Overview of the First Advanced Technology Evaluations for ASSIST

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Abstract—ASSIST (Advanced Soldier Sensor Information Systems Technology) is a DARPA-funded effort whose goal is to exploit soldier-worn sensors to augment the soldier's recall and reporting capability to enhance situation understanding. ASSIST is separated into two tasks; Task 1 focuses on the hardware and Task 2 focuses on the software. NIST's role in this program is to develop and implement evaluation procedures to characterize the performance of the software components developed under Task 2. This paper provides an overview of the ASSIST program, the evaluation procedures, the metrics that the evaluation procedures were addressing, and the technology being evaluated.

Keywords: *DARPA, ASSIST, soldier-worn sensors, evaluation methodology, elemental tests, vignette tests*

I. INTRODUCTION

The Advanced Soldier Sensor Information Systems and Technology (ASSIST) program is a Defense Advanced Research Projects Agency (DARPA) advanced technology research and development program. The objective of the ASSIST program is to exploit soldier-worn sensors to augment a soldier's recall and reporting capability to enhance situational understanding in military operations in urban terrain (MOUT) environments. The program is split into two tasks:

- Task 1, named Baseline System Development, stresses active information capture and voice annotations exploitation. The resulting products from Task 1 will be prototype wearable capture units and the supporting operational software for processing, logging and retrieval.
- Task 2, named Advanced Technology Research, stresses passive collection and automated activity/object recognition. The results from this task will be the algorithms, software, and tools that will undergo system integration in later phases of the program.

The National Institute of Standards and Technology (NIST) Intelligent Systems Division (ISD), along with NIST's subcontractors (Aptima and DCS Corporation), are funded to serve as the Independent Evaluation Team (IET) for Task 2. As the IET for Task 2, NIST is responsible for:

- Understanding the Task 2 contractor technologies
- Determining an approach for testing their technologies
- Identifying a Military Operations in Urban Terrains (MOUT) site to evaluate the technologies
- Devising and executing the tests
- Analyzing the data and documenting the outcome

Section II gives background on how the ASSIST system is expected to be used. Section III provides an overview of the technology that was tested. Section IV described the metrics and the testing methodology. Section V concludes the paper.

II. EXPECTED USE OF THE ASSIST SYSTEMS

Soldiers are often asked to perform missions that can take many hours. Examples of missions include presence patrols (where soldiers are tasked to make their presence known in an environment), search and reconnaissance missions, apprehending suspected insurgents, etc. After a mission is complete, the soldiers are typically asked to provide a report to their immediate supervisor describing the most important things that happened during the mission. This report is used to gather intelligence about the environment to allow for more informed planning for future missions. Soldiers usually provide this report based solely on their memory and still pictures that were taken during the mission, if a camera is available to and used by the soldier. These missions are often very stressful for the soldier and thus there are undoubtedly many instances in which important information is not made available in the report and thus not available for the planning of future missions.

The ASSIST program is addressing this challenge by instrumenting soldiers with sensors that they can wear directly on their uniform. These sensors include still cameras, video cameras, Global Positioning Systems (GPS), Inertial Navigation Systems (INS), microphones, and accelerometers. These sensors continuously record what is going on around the soldier while on a misson. When soldiers return from their mission, the sensor data is run through a series of software systems which index the data and create an electronic chronicle of the events that happen throughout the time that the ASSIST system was recording. The electronic chronicle includes times that certain sounds or keywords were heard, the times when certain types of objects were seen, and times that the soldiers were in a specific location or performing certain actions.

With this information, soldiers can give reports without relying solely on their memory. The electronic chronicle will help jog the soldier's memory on things that happened that s/he did not recall during the reporting period, or possibly even make him/her aware of an important activity that s/he did not notice when out on the mission. On top of this, the multimedia information that is available in the electronic chronicle is available to the soldier to include in the report, which will provide substantially more information to the recipient of the report than the text alone.

III. Technologies under test

Task 2 of the ASSIST program is developing a variety of soldier-worn sensors, data capture, data analysis, and information presentation technologies. Below is a listing of three of the general data types being captured and analyzed by ASSIST technologies. Within each data type, numerous "technology elements" are being applied to organize, process, and present that data. Some of the key technology elements being applied in the ASSIST program are listed below.

