (simulating the warrior's HMD). In this setup five people are positioned with three to the front of the observer with a video camera and two behind. We are undertaking to build a common reference framework and a test-bed environment for integrated simulation and agent-based decision support. In a simulation that feeds Eyekon the people with initial headings begin walking and the observer rotates the camera. The kernel of the architecture consists of four core and five extender components. These define the internal structures, dataflow, and interface to the architecture.

AEDGE™ defines Agents, Entities, Avatars and their interactions with each other and with external sources of information. This standardized architecture allows additional components, such as service-specific DSS tools, to be efficiently built upon the core functionality. Common interfaces and data structures can be exported to interested parties who wish to extend the architecture with new components, agents, servers, or clients. When the core AEDGE™

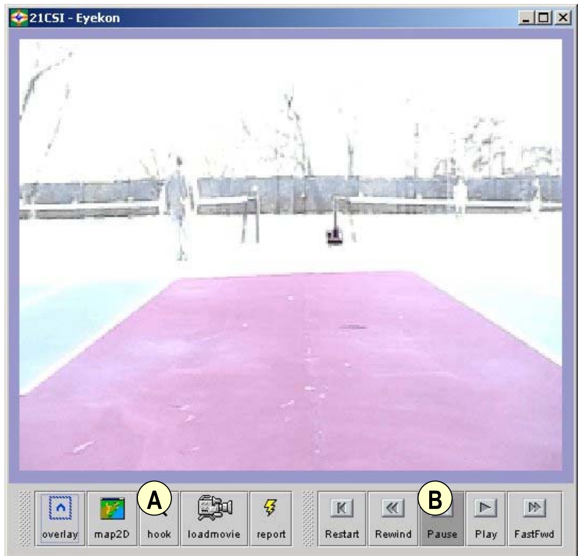

Fig.4. Initial Set Up with Video Only

components developed by 21CSI are bundled with customer-specific components in an integrated environment, a clean separation of those components, through APIs, is provided. Distributed components communicate via Services. Services are an abstract and network-friendly representation of functions, implemented by AEDGE™ components. The Service object is a data storage and transport mechanism for a service request. The request includes the class and the type of the service, an optional sub-type and a list of parameters. Return values for services are provided via ServiceResult objects, which encapsulate a service-success code and the actual return value.

Shown in Figure 5, the developer has selected the video with Eyekon overlay during a simulation run. Note that around the screen is information on weapon position ("C" for weapon elevation, "D" for azimuth or compass and "F" for GPS location). In the screen area, friendly positions are

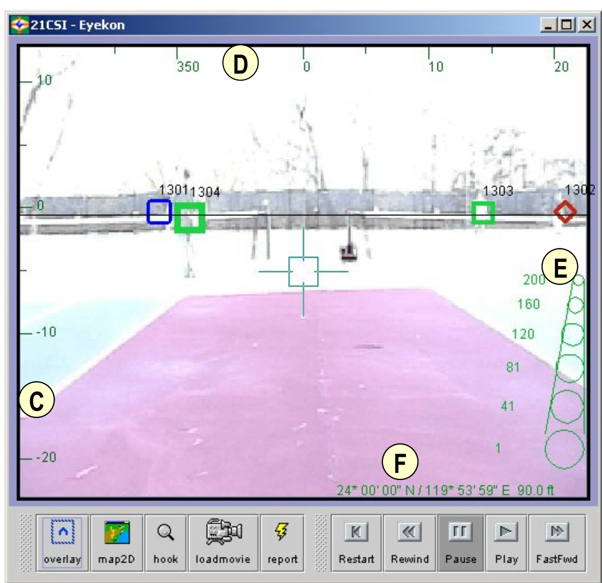

Fig.5. Video with Eyekon Overlay

noted by a blue box, threats by a red diamond. Tracks developed by updated position reports are given an identification number such as 1301 for the friendly and 1302 for the threat.

Assisting Situational Awareness

Maintaining situational awareness both in a training and in an operational environment is the single most important element for achieving the mission objectives as well as for improving the training process. In the present and especially in the future reality of a digital battlefield, the inflow of information from sensors, intelligence reports, and damage assessment most certainly will overwhelm the soldier as a decision-maker and will obscure the tactical picture. A high level of situational awareness is maintained by introducing *monitoring and advisory agents*. The purpose of the monitoring agents is to subscribe to specific data-flows, to observe and analyze their trends, and to raise flags in case the tactical situation has changed significantly. Information fusion techniques will be applied to correlate data from different sources in order to increase the certainty of the tactical picture. Advisory agents occupy the next level in the information processing hierarchy – they subscribe to the information provided by the monitoring agents and react to situational changes by re-evaluating the threats posed to our forces and the risks associated with the mission.

