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ADVANCED SA – MODELING AND VISUALIZATION ENVIRONMENT

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ABSTRACT

In this paper, we present a proof-of-concept prototype system created in an applied research and development effort at Southwest Research Institute. The Advanced Situational Awareness (ASA) Modeling and Visualization Environment is a response to the need for applications that improve the value and presentation of situational awareness information by leveraging the increased integration of sensors, Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR), and Electronic Warfare (EW) systems with networks in ground vehicles. The ongoing U.S. Army Vehicular Integration for C4ISR/EW Interoperability (VICTORY) initiative is providing the framework by which this integration of sensors and systems can be realized. By utilizing the VICTORY concepts and current specifications, the research team was able to develop an ASA system that provides: cross-vehicle reasoning, visualization of situation awareness (SA) data overlaid on video, and a mapping capability.

INTRODUCTION

Current situational awareness (SA) capabilities deployed by the U.S. Army are insufficient and could support the safety and lethality of the warfighter more effectively. Existing systems are not integrated, and provide warfighters large amounts of data on independent data streams (e.g. voice communications, locations of blue (friendly) forces, vehicle electronic systems information). The process of observing and correlating data from multiple sources, often referred to as "data fusion", is currently done manually, and mostly at higher echelons of the command structure. The warfighter obtains information from the individual sensors on the vehicles and uses voice communications to obtain information from secondary sources (other vehicles). Fusing data to create the information about the situation is not the primary mission of most warfighters, but is often crucial to the successful completion of the primary mission.

The warfighter observes and correlates the data that is available in his head, leveraging a priori knowledge of the situation, previous experience, and "gut feelings", and develops overall understanding of the local operational picture (LOP). Synthesizing an understanding of the LOP based on available data, knowledge, and experience can be described as "reasoning". As the LOP exists mostly in the individual warfighters' heads, the differences between the understanding the individual warfighters have of the situation can lead to confusion, ineffectiveness, and even deadly mistakes.

The focus of this Southwest Research Institute (SwRI®) internal research and development (IR&D) effort was to develop methods of automatically fusing and applying reasoning on data in order to generate and formalize trustable and complete SA data, and also to develop new and novel methods for presenting the information to the user in an easy to understand format. This paper provides an overview of the results of this research.

BACKGROUND

Over the past decades, Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance/Electronic Warfare (C4ISR/EW) systems have primarily been integrated on military platforms using a "Bolt On" integration approach. Vehicles are procured with a set of base systems, and additional systems are procured in whole and fitted to the vehicles, often creating duplication of common functionality (e.g. displays, user interfaces). Because the systems that are added to the platforms are not designed to interface with each other, they do not interoperate. Data produced by each system is not made available to the other systems, and is usually not available to the command or other platforms. The disparate and non-integrated systems create difficulties for the warfighter, as he must use the separate user interfaces and correlate the information himself. The result is the potential loss of operational effectiveness.

The U.S. Army has a system that it currently uses to track friendly and hostile forces in order to provide commanders with a SA of the battlefield. This system provides SA graphically via a mapping application, and via free-text and fixed-text messages. This system has been deployed on a number of U.S. Army platforms to include: the Interim Armored Vehicle (IAV) Stryker, the M1 Abrams tank, the High Mobility Multipurpose Wheeled Vehicle (HMMWV), and the Apache Longbow attack helicopter. Though the system provides a tremendous capability for commanders and soldiers alike, the system is beginning to show its age. Since its first use in military operations in 1998, the system has undergone numerous software and system updates. The current version provides the commander with a terrain map view of the battlefield with a nominal update (refresh) rate of 30 seconds. Though a valuable asset to the warfighter, it is clear that new technologies available could be leveraged to provide the warfighter with an improved LOP. The fusion of various platform computing resources and onboard sensors will allow for a wide range of new capabilities that have not been possible up to this point.

The Vehicular Integration for C4ISR/EW Interoperability (VICTORY) initiative is developing a framework for integration of C4ISR/EW and other electronics equipment on U.S. Army ground vehicles. The framework is made up of 1) an architecture [1], which defines common terminology, systems, components, and interfaces, 2) a set of standards [2], which are technical specifications of the items identified in the architecture, and 3) a set of reference designs, which provide guidance for how the architecture and standards can be instantiated to create designs against various types of requirements and environments.

