Medical Communications for Combat Casualty Care

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Medical Communications for Combat Casualty Care (MC4) is the Army program responsible for fielding information management/ information technology systems to document and process the medical care provided to U.S. deployed forces. APL supported the MC4 Product Management Office for more than 10 years in the areas of research, development, testing and evaluation, and systems engineering and served as a trusted agent. APL's contract with MC4 concluded in February 2011.

MEDICAL COMMUNICATIONS FOR COMBAT CASUALTY CARE PROGRAM OVERVIEW

Medical Communications for Combat Casualty Care (MC4) is a U.S. Army Acquisition Category III (ACAT III) program under the auspices of the Program Executive Office for Enterprise Information Systems, PEO EIS [formerly PEO Standard Army Management Information Systems (STAMIS)]. MC4's mission is to integrate, field, and support comprehensive medical information systems, thus enabling lifelong electronic medical records, streamlined medical logistics, and enhanced situational awareness for Army tactical forces. The MC4 Product Management Office receives functional, technical, and requirements oversight through the Office of the Surgeon General, the Chief Information Officer of the Army Medical Department (AMEDD), and the AMEDD Center & School, respectively. It receives acquisition oversight through the Assistant Secretary of Defense for Networks and Information Integration. Funding for the program is managed through the Office of the Surgeon General, Army Information Systems, and its Milestone Decision Authority is PEO EIS.

The MC4 Product Management Office integrates the Defense Health Information Management Systems (DHIMS) government-furnished software into the MC4 system. MC4 also provides new equipment training and supports systems in theater and in garrison. MC4 also addresses all other Army-unique tactical medical requirements.

HISTORY

During the Gulf War and other deployments, the Army identified the need to find a way to central-

ize medical records. In the past, medical records were manually recorded on paper and often lost or destroyed because of environmental conditions during an operational deployment. Because of incomplete or missing medical records, many soldiers are unable to apply for Veterans Affairs benefits. In November 1997, the National Defense Authorization Act identified that all records of health-care services given to service members in connection to a deployment must be maintained centrally to allow future access to those records. As a result of the Special Report of the Presidential Advisory Committee on Gulf War Veterans' Illnesses,[1] the President directed, "Every soldier, sailor, airman, and marine will have a comprehensive, lifelong medical record of all illnesses and injuries they suffer, the care and inoculations they receive, and their exposure to different hazards."[2] The same year, MC4 principles were established under U.S. Code, Title 10 § 1074f, Medical Tracking System for Members Deployed Overseas[3] with the objective to ". . . assess the medical condition of members of the armed forces (including members of the reserve components) who are deployed outside the United States or its territories or possessions as part of a contingency operation (including a humanitarian operation, peacekeeping operation, or similar operation) or combat operation." MC4 was commissioned on 1 May 1999 with headquarters in Fort Detrick, Maryland.

MC4 was first deployed into combat operations at the onset of Operation Iraqi Freedom in March 2003, with initial deployments in Qatar, Kuwait, and Iraq followed shortly after with deployments in Afghanistan as part of Operation Enduring Freedom.

Since then, MC4 has expanded to include Special Operations Forces in 2006 and the Air Force in 2007. MC4 has also been deployed to Djibouti, Germany, Japan, Kosovo, Italy, Philippines, Poland, Romania, Thailand, and the United States. In January 2009, President Barack Obama, in a speech to George Mason University, stated, "To improve the quality of our health care while lowering its costs, we will make the immediate investments necessary to ensure that within 5 years, all of America's medical records are computerized. This will cut waste, eliminate red tape, and reduce the need to repeat expensive medical tests." There continues to be a need to deploy and improve the capture and storage of electronic medical records (EMRs).

APL INVOLVEMENT

In the fall of 1999, the Laboratory was approached to discuss the possibility of providing technical assistance for a newly formed Army medical program (MC4). Discussions continued, and the first task order from MC4 was received in the spring of 2000 with a period of performance from 1 May 2000 to 31 January 2001. The Statement of Work included development of technical

requirements, Global Combat Support System–Army (GCSS-A) interoperability modeling, and applications interoperability and integration. APL delivered the first version of the GCSS-A Medical Information Interface Communications Component (MEDIICC) Operations Concept Document in December 2000. In 2001, APL continued supporting MC4 but at a reduced level of effort until late 2002. A new contract established the creation of an MC4 laboratory at APL for the evaluation of hardware and government off-the-shelf and COTS software. APL also assisted MC4 with medical logistics and the implementation of a database for government asset tracking. By the end of 2003, APL's role in supporting MC4 had increased to seven full-time equivalent staff including test, requirements, logistics, and systems engineers in addition to its key role as Technical Direction Agent.

In the spring of 2004, three APL engineers traveled to Qatar and Kuwait to visit several U.S. military facilities and assess firsthand the operational, functional, and environmental setting of MC4 systems in theater. This resulted in a better understanding of the needs of end users and the demands they place upon deployed systems. Consequently, APL's systems engineering role in support of the program greatly improved.