"Image/Video Data Analysis Capabilities"

- Object Detection / Image Classification – the ability to recognize and identify objects (e.g. identify vehicles, people, license plates, etc.) through analysis of video, imagery, and/or related data sources.
- Arabic Text Translation – the ability to detect, recognize and translate written Arabic text (e.g. in imagery data).
- Change Detection – the ability to identify changes over time in related data sources (e.g. identify differences in imagery of the same location at different times)

"Audio Data Analysis Capabilities"

- Sound Recognition / Speech Recognition – the ability to identify sound events (e.g. explosions, gunshots, vehicles, etc.) and recognize speech (e.g. keyword spotting, foreign language identification, etc.) in audio data.
- Shooter Localization / Shooter Classification – the ability to identify gunshots in the environment (e.g. through analysis of audio data), including the type of weapon producing those shots, and the location of the shooter for those gunshots.

"Soldier Activity Data Analysis Capabilities"

- Soldier State Identification / Soldier Localization – the ability to identify a soldier's path of movement around an environment and characterize the actions taken by the soldier (e.g. running, walking, climbing stairs, etc.)

There is no single integrated ASSIST system at this point in the program's life-cycle. Instead, several university and corporate research and development organizations have formed into "research teams." Each organization is developing specific technology components, and these components are gradually being integrated as a "research team" system. The following sub-sections provide a brief overview of the specific technologies being developed by each research team.

A. IBM / Georgia Tech / MIT Team System

The IBM Team ("IBM") brings together three research and development organizations: IBM, Georgia Tech, and Massachusetts Institute of Technology (MIT). AWare Technologies is also involved in a portion of Georgia Tech's research and development. IBM has an ASSIST suite that includes hardware and software in more than 10 technological areas. The long-term vision for IBM's ASSIST suite is a complete system that captures, analyzes, organizes, and archives data for users (soldier and intelligence operators) to review and search to enhance after-action reporting and intelligence exploitation capabilities.

The IBM team's technology includes:

- Soldier state identification (e.g., driving, walking, running, standing, sitting, situation assessment from cover, going upstairs, going downstairs, lying down, crawling, taking a knee, shaking hands, opening door, raising a weapon, dragging)
- Image Classification -Images captured by the soldier are labeled with one or more classes and subclasses (outdoors, indoors, sky, building, vegetation, people, soldier, commotion, weapon, car, civilian vehicle, military vehicle, face, license plate)
- Object Detection --The presence of an object (faces, clothing color (based on face detection) and license plates) is detected based on data from one or more sensors
- Speech Recognition and keyword extraction is performed on the soldier's speech (keywords include assault, contact, dead, fire, flash bang, go, grenades, incoming, insurgent, intel, intelligence, kill, move, report, shots, spot suspicious, target, update, weapons,

- A4 mm round, AK47, Alpha, Bravo, C4, frag out, halt, IED, m16, RPG, SITREP, and tango)
- Identification of languages spoken in the environment (Arabic, English, French, German, Hindi, Japanese, Mandarin, and Spanish)
- Identification of "impulse audio" (single gunshot, machine gun, and explosions) and vehicles (light truck, transport sedan, transport van)
- Automatic Timeline Segmentation-- For the period of capture, the system automatically tags the timeline with appropriate labels (e.g. soldier was running from time x to time y, explosion detected at time z, etc.).

IBM's ASSIST suite hardware includes cameras, microphones, GPS, accelerometers, compass and physiological sensors. The IBM ASSIST hardware suite can be seen in the Figure 1. A screenshot of their user interface is shown in Figure 2.