Vehicle programs are already beginning to implement the network-centric tenets promoted by the VICTORY initiative, but the current capabilities do not take advantage of the interoperability of the various sensors and systems. The goal of this research was to bridge this gap, and provide a proof-of-concept system that demonstrates the potential benefits of data fusion and reasoning.

TECHNICAL APPROACH

The technical approach for this research was to accomplish the following objectives:

1. Create a situational awareness reasoning algorithm and software application that takes into account primary observations (sensor data that is available from sensors on the vehicle), and secondary observations (data gathered or generated by other vehicles with different perspectives) to create an integrated SA capability.

2. Create a visualization environment that overlays SA data onto video streams to provide visual queues to the warfighter.

3. Integrate a proof-of-concept system to be used to evaluate the Advanced SA application visualization environment.

System Level Overview

The software system for the demonstration system is shown in Figure 1. It contains four main software components: the Situational Awareness Reasoning Engine (SARE); the Video Projection Engine (VPE); the Coordinate Engine (CE); and the SA Mapping System. These software components are described below.

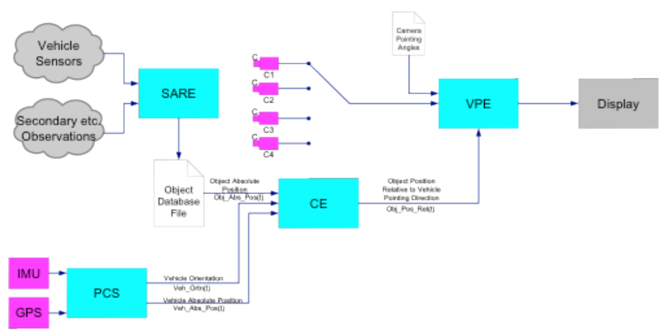

Figure 1: Top-level System Design

Situational Awareness Reasoning Engine (SARE)

The SARE has three main tasks: observation sharing with other SARE instances, observation processing via its Situational Awareness Reasoning Pipeline (SARP), and persistence of its LOP to the file system. Each SARE broadcasts its vehicle position, orientation, direction of travel, and detected threats. This allows the vehicles to track each other and perform reasoning about threat situations using distributed threat sensor information. The hypothesis is that due to shot detection sensor inaccuracies such as false positives and disparities between actual shot location and detected location, the fusing of data from multiple sensor locations will mitigate error probabilities and result in a more accurate picture of the situation. Following SARP threat processing, the resultant threat data and friendly location data is persisted to an objects file that is then used by the Coordinate Engine to display friendly and threat locations on the video feeds. The alternative, naïve approach to this would be to display all threat observations separately on the video feed. This would create a cluttered display that would not provide the user with accurate information about the number of threats and where they are operating.

Information sharing is done over multicast user datagram protocol (UDP) using the Victory Data Message (VDM) format. These are Extensible Markup Language (XML) messages conformant to the VICTORY specification that SwRI is currently helping to develop. These messages contain information about vehicle position, orientation, direction of travel (DOT), and threat position. Local vehicle position, orientation, and DOT messages are received by the SARE from the platform context service (PCS) on a local multicast address. These messages arrive ten times per second. SARE broadcasts its own position, orientation, and DOT information to other listening vehicles four times per second. This rate can be increased or decreased as needed. **Error! Reference source not found.** illustrates the four main processes through which threat information passes. Processing starts with threats arriving at the SARP from one of two locations: the local threat detection system or as external threat messages from neighboring vehicles. Threat information includes absolute position (latitude, longitude, and altitude), timestamp, and source identifier. Source identifier (ID) in this case is the ID of the vehicle that reported the threat. Raw threat information is initially referred to as an observation. The goal of the SARP is to cluster observations from both local and external sources into discrete events and, in turn, produce a LOP that consists of these specific events. An example of this is as follows: Three vehicles are patrolling an area. Each vehicle is outfitted with a shot detection system and an instance of the SARE system. Shots are fired from three locations. Each vehicle's shot detection system detects each of these shots and propagates their readings to the other vehicles. Due to sensor inaccuracies and potential timing differences, it is not a simple matter to accurately correlate one's own threat detection readings with the readings coming in from the other vehicles. To overcome this, the separate vehicles' observations must be processed by the SARP to produce a discrete list of events (each made up of multiple observations) that may be passed on to the other ASA subsystems for further processing and display.