When Hurricane Katrina struck the Gulf Coast in August 2005, MC4 deployed with the Army National Guard. While deployed, APL engineers worked alongside the National Guard to support the humanitarian operation. APL was also instrumental in identifying software compatibility issues between MC4 systems and the Future Combat System Medical Variant software architecture. This resulted in an extensive trade study effort that included several Army and contractor organizations, with APL participating as the technical representative (with voting rights) for the government (MC4).

Over time, APL has been instrumental in assisting the MC4 Product Management Office to reach Milestone C, Full Rate Production, and Deployment and Sustainment phases in its evolutionary acquisition strategy. To that end, APL closely collaborated with government personnel in the preparation of programmatic documentation, developing MC4's DoD Architecture Framework-compliant system architecture, and ensuring that MC4 systems maintained the levels of security and software readiness required for deployment and integration within Army tactical networks. APL also conducted modeling and simulations of network topologies for the Iraq and Afghanistan theaters[4] to better forecast communications needs as demand for bandwidth continued to increase. The increase was due to greater interest in telemedicine and the processing and distribution of diagnostic-quality digital imagery.

In recent years, APL gradually transitioned from a largely test and evaluation function to that of research and development. APL explored a wide range of capabilities as part of a technology roadmap initiative cover-

ing future government off-the-shelf software products, COTS hardware, telemedicine (telepresence, teleconsultation, and telesurgery), mobile technologies and communications [Warfighter Information Network-Tactical (WIN-T), the Global Information Grid (GIG)], and intelligent speech-to-text translation [hands-free (HF) EMR]. Some of these are discussed later in this article. These new capabilities, when applied to the medical domain on the battlefield, hold promise for improving warfighters' survivability.

MOBILE TECHNOLOGIES

In the spring of 2010, MC4 directed the Laboratory to conduct an analysis of alternatives for Web portal technologies to better manage and implement remote access capabilities of deployed systems. The intent was to reduce the time/man power required during the distribution and/or update of software releases to hundreds of Army medical units in a theater of operations. One striking conclusion of this analysis was the possibility of a "lighter," more versatile architecture at tactical Combat Support Hospitals in theater. This new architecture, optimized for more dynamic and secure access to medical applications residing on MC4 servers, was conceived using technologies that are suitable for data streaming over wireless communications networks.

The proliferation of mobile technologies at a global scale, i.e., smart phones and tablets, provides low-cost alternatives for implementing solutions applicable to a tactical environment like the Combat Support Hospitals. The extended network capabilities already available and forecasted to expand could enable the remote access to and from the lowest level of care in the U.S. Army medical infrastructure—the point of injury in the battlefield.

Currently, to document medical care in the combat zone, medics are provided with a PDA-like device (handheld) that runs a localized electronic version of the field medical card (DD1380) for

the creation of a medical encounter, also known as an EMR. Once the encounter is generated, the handheld device needs to be physically interfaced, or tethered, to the nearest MC4 notebook running the tactical version of AHLTA or AHLTA-T. This is the clinical application residing on MC4 systems for the documentation and processing of outpatient medical records. The closest locations where these notebooks are accessible to combat medics are in medical evacuation platforms like ambulances or helicopters. Obviously, combat medics do not always have immediate access to evacuation vehicles to upload pending EMRs into MC4 systems. More importantly, the notebooks on the evacuation vehicles lack direct connectivity to the NIPRnet. Therefore, the medical records are not being processed to the central
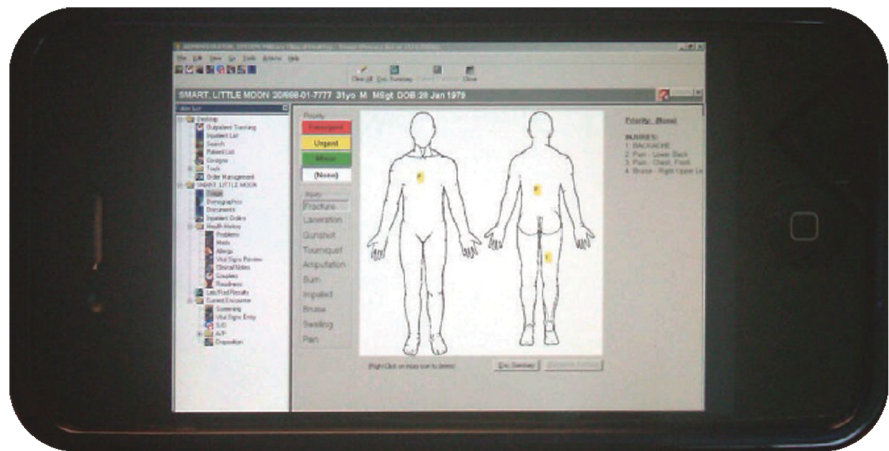