Figure 1: IBM's Hardware

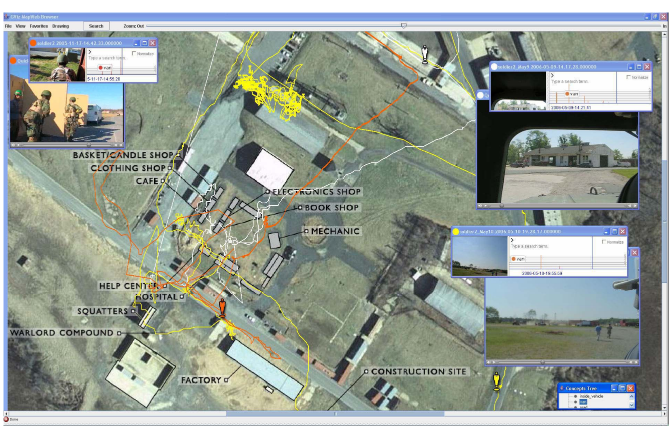

Figure 2: IBM's User Interface

B. Sarnoff Team's System

The Sarnoff ASSIST team also consists of three research and development organizations: Sarnoff Corporation, Carnegie Mellon University, and Vanderbilt University. However, each of these three groups is focusing on unique technologies that will not be integrated with one another during this initial phase of the ASSIST project. As a result, each organization was treated as a separate team. The following sections discuss the systems from each team.

1) Sarnoff's System

Sarnoff is developing a prototype system that captures data from stereo-vision cameras, GPS, and an inertial navigation system (INS). These data capture devices are carried on a backpack framework along with a laptop computer. The Sarnoff system applies software algorithms (e.g. landmark matching) to support Soldier State Identification, Soldier Localization, and Object Detection. The team has also developed mission-map viewing software to allow the soldier to visually relive their mission.

Sarnoff's technology includes:

- Soldier localization – The ability to locate a person outdoors and indoors in GPS coordinates using Video INS, INS, landmark matching and GPS (where available)
- Object detection – The ability to identify people, vehicles, and weapons (no sub-classification)
- Mission map viewer –The ability to overlay wearer's path on overhead map. Click on different points on path to retrieve visuals of what the wearer sees at that location. Move along path and dynamically view the world. Detected objects will be highlighted.

Sarnoff's system can be seen in Figure 3 and their user interface can be seen in Figure 4.

Figure 3: Sarnoff's Hardware

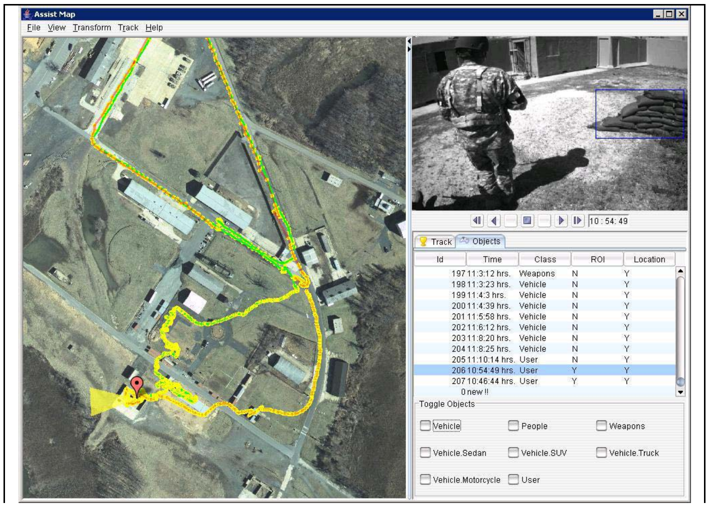

Figure 4: Sarnoff's User Interface

2) Carnegie Mellon University's System

Carnegie Mellon University (CMU) is developing Arabic text recognition and translation technologies. CMU's goal is to extract and translate Arabic text in pictures of the environment taken with a consumer-grade digital camera.

CMU's technology includes:

- Edge detection, layout analysis, and search algorithms to identify Arabic text in an image
- Optical character recognition software to extract the text from the image
- Statistical machine translation technology to translate Arabic to English.

CMU's user interface can be seen in Figure 5.