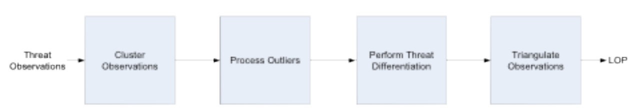

Figure 2: SA Reasoning Pipeline

Video Projection Engine (VPE)

The intent of the VPE is to fuse the near real-time SA data and live video streams, to present a coherent view of the world (Advanced SA) to the user. The VPE does this by highlighting regions of space that are of interest to the user. In our demonstration system, these include both friendly objects (both dismounted units – soldiers, and other vehicles) and threats that have been identified by threat detection sensors. Figure 3 is a screenshot of the VPE used in our demonstration system. The individual lines around the objects are intended to indicate the likelihood that the real object is, in fact, encapsulated within the lines on the screen. There is a high probability, for example, that the real object is within the bounds of the outermost of the three lines (represented here with a thick width). The innermost line, however, is composed of a thinner width, which indicates a slightly lower probability that the object is contained within that line.

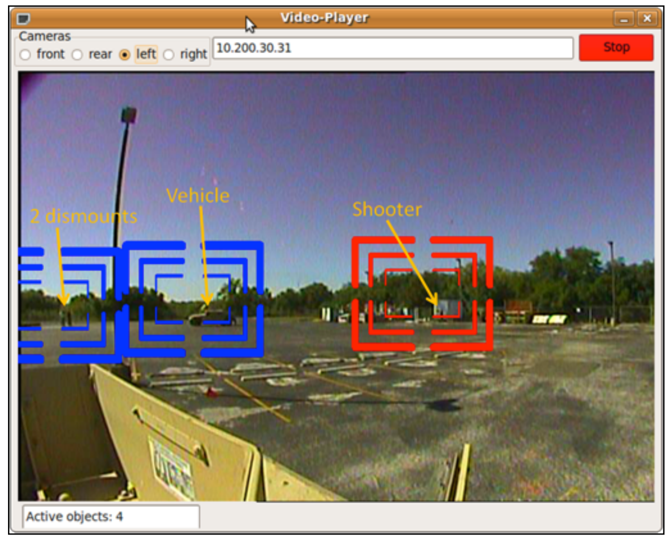

Figure 3: Friendly (Blue) and Enemy (Red) Represented on the VPE

The VPE is the only software component with which the user interacts directly, and is responsible for displaying "virtual objects" in accordance with live video feeds from the vehicle's video cameras. The VPE accomplishes this using a multi-step process. First, the VPE will receive the "relative position" information for each object sent out by the CE and perform one last coordinate transformation to maintain object data with respect to each camera. The VPE has several static configuration parameters to calibrate the transformation, including the angular and linear offsets of each camera with respect to the vehicle.

While the VPE is processing object data, it is also receiving digital video data from the cameras (as shown in Figure 1) and de-warping the fisheye effect of the camera lens. It will then render both the live video feed and the near real-time object data onto the screen, on a frame-by-frame basis. The effect of this is that the "virtual objects", in the form of colored outlines, are projected atop the "real objects" in the live video feed. This draws the user's attention to the region in which the friendly or enemy is believed to be located, without obscuring the visual data.

Coordinate Engine (CE)

The primary function of the CE is to perform coordinate transformations on the objects identified by the SARE so they can be understood geospatially with respect to the vehicle's coordinate system. Accordingly, the CE uses as inputs the following:

- Direction of Travel data (UDP multicast) from the PCS
- Orientation data (UDP multicast) from the PCS
- Position data (UDP multicast) from the PCS
- Object data, read from the "Object Database File"

Once the CE has position and orientation information of the vehicle, as well as position information of the various objects (both friendlies and threats), it will perform the required coordinate transformations. The CE will then transfer "relative position" and other data for each of the objects to the VPE so they can be presented to the user. The position information includes Cartesian coordinate with respect to the vehicle (X meters, Y meters, Z meters) as well as azimuth, elevation, and range to the object. The "other data", in addition to the position data, includes items such as color (typically blue for friendlies and red for enemies), scaling factors for the objects, and opacity factors that the VPE can then use to display the data in the most coherent way to the user. These messages are typically sent out in the form of UDP multicast so that multiple sinks can utilize the data in accordance with overall system design.