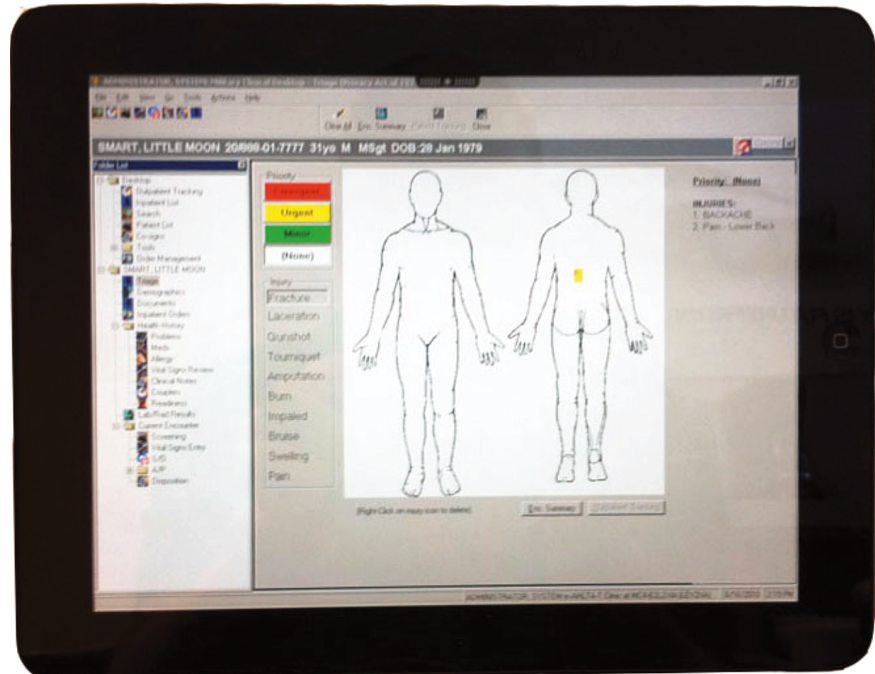**Figure 1.** Outpatient application on an iPhone 4.

Figure 2. Outpatient application on an iPad.

repositories in the continental United States or to the nearest medical treatment facility in a timely manner.

The Laboratory's solution to the Web portal analysis of alternatives included the Citrix XenApp application for data streaming. Similarly, Citrix provides a client application for mobile devices running Apple iOS and Droid OS. APL saw this as an opportunity to implement a remote connectivity capability for smart devices such as iPhone, iPad, iPod Touch, HTC EVO, and Samsung Epic over Wi-Fi or 3G networks to the centralized servers running AHLTA-T. In previous studies, the EMR applications had issues with screen resolutions and various input methods. Initial tests at APL indicated that the client was able to run and launch the applications successfully on all platforms. Zoom capabilities and screen size impose certain limitations for entering data. However, the iPad device had the most successful tests because of its screen size and clipboard-like configuration. Figures 1 and 2 show the outpatient clinical application currently used by Army tactical medical units running on the iPhone 4 and iPad, respectively.

By allowing the operation of these applications on smart phones or an iPad, medical personnel would have a portable device they can use to easily input EMR data while moving from bed to bed in a Combat Support Hospital or from anywhere, including the point of injury, over global networks.

HANDS-FREE-ELECTRONIC MEDICAL RECORD

Medical first responders in today's battlefield environments are equipped with technology to electronically document medical care. However, these technologies require providers to use their hands to perform the documentation. This solution is unsuitable because their hands usually cannot be diverted from the casualty to interact with the medical documentation device. Consequently, documentation is often not captured at the point of injury. The unsuitable nature of the currently fielded technology results in gaps in information that may have been used to improve combat casualty care, medical situational awareness, and training. Furthermore, such gaps may create voids in the lifelong medical records for service men and women who are injured in combat.

To address these issues, MC4 tasked APL to explore the development of an HF EMR system for this operational environment. In addition to MC4, other stakeholders in the development of this HF EMR system include the AMEDD, the Telemedicine and Advanced Technology Research Center (TATRC), the U.S. Army Institute of Surgical Research (USAISR), and the Defense Advanced Research Projects Agency (DARPA).

Research into various methods of HF data entry resulted in the selection of speech as the most mature technology in today's state of the practice. However, the battlefield represents a challenging acoustic environment, requiring the development of a technical solution to minimize the effects of ambient noise and preserve the voice of the health-care provider. The recorded voice must be intelligible enough such that a human, or ideally an automated speech recognition (ASR) system, coupled with a natural language processor, can convert the unstructured recorded voice into a structured, mineable data record compatible with DoD enterprise-level EMR systems such as AHLTA-T.

The objective of this study was to develop requirements for a HF processing system that creates an EMR at all levels of Combat Casualty Care. HF EMR technology has applicability across a wide range of programs such as the Soldier as a System and the MC4 programs as well as homeland civilian support operations. Accordingly, there are a wide range of operational considerations for this type of system including mobile (mounted and dismounted), far-forward scenarios with harsh environmental conditions (including weather, noise, shock, vibration, etc.), and clinical settings involving relatively benign environments. Furthermore, because each of the programs that may benefit from HF EMRs utilize a wide range of computing platforms and networks, the technical considerations include multicomputing platform applications (Windows, Linux, Embedded), near-real-time, accurate, complete medical records, and interoperability with other systems. The Laboratory's approach to this study involved a multiphase process for evolving advanced technology to mature technical solutions that meet operational requirements and produce requirements and specifications from which a production system can be developed.

