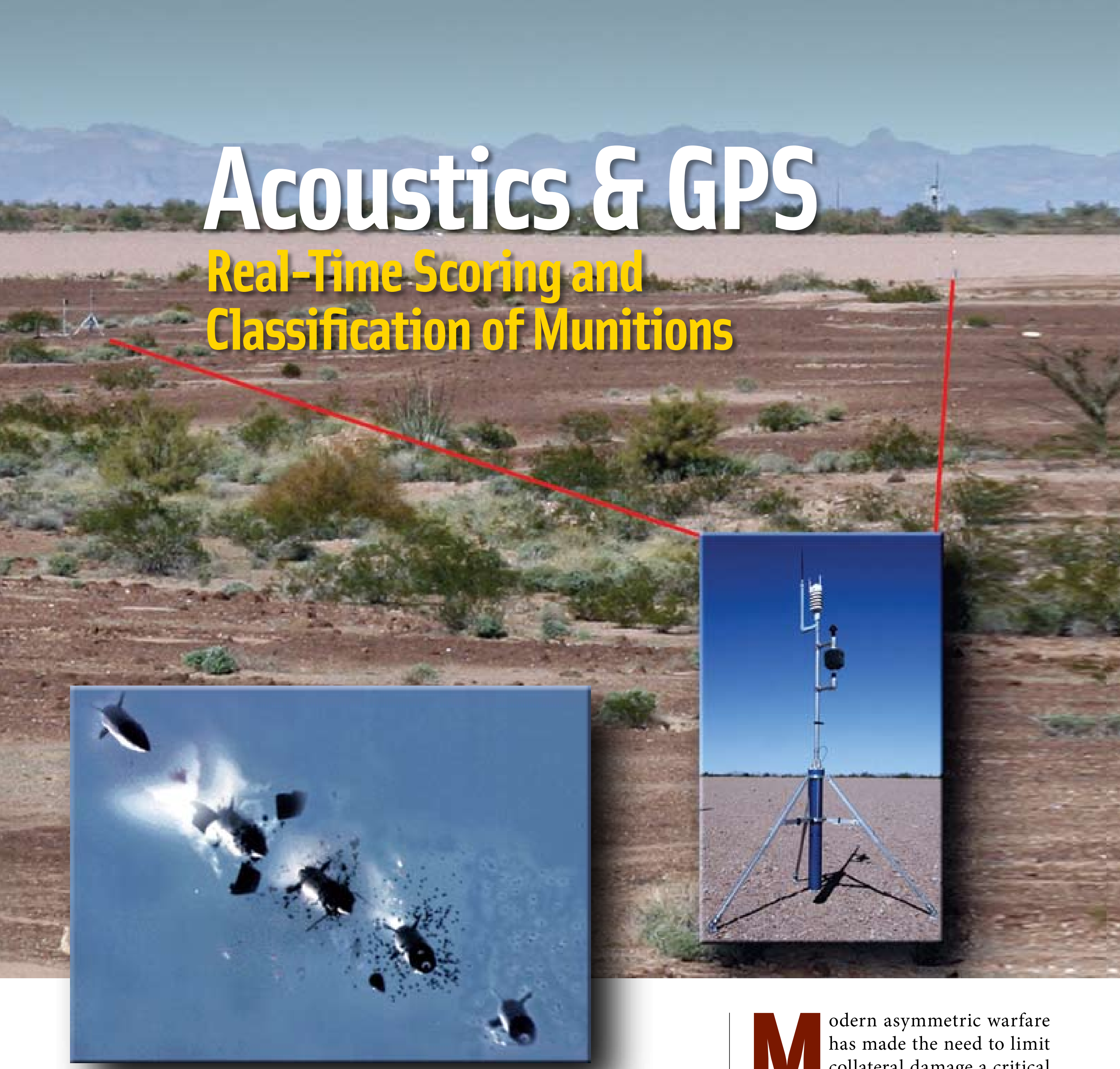
Acoustics & GPS

Real-Time Scoring and Classification of Munitions



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The development of more precise weapons with GPS on board has created a corresponding need for more precise and flexible methods of testing them. Here's a look inside the development of a highly accurate, real-time, portable, and low-cost alternative to traditional weapons testing systems. It incorporates state-of-the-art acoustic, GNSS, and data processing and analysis technologies and has been undergoing tests at the U.S. Army Yuma Proving Ground since May 2009.