SA Mapping System

Not shown in Figure 1 is the SA mapping system that was developed. The system was developed to display the SA data on a traditional map, much like the current U.S. Army system mentioned in the Background section of this paper. The mapping system indicates friendly vehicles and dismounted soldiers with icons, and indicates threats on the map with red "x" symbols. There is also a popup that is displayed when a threat is detected. **Error! Reference source not found.** shows a screen shot from the mapping system with positions of friendly vehicles indicated by the two blue HMMWV icons, and a friendly dismount indicated by the green "toy soldier" icon. The symbology used in the mapping system does not follow the Department of Defense (DoD) symbology standard [3]. Instead, the icons were selected to provide a simple view of the entities involved in the research experiments. As stated above, the threats displayed in **Error! Reference source not found.** are indicated with the popup messages and red "x" symbols.

Figure 4: SA Mapping System

The mapping system uses the Google Maps JavaScript API V3 to retrieve the SA information from the network and place icons on the map in the appropriate locations and with the appropriate orientations. The project team developed JavaScript and HyperText Markup Language (HTML) code in order to provide the mapping capability in an Internet web browser. The purpose of using Google Maps and a web browser was twofold: 1) the technology provided the project team with a mapping solution that could be rapidly developed; and 2) the use of a web browser demonstrates that a mapping solution could be realized using common desktop components. The project team is not suggesting that the DoD would adopt Google Maps for their mapping requirements, but that they could use a similar technology. The resulting mapping solution displays the positions and orientations of the SA objects update every one (1) second, as opposed to 30 seconds on the current U.S. Army SA mapping application. The one-second update rate was chosen to provide a responsive mapping experience and is not indicative of a technological limitation. In testing, the latency between events on the network and their appearance on the map (e.g. a simulated shot and the update showing on the map) was consistently less than two seconds. User feedback indicated that delay between detected events and their appearance on the mapping system display was not noticeable.

Demonstration System

The demonstration system developed includes two vehicle platforms (HMMWVs), a Tactical Operations Center (TOC), and a number of "dismounted" units, which each carry an Android phone in order to share information about their position. Also, these entities are connected by a commercial off the shelf (COTS) 802.11 wireless network, in lieu of military wireless networks, due to transmission restrictions in the San Antonio, Texas area. Figure 5 shows the vehicle platforms and TOC that were implemented for the demonstration system.

Figure 5: TOC and Vehicle Platforms

Each vehicle hosts a computation suite of COTS components that runs the software described in Figure 1. To power this computation suite, a power sub-system was designed and integrated, along with network access points, to provide connectivity to the other entities. The power and computation subsystems for the vehicles can be seen in **Error! Reference source not found.**.

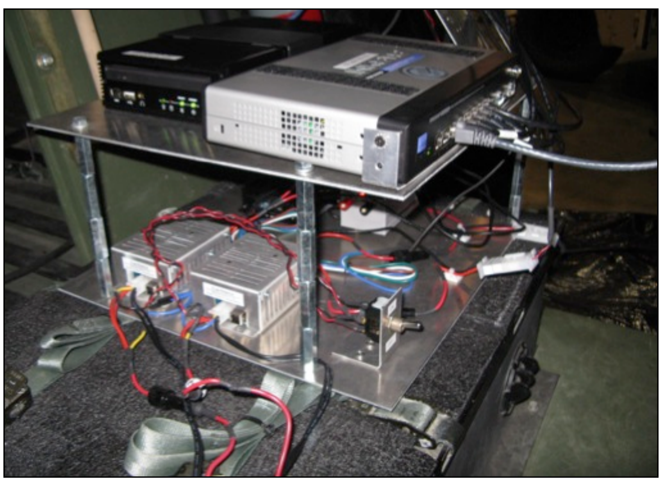

Figure 6: Power and Computation Subsystem

The power conversion subsystem supplies regulated power for the entire system. It takes the unregulated 12 Volt input from one of the batteries in the vehicle and regulates it to different voltages for different components. For example, it up-converts to 48 Volt to power the power-over-ethernet (POE) switch, and regulates a clean 12 Volt output for the displays, cameras, and the central processing unit (CPU).