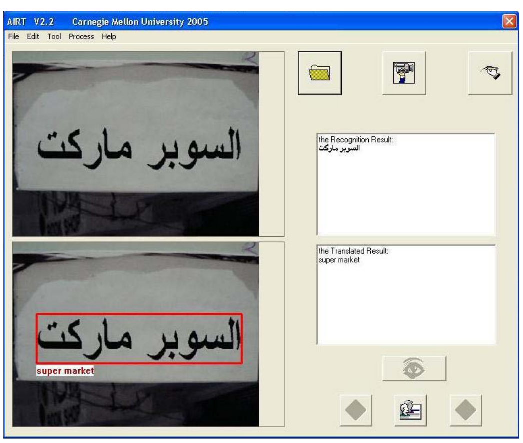

Figure 5: CMU's User Interface

3) Vanderbilt University's System

Vanderbilt University is developing shooter localization technology. Their technology seeks to locate a shooter, determine bullet trajectory, and classify the type of weapon being fired. The current hardware suite consists of 10 acoustic localization sensors and 2 acoustic weapon classification sensors (currently, mounted on tripods, but will ultimately be worn by the warfighters).

Vanderbilt's technology includes:

- Shot localization - Determine the trajectory of shots from 50 m -300 m. Determine the shooter origin at short range of a shooter firing automatic rounds.
- Shot classification - Classify shots from an M16, AK-47, 50 caliber sniper rifle, M4, M240, and M249.
- Data display - Localization and classification data displayed on a single laptop.

Vanderbilt's user interface can be seen in Figure 6.

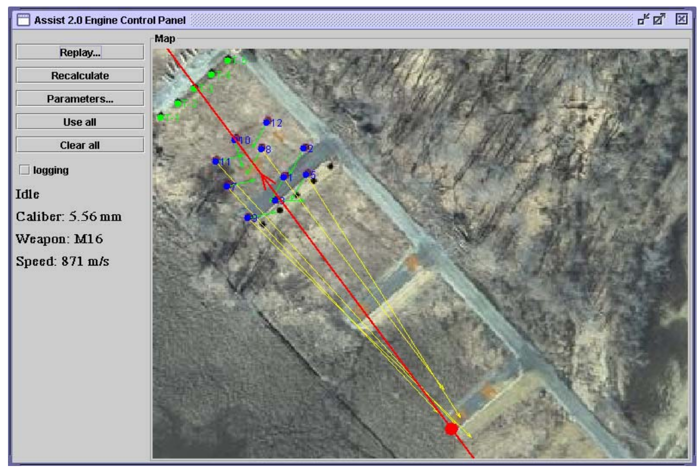

Figure 6: Vanderbilt's User Interface

C. University of Washington's System

The University of Washington ("UWash") team consists of the University of Washington, Intel Research Seattle, and Lupine Logic. This team is developing an integrated system that provides graphical and textual summaries of soldier activity over long periods of time. The system features a small, lightweight sensor pack that can be used up to eight hours for data collection in the current configuration. The system uses relational, hierarchical models of temporal data, and can be "trained" to recognize and distinguish different soldier activities.

Washington's technology includes:

- Soldier localization - GPS trace overlaid on overhead area image
- Soldier state identification - Identify activities of individual soldiers (indoor, outdoor, riding in vehicle, walking, running, standing, performing situation assessment from cover, going upstairs, going downstairs)
- Sound recognition - Manual review of audio data

during GPS trace

- Map/Mission viewer - Displays the wearer's path on an overhead map. Identifies soldier activities and audio events on a synchronized mission timeline.

Washington's system can be seen in Figure 7 and their user interface can be seen in Figure 8.

Figure 7: Washington's Hardware

Figure 8: Washington's User Interface

IV. Experimental Design

An experimental method was designed to evaluate the ASSIST technologies given their expected state of maturity at both 6 months and 12 months into the program. The IET attempted to design an evaluation approach that would scale well with the developing technologies, thus allowing valid assessments of technology performance improvements over time.

The ASSIST evaluations were intended as the first in a series of independent evaluations. As Per the ASSIST Broad Agency Announcement (BAA) [1], the following three metrics were the focus for the Task 2 evaluation:

1) The accuracy of object/event/activity identification and labeling
2) The system's ability to improve its classification performance through learning
3) The utility of the system in enhancing operational effectiveness

The IET developed a two-part test methodology to produce these metrics. Metrics 1 and 2 were evaluated through "elemental tests," and metric 3 was evaluated through "vignette tests." In short, elemental tests were designed to measure the progressive development of ASSIST system technical capabilities; and vignette tests were designed to predict the impact these technologies will have on warfighter's performance in a variety of missions and job functions. In specifying the detailed procedures for each elemental and vignette test, the IET attempted to define evaluation strategies that would provide a reasonable level of difficulty for system and soldier performance at both the 6-month and 12-month evaluations.