Modern asymmetric warfare has made the need to limit collateral damage a critical parameter for weapons developers. In recent years this need has led to more accurate weapon types with longer ranges and more sophisticated deployment mechanisms.

Even traditional ballistic artillery has evolved to include GPS-based navigation and aerodynamic surfaces to achieve accuracies approaching one meter and rocket-assisted propulsion to achieve unprecedented ranges. Further, airburst deployment mechanisms can distribute ordnance in pre-selected patterns to optimize kill probability for different types of targets.

This myriad of weapons types has led to a significant increase in the operational and logistics support costs for weapons testing. Multi-million–dollar radar systems, optical tracking systems, and telemetry systems deployed in fixed locations over large test ranges have become the standard for weapon system testers. These traditional methods require not only substantial expenditures to operate and maintain, but also require highly skilled data analysts and weeks of data processing and analysis to produce intelligible results.

Arguably the revolution in weapon systems development requires a new paradigm in weapon systems testing. The application of state-of-the-art acoustic and data processing and analysis technologies has led to our development of a highly accurate, real-time, portable, and low-cost alternative to traditional weapons testing systems.

This new capability has been fielded at the U.S. Army Yuma Proving Ground in multiple test scenarios since May 2009, for a cost of less than $1 million and requiring only a two-person field deployment, data processing and analysis team. In this article, we will describe the design, development, and testing of our new acoustics-based testing system for munitions in which GPS technology contributes several important elements.

Below, an optical tracking unit with a digital imaging-based kineto tracking mount is hauled on a trailer to a surveyed sites. Inset photo: unexploded ordnance

Traditional Scoring Methods

Depending on program requirements, the assessment of munitions performance and accuracy has traditionally involved trades between expensive equipment (with skilled operators and complex signal processing) and fidelity of the results. Scoring methods generally fall into four basic categories: physical, optical, radar, and acoustic. These methods may also be hybridized, such as when a ranging laser radar is combined with optical instrumentation.

Scoring methods involving the physical survey of impact craters, the use of trained spotters with georeferenced landmarks, or the use of surveyed targets or "witness plates," have been used for years as a typical scoring methodology. These methods tend to work well for single-round munitions but exhibit several limitations. Range delays are required for physical survey of impact craters, including time required to make the range "safe" prior to physically accessing the range.

If witness plates are used, these assets must be replaced after each successful impact; and if the witness plate is not impacted, the scoring accuracy degrades to one of the other methods. Further, these methods are generally not applicable to the scoring of dispensed munitions and are difficult to apply during night-time operations.

Optical methods have been applied in various forms for several years. In this technology's simplest form, operators set up manual theodolites over surveyed benchmarks to mark angles from the observer post to the event location. Combination of angle data from multiple theodolite positions then allows triangulation of the event position.

Because of the difficulty in getting on target, for in-air detonations optical scoring generally references the smoke plume remaining after the event, rather than the event itself. In the more extensive implementations of this technology, a digital imaging-based kineto tracking mount (KTM) is hauled on a trailer to a surveyed pad, and this optical tracking unit — which may include an integrated operator on the mount or be controlled remotely — is then used much the way that traditional theodolites are used for scoring.

For high-speed projectiles with high tracking slew rates, multiple instrumentation pods and responsive tracking algorithms are required to generate 3D munitions trajectories. These units are expensive, require skilled operators and significant support staff, and generally cannot be employed to score multiple, simultaneously dispensed munitions.

Even with the complete dispersion area within the optical field of view, algorithms for optical scoring do not generally support the generation of an individual munition score for the case of dispersing ordnance. Although these methods are generally applicable to both live and inert ordnance, in the case of inert ordnance, night-time operations are usually not conducted with optical scoring equipment.

Radar scoring provides similar advantages and disadvantages to the more complex automated optical scoring methods. Although radar generally provides good feedback on statistical characteristics of a given event scenario and can be used at night, individual event locations are generally not available in the case of dispersive munitions. As with optical instrumentation, radars require skilled operators, a surveyed emplacement with good field of view, and significant signal processing and interpretation after the event.