In addition to the computation subsystem, the vehicular suite also consists of two displays that are used to display relevant information to the user. One display is used to display the VPE and its real-time video feeds with virtual objects projected on them. The user can switch between each of the four camera feeds by selecting radio buttons on the warfighter machine interface (WMI). The other display is used to display the mapping technologies developed as part of the internal research.

Figure 7 is a picture of the video capture subsystem, which consists of four analog video cameras and four single channel encoders for digitizing the video of each camera. This system is mounted atop the vehicle in our demonstration system, but each camera could easily be mounted in a separate location. Our VPE software is flexible enough to handle the final coordinate transformations for cameras in four different planes, if necessary. Additionally, a global positioning system (GPS) antenna is mounted near the video capture subsystem, which provides the vehicle with data related to its latitude, longitude, and elevation at a 10 Hz refresh rate.

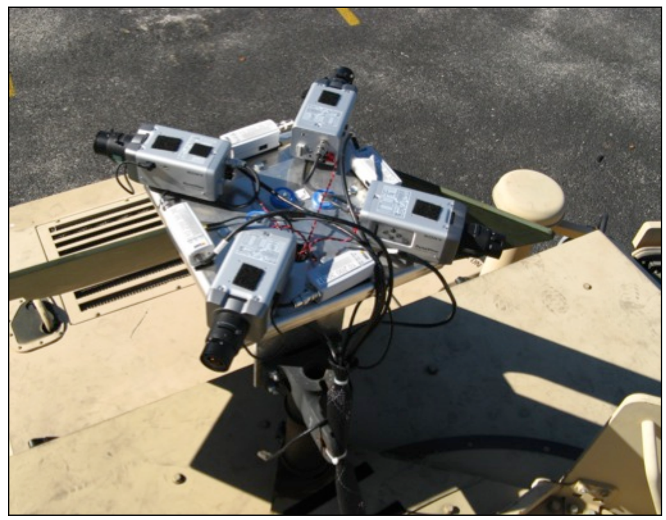

Figure 7: Video Capture Subsystem

Not pictured in Figure 7 is the inertial measurement unit (IMU) which is mounted at the front of the vehicle, and is used to provide roll, pitch, and yaw of the vehicle for use in coordinate transformations and direction of travel inference.

RESULTS

Overall, this research proved the hypotheses that data fusion and reasoning will improve the value of SA information, and that visualization techniques such as augmented reality will allow the user to gain understanding of the current situation more quickly. Furthermore, it demonstrated that these capabilities are realizable on vehicles using current hardware. The research did not extend to large-scale tests to measure the impact of the improvements on survivability and lethality of warfighters in representative scenarios. As is the case in many applied research programs, the behavior of the sensor systems in a laboratory setting was not matched by its behavior in the real world. Much of the effort was spent in developing methods of compensating for the inconsistent behavior of the sensors, and in integrating the algorithms with the real vehicle and sensor environment.

The results of the research include a reasoning-based advanced SA algorithm, an implementation of that algorithm in the SARE software components, an augmented reality SA visualization technique, an implementation of that technique in the CE and VPE software components, and a research-quality SA mapping system based on Google Maps.

PATH FORWARD

The artifacts from the research effort are very much “proof of concept”. As can be seen in the figures provided in this paper, much of the hardware was COTS and would not be suitable in an operational context without ruggedization efforts. However, the results of the effort clearly demonstrate new capabilities that could be transitioning into military use. It is the intent of SwRI to seek strategic partnerships with industry and government entities to help develop and mature these capabilities, and to evaluate their potential for transition. Such evaluation will include development of representative military scenarios, input from experienced users, and perhaps coordinated exercises at an Army test facility.

REFERENCES

[1] VICTORY Standards Support Office, “Vehicular Integration for C4ISR/EW Interoperability (VICTORY) Architecture”, Version A, 29 April 2011.

[2] VICTORY Standards Support Office, “Vehicular Integration for C4ISR/EW Interoperability (VICTORY) Specifications”, Version 0.7, 29 April 2011.

[3] Military Specification MIL-STD-2525C, Common Warfighting Symbology, revision C (DOD, 17 November 2008).