A. Elemental Tests

Elemental tests were developed to test ASSIST technologies in an "ideal" environment, and allowed focused examination of specific system components. While these tests did not immerse the technologies in realistic military scenarios, they afforded the ability to modify certain variables in a controlled fashion to assess the impact of those variables on technology performance in a MOUT site environment. For example, to test CMU's Arabic text translation technologies, the IET established a method that varied the system's distance from Arabic signs, the angle at which the sign was viewed, and the amount of light in the environment. Similar variables were identified and manipulated in the other elemental tests. The five elemental tests are described below.

1) Shooter Localization

This test evaluated Vanderbilt's technology's ability to identify gunshots, the type of weapon producing those shots, and the source of those gunshots in an environment with some obstructions and minimal background noise. A "zero line" and four firing lines (≈50 m, ≈100 m, ≈200 m, ≈300 m) were marked on the firing range. The ASSIST system's acoustic sensors were placed around and behind the zero line, and randomly covered an area that was ~30m x ~30m. Five targets were set up behind the sensor region. Simple wooden-walled structures (single story and two story) with windows were constructed at the firing lines and in the sensor region to simulate the buildings and obstructions that would be found in a MOUT environment, and to provide unique shooter positions through windows, next to walls, and on upper levels. Three to six shooter positions were specified at each firing line. The following variables were considered in the placement of shooter positions:

- Shooter positioning relative to walls at the firing line (within a window, next to a wall, from a clearing)
- Obstructions between the firing line and sensor field (Positions obstructed by walls that could occlude a bullet's muzzle blast and/or shockwave from a subset of the sensors)

2) Soldier State/Localization

The goal of the soldier state / localization elemental test was to determine the ASSIST systems' ability to localize a soldier in indoor and outdoor environments, and to characterize the motion of the soldier (e.g., running, walking, going inside a building, going up stairs, lying down, etc.). In the six-month evaluation, there were 6 test runs. Each test run exposed the system to a different level of difficulty for soldier state / localization identification. Run 1 was only outside in open areas. Run 2 was also outside but included some tight, GPS-hampered locations. Run 3 was both outside and inside, but did not force a change in elevation. Run 4 was predominantly inside and traversed two floors of a building. Run 5 involved a loop around a large portion of the MOUT complex, in which each action occurred for a longer period of time. Run 6 introduced a new part of the MOUT complex, and included much more driving and going up and down stairs. Each run required a soldier, shadowed by a researcher wearing the ASSIST system, to traverse a predefined path of waypoints in a scripted fashion.

101 waypoints were marked with two centimeters accuracy using differential GPS and surveying equipment. There were 42 indoor points across two different levels of buildings. There were 59 outdoor points, about 20 of which were placed next to walls and buildings, thus making it difficult to pick up a GPS signal. Poles were placed in orange cones at each waypoint. Colored signs attached to the poles indicated a letter for each waypoint in a run (e.g. A, then B, then C, etc.), gave a brief description of the action to performed at the waypoint and on the way to the next waypoint (e.g. "lie down for 10 seconds then run," "drive," "go up stairs," "stand for 10 seconds then walk," etc.), and provided an arrow pointing to the next waypoint.

3) Object Image Classification

The goal of the object detection / image classification test was to evaluate the capabilities of the ASSIST systems to classify imagery based on the presence of various objects (e.g., people, vehicles, weapons, etc.) and states (outdoors and indoors).