SYSTEMS ENGINEERING APPROACH FOR THE HF EMR PROJECT

A disciplined system engineering process is required to successfully develop such a complex system incrementally from generation to generation. The five steps are shown in Fig. 3. MC4's HF project reached Step 3—technical performance evaluation of digital voice recorder (DVR) technology—in the iterative research and development cycle. A Measurement and Analysis Plan describes a methodology for providing a performance baseline for a set of selected DVRs that are candidate solutions for this system.

EVALUATION STRATEGY

Initially, the evaluation focuses on the audio hardware and signal processing of the DVR, followed by evaluation of downstream speech and language processing. Though the DVR and speech/language evaluations can occur separately, they cannot be conducted entirely independently of one another. For example, certain lan-
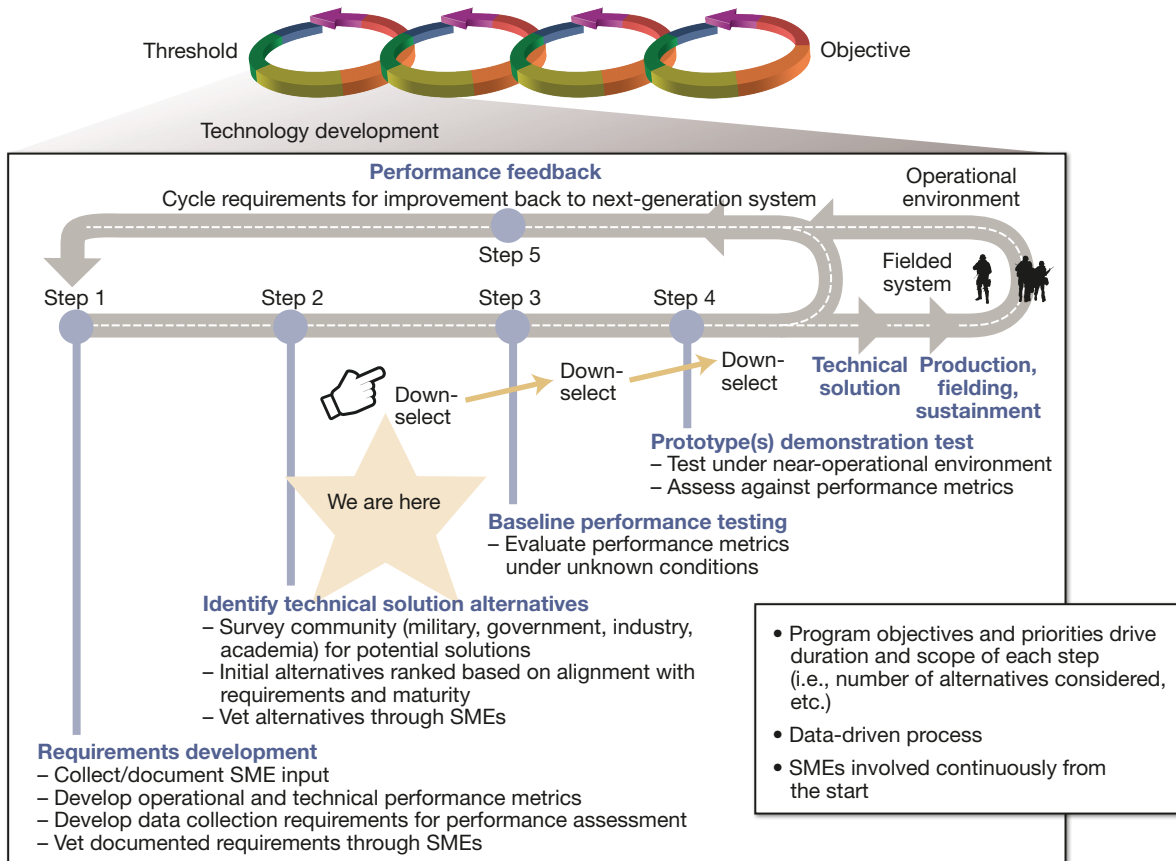
Figure 3. DVR roadmap. SMEs, subject-matter experts.

guage processors perform better than others at lower speech-to-noise ratios. Additionally, different DVR systems may produce audio outputs with degraded speech quality. It is up to the speech and language processors to contend with a potentially low signal-to-noise ratio and degraded speech quality. In order to compare the intelligibility performance between DVRs, the speech and language processors must present inputs from each of the DVRs, where the DVRs have been subjected to operationally relevant inputs (speech and noise).

Through a product survey using information (reports and briefings) provided by industry, the candidate DVR solutions were compared and assessed for further evaluation in a controlled laboratory setting. DVRs not selected for initial laboratory testing may have an opportunity to be reconsidered during a subsequent development/assessment cycle.