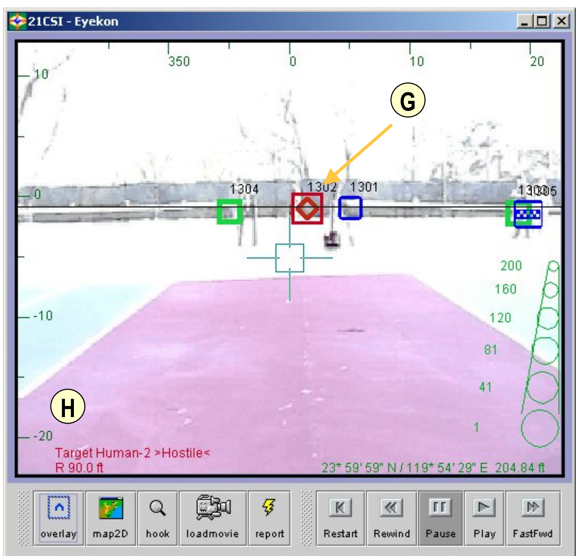

Fig.6. Target Selected

Figure 6 is a result of the decision aiding process where track 1302 has been selected or "hooked". Hooked refers to target selected from either the map or sight picture and tracked. The "G" points to the target (1302) and has a box around it to denote that special attention is to be given to this object. Object is identified, in lower left corner of the screen, "H", as a human and as a hostile target. Advisory agents then communicate with the human user (via specialized user interfaces) to alert him of the changed risks and the underlying reason for that change, such as new enemy detected, or friendly forces that have suffered excessive damage. Advisory agents can focus the user's attention to a particular area of the tactical picture or can highlight a trend in the picture that was impossible to observe due to information overflow. Eyekon provides two types of decision aids: 1) a passive decision aid, which presents the right information at the right time to the right user; 2) a proactive recommendation agent, which provides tactical advice and recommends a COA. These two approaches are often complementary and thus, their combined application provides greater utility. In addition, the user is presented with a flexible decision support environment, which adapts to the current tactical requirements as well as to his personal preferences.

The passive decision aid is based on the monitoring and advisory agents and their ability to analyze the enormous amounts of incoming information and highlight important changes. The agents do not interact directly with the user, but rather sit in the background and monitor the development of the tactical picture. Once the picture changes, the advisory agents dynamically reconfigure the user display to show these changes and the predictions for future effects. For example the monitoring agents may detect movement of the enemy forces at the left flank. This movement will initially trigger re-evaluation of the threat based on the enemy's new positions and simultaneously will invoke a heuristic predictor of the enemy's future positions and intentions.

The displayed information (enemy movement route at the left flank and future positions) will depend on the likelihood of this change adversely affecting our current operations. As a result the new threat and projected future threat areas will be shifted toward the left flank. The dynamic reconfiguration based on heuristic threat estimation goes beyond improving the situational awareness of the user. This capability provides the commander with clues as to what his next action should be. In the pro-active decision aid, a class of recommendation agents is used to provide explicit COA recommendations. These agents are based on the human-role-playing and the human-assistant agents described earlier. While the role-playing agents are capable of following orders and reacting to the changing environment, the human-assistant agents are more analytical and are able to use trend and rule-based cause-effect analyses. Combining these agent capabilities with a dynamic alternative generator and utility function evaluator provides powerful real-time decision support.

Essentially, we view the process of decision-making support as general resource allocation system (a system consisting of tasks, which require resources … sensors, processors, humans, information, etc.) with functional and non-functional properties. The system's goal is to recommend to the human decision maker, to implement automated decisions, and to allocate resources, subject to the conflicting objectives and constraints, in the best possible way (there is possibly significant competition for the resources). This allocation process differs in level of detail only, across different stages of combat control process. Failures result from poor allocation choices. Given the general growth of the problem space, the process has to consider heuristics and approximate "best effort" strategies (exact allocation is computationally prohibitive) must be used. The study provides a slate of heuristics, which can be called explicitly by the user, or by the system under general instructions given by the user. These will include commonly available and "home-grown": genetic, neural net, projection, greedy, and other methods for designing and developing large-scale, complex software. Three-modi operandi will be supported: search (entire space is considered per iteration), construction (a fixed number of objects are considered per iteration), and hybrid (the heuristic relies on a strategy/user to switch modes; e.g. first, do a quick global search, then optimize-construct a local region...).

Conclusion

Eyekon will directly enhance the warrior's lethality by quickly and intuitively locating targets in the weapon sight. It will also reduce the warriors' vulnerability by aiding in the designation of most dangerous threat and identifying teammates. The result is an AR system using intelligent agents to superimpose smart icons (Eyekon) on the real world weapon sight picture. The team decision aid function of Eyekon can provide the team leader and the team with a method of designating and assigning targets to individual (networked) soldiers in a very flexible robust self-organizing environment.

The work to date is still in feasibility concept design to influence U.S. Army programs. The next step is to develop a prototype for evaluation by the U.S. Army or similar agencies.

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