The elemental test was designed to provide ample opportunities for the ASSIST systems to view the above list of objects and states. Prior to the evaluation, the courtyard area of the MOUT site was chosen as the environment to conduct this elemental test. The ~45m square area contains 10-single story and two-double-story buildings. Each building had several doors and windows. Various pieces of furniture (e.g. chairs, desks, and tables) were distributed throughout the buildings. Approximately 50 waypoints were marked with two-centimeter accuracy using differential GPS and surveying equipment. The waypoints included a range of indoor, outdoor, ground-level, and upper-story locations (including positions in front of doorways, windows and other building features). These waypoints were used to mark the locations from which imagery would be captured by the ASSIST-wearer, and the locations of additional objects to be placed in the environment. Additional objects in the environment included vehicles (both civilian and military) with license plates (both US and Iraqi), people (soldiers and civilians dressed in simulated middle-eastern attire), weapons (both US military and foreign that were either carried by people or placed within the environment), IED materials (spools of wire, wire cutters, duct tape, etc.), simulated pipe bombs, Arabic signs, tires (both stacked vertically and resting against buildings), trash piles, barrels, boxes (various sizes) and sandbag piles, etc.

Imagery was collected from 25 viewpoints. The 25 viewpoints were distributed across 10 waypoints, each of which have multiple viewpoints to capture data from different orientations. Each team collected a single data set (image) at each of the 25 data collection viewpoints.

4) Sound Recognition

The goal of the sound recognition test was to evaluate the ASSIST system's ability to detect certain sounds in the environment.

To conduct this elemental test, the following sound events were scripted to occur in the environment at specified times relative to the start of a given evaluation run:

- A soldier fired blank rounds from one of three weapons: M240, M4, M107
- A soldier standing next to the ASSIST wearer spoke one of ten text phrase which incorporated some combination of the keywords listed above
- A person in the environment either spoke or played a digital voice recording of people speaking the languages listed above
- A soldier drove one of the vehicles specified above and either accelerated or decelerated past the ASSIST wearer.

There were 7 runs, each of increasing complexity. During the early runs, there was little or no ambient noise, the ASSIST wearer was stationary, there were no overlapping sounds, and most of the sounds in the environment occurred fairly close to the ASSIST wearer. During the later runs, there was a lot of ambient noise, the ASSIST wearer was moving, there were overlapping sounds, and the sounds in the environment were moving to and from further distances from the ASSIST wearer. The last two runs in the evaluation incorporated the ASSIST wearer being in confined and indoor locations.

Ground truth locations of the ASSIST wearer and the sounds in the environment were measured based upon known points in the environment. Before the test, the locations of certain points in the environment were mapped out to specific GPS locations with two centimeters accuracy. These points were given letter tags. When stationary, the ASSIST wearer remained at a specific lettered point in the environment; when moving the ASSIST wearer moved between specific lettered points. Similarly, the sounds were generated at specific lettered locations, or moved between lettered locations.

5) Arabic Text Translation

The goal of the Arabic text elemental test was to evaluate the ASSIST system's ability to detect, recognize, and translate Arabic signs.

Three signs were placed in the environment at marked positions so that sets of images could be taken at known angles and distances from the signs. The first sign contained hand-printed characters, while the other two had machine-printed characters. One of the signs used a font known to be accepted by the optical character recognition (OCR) stage of the system.

The elemental test had three parts.

- *Sign Detection*. The signs were used to evaluate the ability of the system to extract text regions from signs.
- *Text Extraction*. The regions extracted from the signs were processed and the results evaluated. In addition, pictures of text were submitted to the OCR program. The output Arabic characters and words were compared with those on the signs. The fonts and point sizes of the text were controlled and were limited to those that the OCR system can handle.
- *Text Translation*. A set of Arabic words and sentences was input to the translation system in its preferred format and the resulting translations evaluated.

Note that in most cases, members of the research teams wore the technology, since the hardware at this stage was not intended to be hardened. Soldiers observed and guided the researchers in the elemental test activities to ensure a reasonable level of realism in the behaviors of the researcher wearing the technology.

B. Vignette Tests

The vignette tests were designed to assess the value of ASSIST systems in 1) infantry squad reporting of critical information, events, and intelligence encountered during a mission, and 2) S2 (intelligence officer)/intelligence operations. These tests engaged soldiers in two realistic, albeit short, missions, where the ASSIST technologies were used to "shadow" the soldiers as they conducted the missions, and the S2 officer conducted debriefings post-mission. Additionally, a third vignette was employed to assess the contributions that ASSIST systems provided to another aspect of S2 responsibilities; data-gathering for a strategic product (actual production was not the focus here).