Traditional acoustic scoring, as

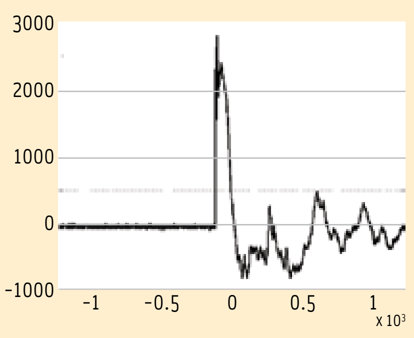


FIGURE 1 Sample near-field impulsive transient acoustic signature from a small detonation

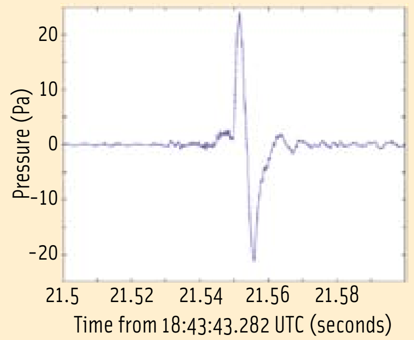


FIGURE 2 Sample propagated impulsive transient acoustic signature from munitions detonation

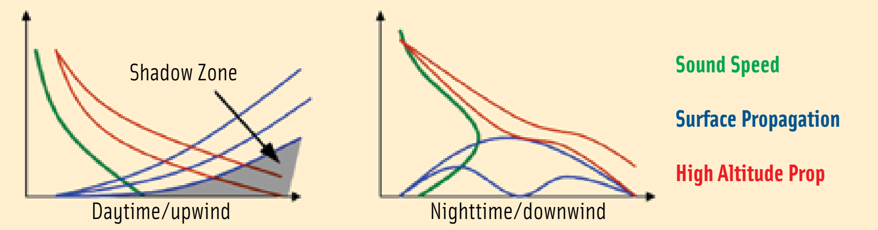


FIGURE 3 Sample ray traces, showing upwind and downwind propagation from surface and high altitude sources, in daytime and nighttime environments

implemented on existing test ranges, employs microphones installed on test stands at surveyed locations surrounding the impact area. Because these are generally portable set

ups, the locations are often surveyed at or just prior to deployment. Coaxial cables are then used to connect the microphones to the data recording equipment, often requiring cable runs of a few thousand feet to bring data from microphones on all sides of the impact area.

Water intrusion, long parallel cable runs, and damage from previous scoring exercises all take their toll on the data and induce noise into the process. Once the data are recorded, signal processing and a skilled operator are required to survey sensor locations and generate a score using operator-determined event times and time-difference-of-arrival (TDOA) processing.

While theoretically scores can be generated with traditional acoustic techniques for multiple dispersed munition events, realistically such systems are generally limited to counting detonations and statistical scoring.

Next-Generation Acoustic-Based Scoring

Acoustic-based scoring, in its most general sense, is the application of time-difference-of-arrival algorithms to audio recordings made at known locations. Events that create acoustic signatures, such as detonations, ground impacts, or in-air detonations result in characteristic impulsive features on visible displays of audio signals. These features represent the arrival of the acoustic signature at the sensor location, after being generated at the event location and propagating through the atmosphere.

Although these techniques have been applied successfully for years in a number of high-accuracy water-impact scoring systems — many of which have been developed by the authors — acoustic scoring in air has always been a more challenging problem due to the heterogeneity of the acoustic propagation environment. And, although the general techniques have been applied to the determination of military indirect-fire gun location, typical accuracies of these "line of bearing" methods were generally in the range of a few hundred meters and not suitable for munitions scoring.

Time-Difference-of-Arrival (TDOA) Algorithm. The next-generation acoustic-based scoring method incorporates a TDOA algorithm to calculate event locations. This algorithm uses a set of parameters (sensor locations) and measurements (signal arrival times) to estimate the unknown event location and time through a linearized least-squares process that minimizes the error in a "cost function."

GPS technology is critical to this process in several stages, depending on the specific implementation. In the system described in this article, an automatic differential GPS survey provides the sensor locations, or parameters for TDOA. The acoustic signals recorded at each sensor are assured of accurate timing through the use of GPS-synchronized high rate digital sampling, reducing the error on each measurement. Finally, the acoustic propagation environment is characterized through the use of GPS-equipped weather sampling, measuring the vertical wind profile by calculating the differential GPS trajectory of a weather balloon as it ascends over the test range.