As illustrated in Fig. 4, DVR speech intelligibility evaluation involves several activities, including:

- **Speech Corpus Collection**: collection in a noise-free setting of human subjects reading prescribed sets of words

- **Sound Trials**: collection in a sound-reproduction facility of speech in the presence of simulated battle-field noise using the DVRs under evaluation

- **Speech Intelligibility Analysis**: analysis of the data collected during the sound trials with the goal of ranking the performance of the DVRs

In addition to analyzing speech intelligibility, the evaluation methodology also includes an assessment and analysis of the spatial discrimination and signal-processing characteristics of each of the DVRs. An analysis of the spatial discrimination is important. Operationally, these devices will be used in environments where noise is received at numerous angles and azimuths and the ability of the devices to fixate on the speech signal in the presence of this multidirectional noise field will be key to assessing how well each device preserves speech while rejecting noise. Additionally, technical characteristics such as dynamic range and interference rejection are key to the performance of these DVRs and are also included as evaluation criteria.

HF EMR RECENT ACCOMPLISHMENTS

High-Intensity Sound Test

The High-Intensity Sound Test (HIT) provides a baseline evaluation of COTS voice recorders in support of the HF EMR requirements development process. It is reasonable to assume that COTS audio data may become
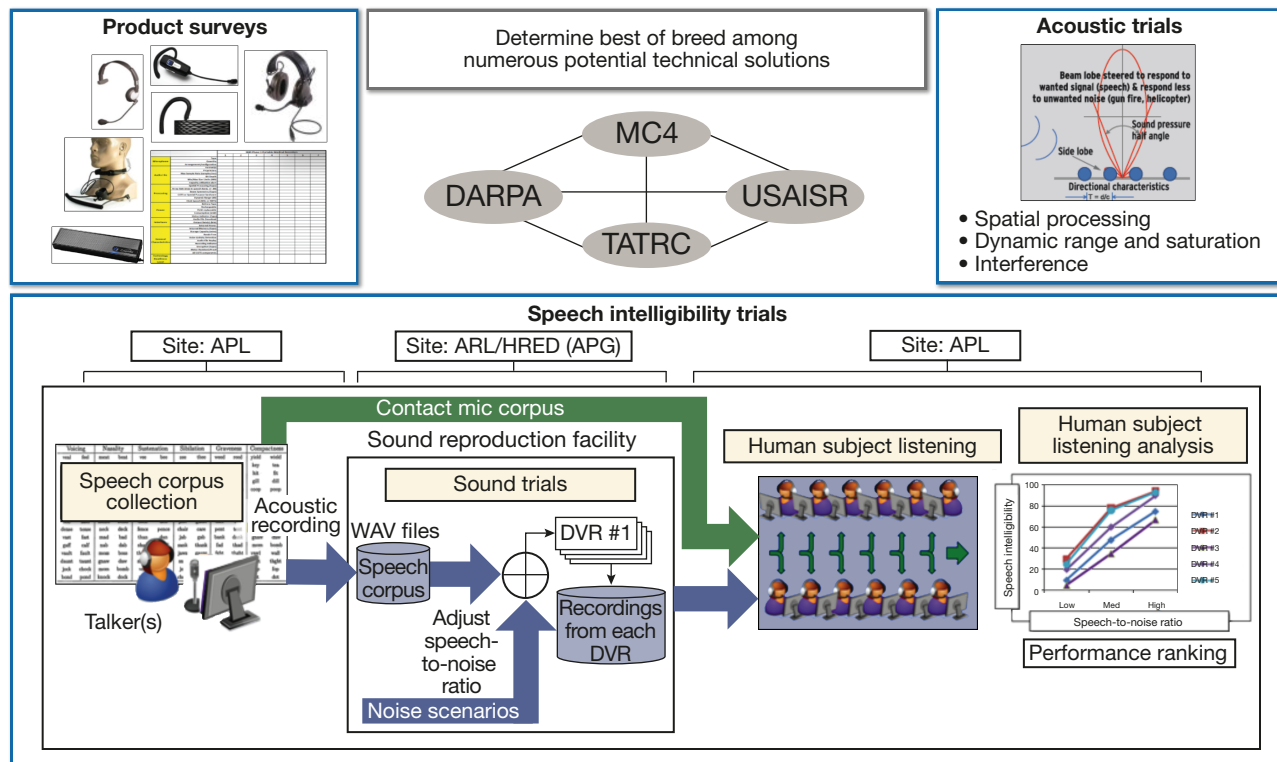
Figure 4. DVR evaluation strategy. ARL/HRED (APG), Army Research Laboratory/Human Research and Engineering Directorate (Aberdeen Proving Ground).

clipped or distorted under the acoustic environment of a battlefield. The goal of the HIT was to evaluate clipping and distortion by subjecting the COTS devices to sound pressure levels that may be experienced on a battlefield: a peak pressure of 140 dB(P) (peak pressure) and a root-mean-squared pressure of 120 dB(A) (A-weighted), with both levels referenced to 20 µPa at 1 m. The HIT was conducted at APL in two phases during July and August 2010. Figure 5 shows the test configuration, a schematic of the test procedure, and selected results. A starter pistol was used to generate the peak sound pressure levels needed to measure clipping and can be seen in the top picture. Narrow band-limited noise signals were also transmitted at high sound pressure levels to measure the harmonic distortion of the DVRs. Harmonic distortion was measured by comparing the DVR recordings to a ground truth recording.