The scenario for Vignette 1 mimicked a presence patrol. The presence patrol included leaving a forward operating base (FOB) to patrol a local village, make the military presence known, and collect intelligence on the village and/or villagers before returning to the FOB. In Vignette 1, the soldiers were instructed to conduct a presence patrol in the market area of the village, and then conduct a deliberate search of the factory area.

The scenario for Vignette 2 focused on collecting intelligence about an Improvised Explosive Device explosion which had occurred overnight. The soldiers were instructed to gather detailed information about the IED event. Upon completion of that mission, they were to conduct a presence patrol in the market and factory areas of the village, while attempting to identify and/or detain several "gray list" and "black list" individuals.

As with the elemental tests, only the researchers wore the ASSIST systems unless otherwise requested. Each researcher was assigned a specific soldier to shadow during all parts of the mission.

After the vignettes were completed, the S2 was tasked with gathering data he would use to produce an intelligence report on the state of the village with respect to the upcoming election, including any related violence or unrest.

5) Soldier Test Procedures

For Vignettes 1 & 2, the following procedures were used:

1) A "simulated squad" of soldiers, comprised of two fire teams, with researcher 'shadows,' ran through an operationally-relevant scenario.
2) Upon completing the mission, the squad produced an after-action report, based the template provided.
3) Soldiers were asked to identify their information needs with respect to producing their report, e.g., information they would have preferred to include in their report but did not recall.
4) Each research team shared its processed data with the squad. Each soldier was asked to rate the importance of each information need and how well each ASSIST technology addressed each need

5) The soldiers participated in a semi-structured interview to get at more overall impressions from the exercise and ASSIST systems. The interview facilitator focused discussion on assessing if and how the after-action report produced by the squad would be different if the soldiers had been given access to ASSIST system functionality.

For Vignette 3, the following procedure was used:

1) The S2 was asked to identify information needs, e.g., information that would improve situation awareness, information about critical events, individuals, or situations, etc.
2) The S2 met with representatives of each research team to address the identified information needs.
3) The S2 was asked to rate the importance of each information need and how well the ASSIST system addressed each need.

Following the vignettes, the S2 participated in a semi-structured interview to capture his overall impressions of the ASSIST system capabilities and areas for improvement. The interview facilitator focused discussion on assessing if and how the S2's situation awareness and performance would be different if he were given access to ASSIST system functionality.

V. CONCLUSION

In this paper, we described the testing procedure that was implemented for Task 2 of the DARPA ASSIST program. The objective of the ASSIST program is to exploit soldier-worn sensors to augment a soldier's recall and reporting capability to enhance situational understanding in MOUT environments.

The following three metrics were the focus for the Task 2 evaluation:

1) The accuracy of object/event/activity identification and labeling
2) The system's ability to improve its classification performance through learning
3) The utility of the system in enhancing operational effectiveness

The IET developed a two-part test methodology to produce these metrics. Metrics 1 and 2 were evaluated through "elemental tests", and metric 3 was evaluated through "vignette tests". Elemental tests were designed to measure the progressive development of ASSIST system technical capabilities; and vignette tests were designed to predict the impact these technologies will have on warfighter's performance in a variety of missions and job functions. In specifying the detailed procedures for each elemental and vignette test, the IET attempted to define evaluation strategies that would provide a reasonable level of difficulty for system and soldier performance at both the 6-month and 12-month evaluations.

The evaluation procedures described in this report were found to be very appropriate and successful at obtaining the information pertaining to the three metrics desired by DARPA. The separation of the technology evaluation (elemental test) from the utility tests (vignettes) allowed the IET to focus on these very important but also very different aspects separately, thus allowing for a better evaluation, from the IET's perspective.

The ASSIST program is expected to continue through at least 2009 and NIST expects to continue applying and refining these testing procedures as the project progresses.

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DISCLAIMER

Certain commercial software and tools are identified in this paper in order to explain our research. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the software tools identified are necessarily the best available for the purpose.

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