Sound Propagation in Air

The acoustic signatures created by munitions events tend to be characteristically broadband transient impulses and often form shock waves at very short propagation distances (see Figure 1 and Figure 2).

In an ideal propagation environment, these signatures would travel from the point of detonation to the sensors along a curved ray path that is dependent only on the temperature profile. In a realistic propagation environment, however, steady state winds and localized environmental effects, such as wind shear and temperature variations, can significantly complicate the measurement of travel times from event to sensor. A notable instance: wind shear that is typically present near the ground will tend to favor propagation downwind to a sensor near the ground, and propagation of sound upwind is often problematic, leading to regions of reduced sound propagation, commonly referred to as "shadow zones" (see Figure 3).

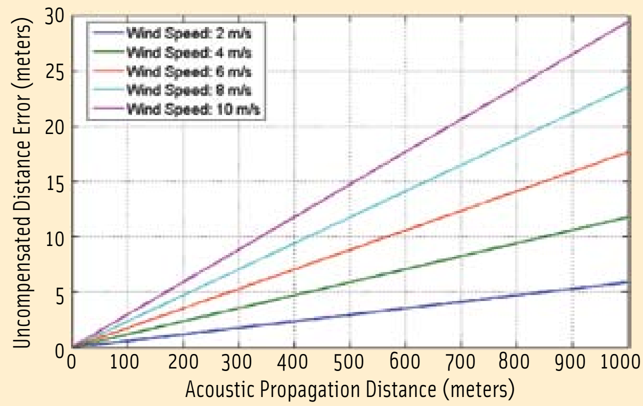


FIGURE 4 Distance error vs propagation distance, assuming steady-state wind uncompensated

In addition to the tendency of wind shear to affect the propagation path, the wind speed acts as an additive vector component to the ambient sound speed, increasing or reducing the effective sound speed, so that for a given propagation path, the error in distance that would result from ignoring the steady state wind (see **Figure 4**) can be considerable, especially for a system that has a design goal of one-meter accuracy or better.

As an example, if we have a design goal of scoring in the presence of steady state winds up to 10 meters/second within an impact area of 200 meters radius, the uncompensated error is approximately 6 meters. For larger impact areas the error grows linearly, so that over a propagation distance of 1,000 meters the error is nearly 30 meters.

For a system that must score munitions at an accuracy of one meter or better, the effects of wind must therefore be considered. Further, in the case of airburst munitions, we must also measure the profile as a function of altitude, not because of the path perturbations but because of the propagation travel time. A commercial off-the-shelf (COTS) meteorological balloon with on-board GPS to measure wind speed and sound speed as a function of altitude satisfies this requirement.

The sensor position is computed using differential GPS relative to the launch station to measure altitude and horizontal displacement to estimate winds aloft. These data are then combined with the surface-based measurements (as discussed in the next section) to characterize the three-dimensional acoustic propagation environment.

Practical Techniques in Acoustic Scoring

While the previous discussion points out the consequences of not compensating for weather effects on acoustic propagation, a practical example of compensating for those effects is useful in understanding the techniques that can be applied. We attack the problem by first considering the two-dimensional surface sound

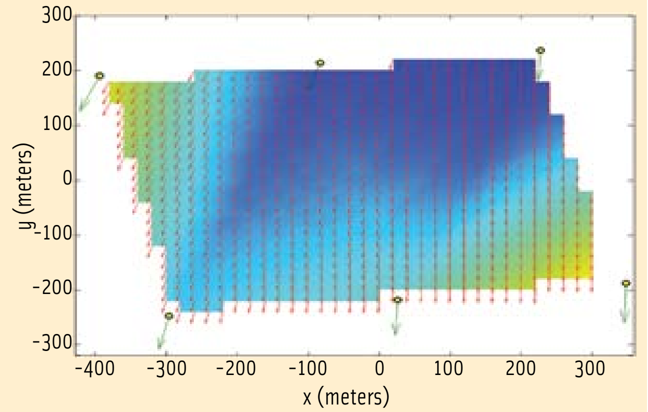


FIGURE 5 Sample wind field from six-sensor measurement at test range

speed and then applying data from a vertical profile to include the sound speed variation with altitude, primarily important for airburst munitions.