HIT Results

Initial indications showed that although transient high-intensity noises may clip the COTS devices, many of the devices recovered quickly and were less impacted than originally thought. Steady-state loud noise, however, often distorted the recordings because of a nonlinear response of the microphone and preamp electronics at such high levels. This distortion was quantified and provided a ranking of the devices to be used as a downselect tool for evaluations.

ASR and Speech Intelligibility Risk Reduction Trials

The purpose of this test was to evaluate the performance of automatic speech recognition software to transcribe (i.e., speech-to-text) audio recorded in austere environments encountered by combat medics. All of the audio files were recorded using commercial DVRs and headsets under nominally equivalent environmental conditions. The test conditions included noises selected to resemble sounds heard on the battlefield during medical care (care under fire, tactical field medicine, medical/casualty evacuation). The DVRs and headsets were worn by active duty combat medics while they performed simulated care as part of an operational demonstration. This demonstration was the second of two conducted by the Joint Medical Distance Support and Evacuation Joint Capability Technology Demonstration project at the Air Force Medical Evaluation Support Activity in Fort Detrick (see Fig. 6).

The ASR evaluation method is shown schematically in Fig. 7. Human transcription of audio files will be considered ground truth and compared with ASR speech-to-text products. An independent listener with a medical background manually transcribed each audio file to text. These manual transcriptions were then used as the ground truth for all analysis. The ASR tool, Dragon NaturallySpeaking 9 Medical, processed the raw audio files. This ASR tool specifically has a preloaded medical vocabulary in addition to the ability to create
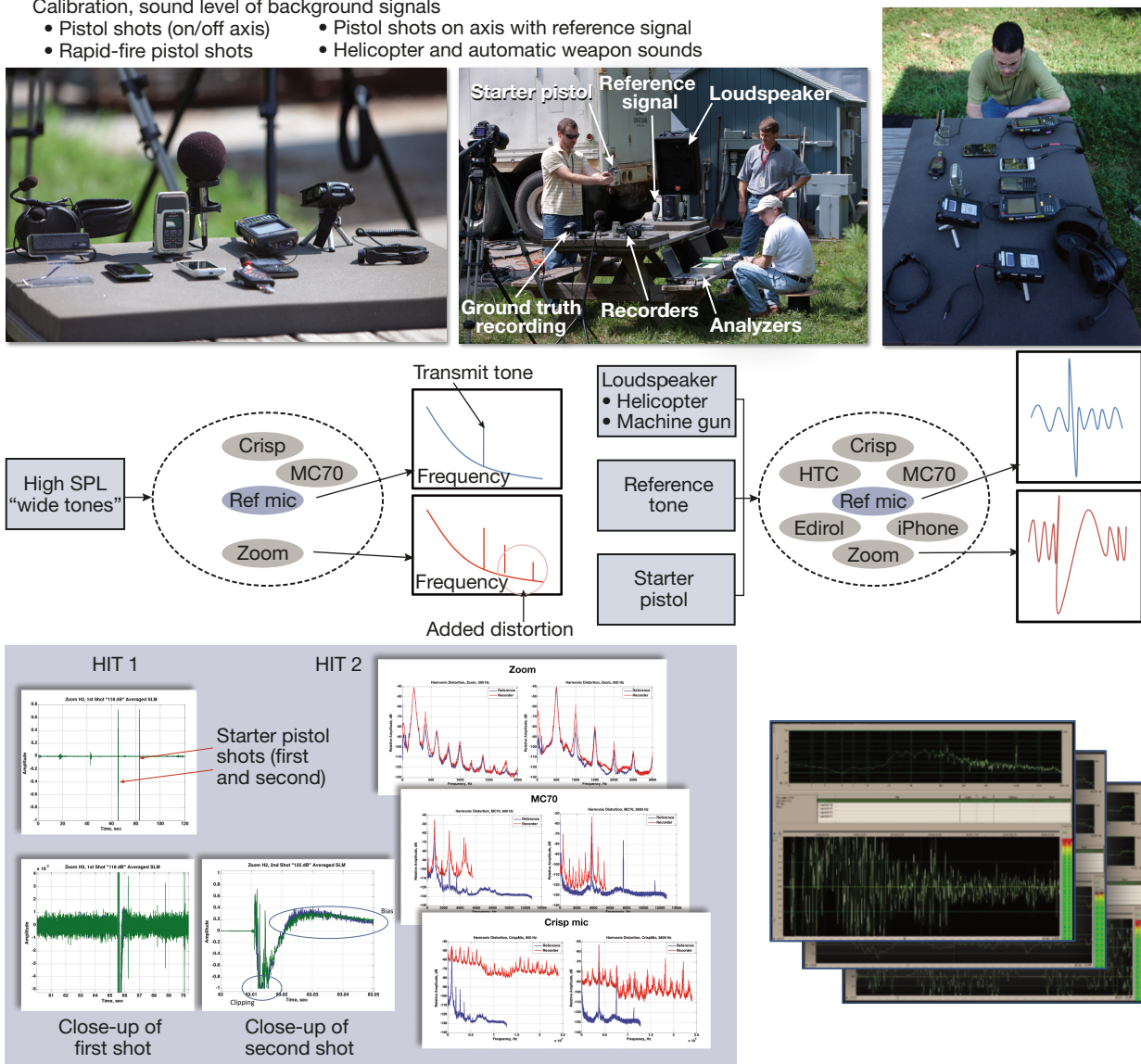
Figure 5. HIT setup and analysis.