Figure 5 plots wind data collected from a distributed sensor network of six weather stations, showing the wind direction vector at each sensor and the calculated wind field that results from interpolating the data. These vectors are then considered along each acoustic propagation path that is calculated in the system.

In addition to the wind speed and direction, these weather stations measure temperature, pressure, and relative humidity, so that the ambient sound speed may be calculated. The resulting two-dimensional sound-speed map then looks similar to the example shown on the right side of **Figure 6**. Here the data from the deployed weather sensors are used to generate a sound speed at each position, then interpolated across the test range.

While the surface data are collected continuously during a scoring operation, the collection of vertical data is more challenging. It requires deployment of a GPS-equipped radiosonde weather balloon periodically to measure the ambient sound speed and the wind speed and direction as a function of altitude. Because the vertical data are collected only periodically, the three-dimensional sound speed uses the vertical profile anchored to the surface sound speed at any particular time to maintain continuity of the sound-speed function.

The system calculates an average sound speed, from the surface to a given altitude, by integrating through the profile vertically and then fitting a polynomial to the resulting data. If a vertical profile is not available, we use a standard temperature lapse rate to calculate the vertical sound-speed profile.

Acoustic Signatures and Filtering

A sample acoustic signature shown earlier in Figure 2 is representative of the isolated munitions signatures that are typically presented to the processing software. However, the real value in an automated scoring system, such as the one described in this article, is the ability to ingest real data generated by sometimes very complicated scoring scenarios such as for distributed munitions artillery shells. In those cases, the signatures often look more like those shown in **Figure 7**.

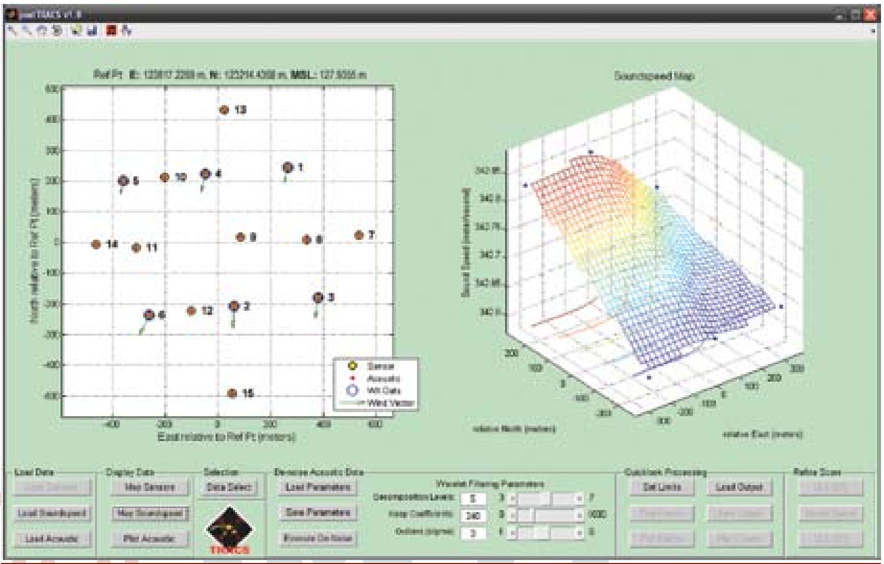


FIGURE 6 Sensor and wind vector map and effective sound speed plot

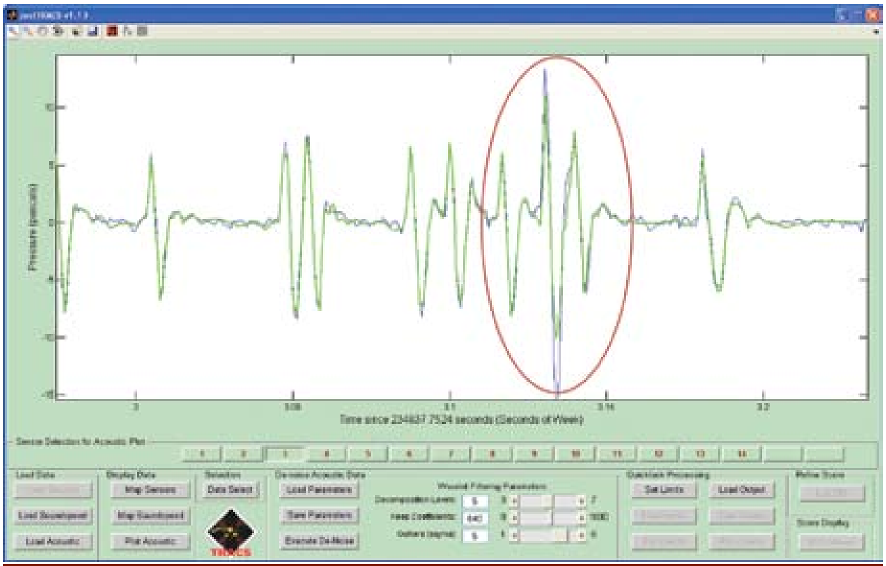


FIGURE 7 Sample acoustic data and wavelet-filtered data plot (red oval marks normalized data)

In these signatures, one of the key difficulties is the isolation of signature-specific features as well as the normalization of data that propagate to the sensor at different ranges. The pre-processor that we chose to apply to these data is based on *wavelet filtering*. Wavelets are particularly well suited to impulsive time-limited waveforms and are significantly better than traditional frequency-based filtering at removing noise from impulsive signatures while maintaining the phase information.

In addition to this advantage, the coefficients generated during the wavelet filtering process can be used to perform normalization of the waveform prior to reconstruction (see the red oval in Figure 7). This normalization prior to processing the data through the event detection algorithms keeps events that occur near a particular sensor from dominating the event reconstruction process. The resulting event reconstruction for these data is shown in **Figure 8**.

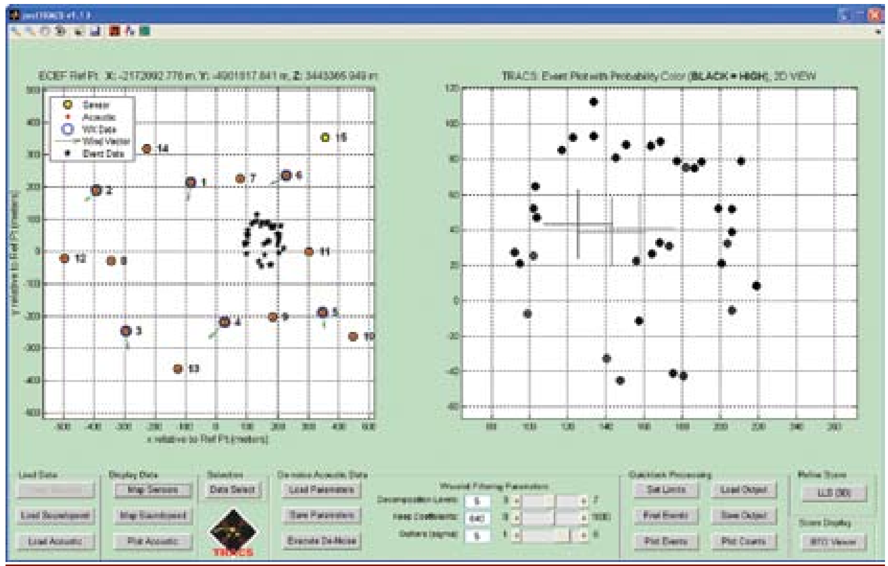


FIGURE 8 Sample events reconstructed from a multiple-event data set

Real-Time Acoustic Scoring with TRACS

Trident's Terrestrial Realtime Acoustic Classification and Scoring (TRACS) System is composed of four primary elements shown as an artist's rendering in **Figure 9**: real-time remote sensors, meteorological sounding system, the command and control station (CCS), and a remote command and control