customized vocabularies. The text outputted from this tool is then compared with the text ground truth using ScLite. ScLite is a National Institute of Standards and Technology software tool that matches like texts to determine the word error rate (WER). The WER is calculated using the equation shown in Fig. 7.

An alternate method (objective) of evaluating speech intelligibility known as the spectro-temporal modulation index model was also investigated and compared with the subjective method, i.e., the human subject listening method, which was illustrated earlier (see Fig. 4, Speech intelligibility trials). The spectro-temporal modulation index model uses knowledge of neural mechanisms of cortical auditory processing to formulate models that address problems of speech intelligibility. Experimental performance under certain noise conditions shows agreement with psychoacoustic analysis under the same condi-

tions. A spectro-temporal modulation index model will be evaluated using audio files collected during the speech intelligibility trials at the Joint Medical Distance Support and Evacuation operational demonstration event.

FUTURE TESTS

DARPA selected and funded three companies for Small Business Innovation Research program phase two, development of DVR technology. These are to meet the operational needs of the HF EMR. APL created a measurement and analysis plan to assess the performance of the DARPA phase two vendors. Potentially, this will also assess other DVR development candidates using a common set of battlefield noise and speech samples.

Acoustic risk-reduction tests have provided insight into the performance of COTS DVRs and useful distor-
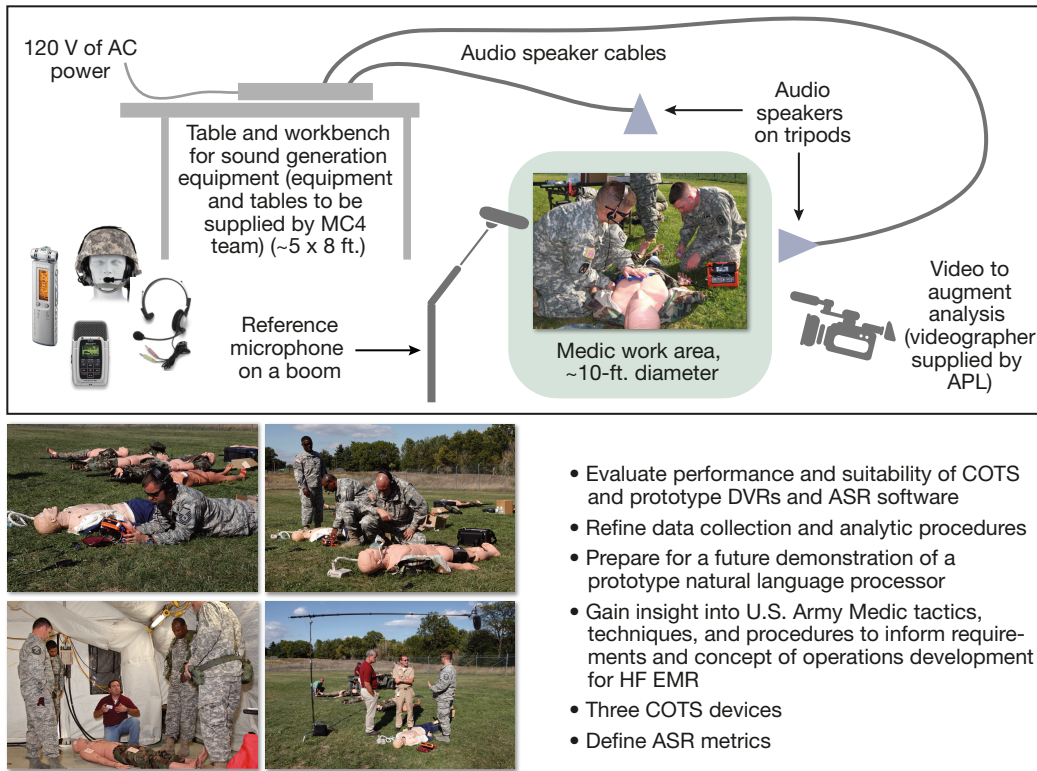
Figure 6. Speech intelligibility field trial at the Air Force Medical Evaluation Support Activity in Fort Detrick.

tion metrics appropriate for evaluating DVRs in future acoustic trials. Although analysis of the speech intelligibility risk reductions trials is ongoing, it is safe to assume that an increase in distortion observed in the HITs will cause a decrease in speech intelligibility. Through literature research and future testing, APL plans to develop intelligibility scores as a function of distortion. If APL can develop confident unambiguous relation curves, these can be used to predict device performance and reduce the need for human subject testing.