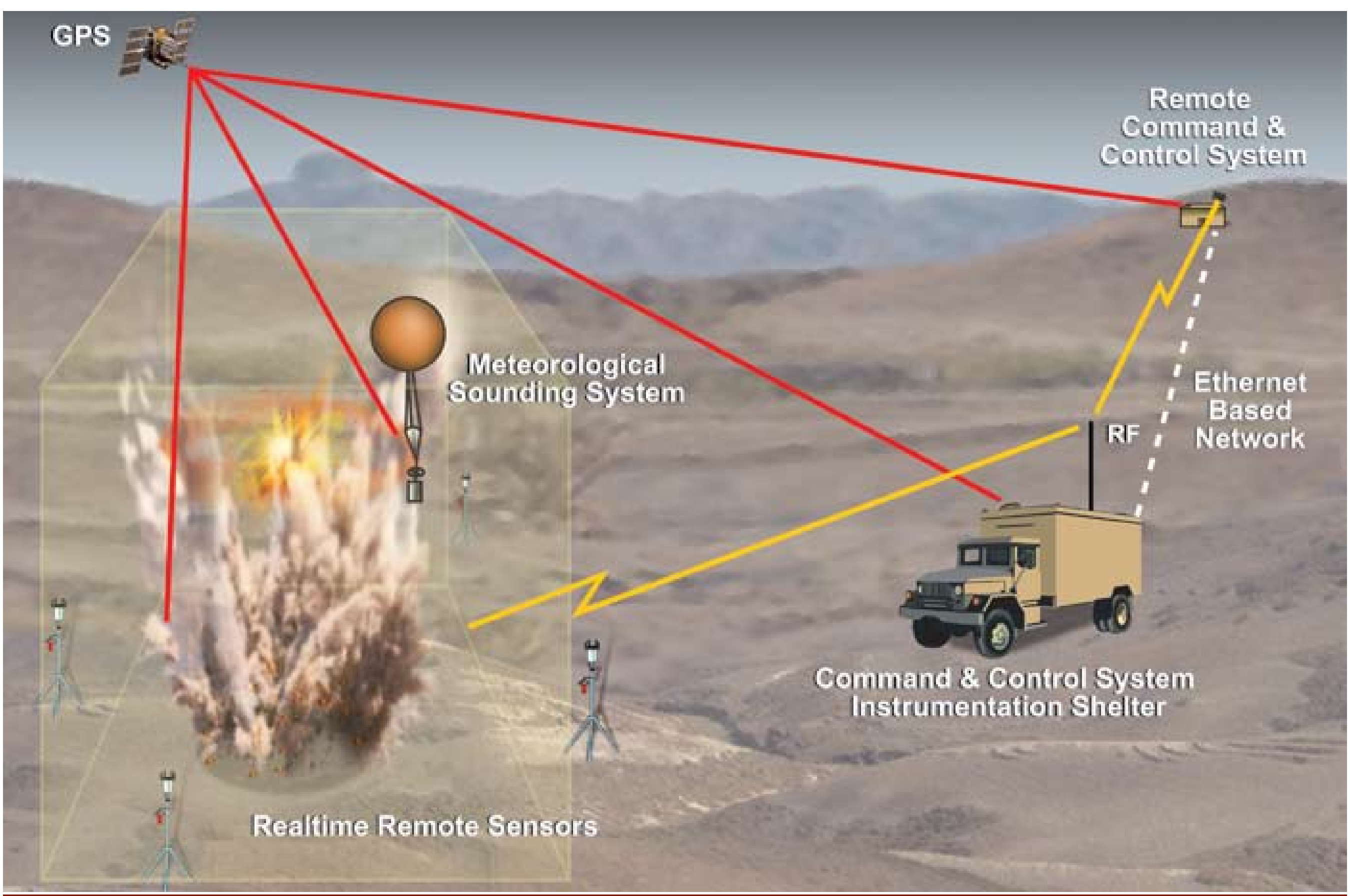


FIGURE 9 Artist rendering of the TRACS system concept

The TRACS system command and control center (top) and the vehicle that houses it

station (RCCS). Accompanying photos show the CCS and the truck/trailer unit that houses it.

TRACS employs GPS technology in each of these elements for precise positioning and timing, which is critical to the development of absolute WGS-84 coordinates and coordinated universal time (UTC) timing for scoring munition detonations. A typical test scenario calls for numerous real-time remote sensors, which incorporate a 12-channel OEM GPS receiver board, to be deployed across test areas that can vary in size by as much as 6.4 kilometers.

System components communicate wirelessly using a 900MHz RF network capable of distributing real-time component health and status, GPS position and tracking information, and acoustic data to multiple sources. The primary recipient of this data is the CCS, although the data is also retransmitted to the RCCS in the event that the primary CCS cannot be staffed physically. The RCCS is fully mission-capable and can support all system operations as long as the facility is linked by RF or fiber-optic communications with the CCS.