Upon completion of the acoustic and speech intelligibility assessments, APL has the capability to field prototype HF EMRs with Army medics during training evolutions in order to assess the operationally suitability of the candidate technical solutions. As sensor technology matures, alternative input modalities such as gaze-driven or brain sensors may be incorporated into the HF EMR system in order to improve the accuracy and speed of recording point-of-injury medical documentation.

SUMMARY

During the course of the MC4 contract, APL focused on protecting the interest of the government and ensur-
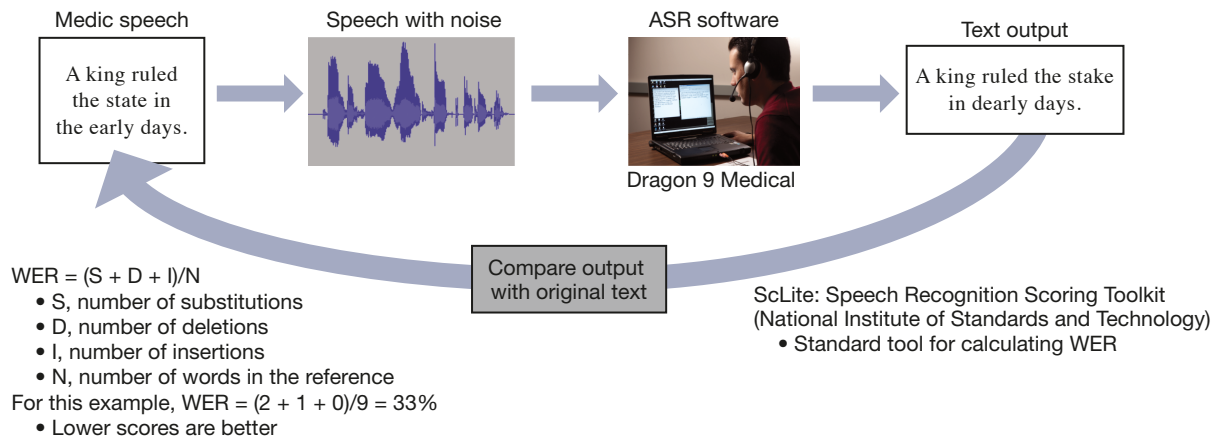

Figure 7. ASR software assessment method.

ing that every aspect of the APL effort was oriented to safeguard the integrity of the warfighter. At the conclusion of the contract, it is clear that several initiatives are still a work in progress. These include the technology roadmap, mobile devices, and the HF EMR. APL's transition plan included specific recommendations to the government for the continuation of these initiatives. The need for an HF capability at the combat medic level has been documented and is well known. The HF research and development completed by APL is an example of how this technology can be deployed in a diverse combat setting. The opportunity for the Army to achieve this capability has been fully demonstrated by APL.

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The Authors

The lead and principal engineer, **John H. Benson**, is a member of the APL Principal Professional Staff and a registered Maryland Engineer in the Research and Exploratory Development Department (REDD). He orchestrated the HF research and development, providing expert management and advice throughout the task. **William A. Irizarry-Cruz**, a software engineer in APL's Asymmetric Operations Department, has been a key contributor in two areas. He was the principal architect in the design and integration of the software and hardware components for the proof-of-concept HF EMR system. He also developed and defined an evaluation method for assessing the intelligibility of DVRs. **Jerrold E. Dietz** is a senior research engineer in REDD with more than 9 years of experience in undersea warfare, homeland protection, and biomedical research. Mr. Dietz defined test and evaluation procedures for the analysis of current and future technologies. **Jorge A. Aviles**, also of REDD, is a Senior Systems Engineer with more than 10 years of APL experience. Mr. Aviles provided overall systems engineering analysis and support to MC4 throughout the duration of the program at APL. **Christian D. Reid** is a retired Army combat medic with 26 years of medical experience. Mr. Reid guided a combat, common sense approach to what the ultimate solution should provide for the combat medic. His insight was invaluable to the success of this task. **M. Shane Stephens**, a former network engineer at APL, provided technical communications and network expertise for the overall interaction of the test. **Kristen N. Steinman** is an APL Associate Staff member in the Global Engagement Department. For this project, she was responsible for researching experimental designs, performing an analysis of variance, evaluating DVRs in an analysis of alternatives report, and assisting with testing efforts. For further information on the work reported here, contact John Benson. His e-mail address is john.benson@jhuapl.edu.

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