The TRACS system has the ability to perform real-time health checks across the network of sensors to ensure that the system is ready for data capture or to alert an operator to a failed segment. The system also has replaced previously required manual surveys with a GPS-based self-surveying capability, reducing installation and setup time and labor. Each real-time remote sensor also monitors its GPS–based survey position so that it can warn the operator in the event of significant displacement due to such factors as high winds or a near-field ordnance detonation.

The real-time acoustic data can be audibly and visually reviewed as well as processed to generate a localization and classification for each acoustic impulse event captured within the scoring zone. A single person can deploy the system (each sensor weighs less than 40 pounds); however, a trailer or pickup truck is usually employed to accommodate the TRACS network array of 10 to 15 sensors. In such cases the network of sensors can be deployed to support a 1.6 x 1.6–kilometer test area in under two hours.

All elements of the TRACS system, particularly the real-time remote sensors, are ruggedized to support tropic, arctic, and desert operating areas.

The system was designed to operate on numerous weapons types at various ranges simultaneously. Integrating this capability into a single sensor meant creating a design that could detect events ranging from distant fuse detonations to full high explosive (HE) rounds at close range. As a result, we designed the real-time sensors with dual transducers.

The custom electronics circuit boards and firmware within the sensors receive a data stream from both a microphone and a hydrophone, which is then filtered to create a generic sensor data stream with an acoustic center equidistant between the two phones. The resulting capability is a transducer with 75dB of sensitivity that maintains low noise characteristics while sampling at 40,000 samples per second. TRACS stores the full bandwidth data stream locally to media while a down-sampled version is transmitted wirelessly in real-time.

Immediately following an ordnance release, the real-time processor is employed on the data streams received from all deployed sensors. The real-time processor includes a wavelet-based timing of each discrete acoustic event obtained from the low-fidelity acoustic data stream, followed by a probability filter that correlates likely events among sensors, which finally leads to a linear least squares (LLS) iterative solution on the detonations.

This method provides an approximate detonation localization and time for each munition and a count of the total number of munitions observed.

Prototype (left) and production TRACS real-time remote sensors in the field

Real-time processing is typically performed within 30 seconds for a single discrete event and within 5 minutes for a multi-munition event. Further processing and solution refinement is also possible in near real-time through filter optimizations.

Post-mission scoring is accomplished by harvesting the high fidelity data stored on board each sensor and compiling the different munitions records into processing segments. The processing engine combines all of the meteorological, time, and position data to create a three-dimensional effective sound speed map that covers the entire testing area (see Figure 6, previously). The sound speed maps helps to accommodate situations in which the sound speed is neither uniform nor linear across the test area.

The dual-frequency GPS data collected at the CCS is used to survey the CCS relative to an existing benchmark location. The CCS surveyed location and GPS data is then used to survey each of the real-time remote sensors with centimeter-level accuracy.

Once the operational environment has been defined and all of the data harvested, the acoustic data is reviewed and synchronized to a common time frame in preparation for iterative processing. The software automatically plots the available data while the user selects the time period of interest. Users also fine-tune the processing time period and manually perform each sensor's inclusion in the data processing.

The first processing step is to filter through the test area in 2D and 3D searching for potential event source locations. Second, the outputs of this process are fed through an LLS algorithm to establish the location of detonations. The amplitude characteristics captured for each of the LLS outputs is then analyzed to determine event classification. Lastly, a summary of all of the final output event locations is compiled into a single human-readable report for review.

Prior to range deployment, we tested this process in the Austin, Texas, area using a small 100 x 100–meter test area and an array of 14 real-time sensors. We simulated ordnance events using small-caliber weapons fired in a fixed elevation above the ground.

The small fixed-array size and redundant survey measurements provided accurate survey truth to within ± 10 centimeters. The real-time and post-mission results of these tests are presented in **Table 1** and indicate 2D scoring accuracy within three meters RMS for all real-time cases and within one meter RMS for all post-mission cases. Real-time results were typically generated within five minutes after each event, and post-mission results were generated within two hours for all events, following data download.

In addition, we also tested the system's capability for capturing a large number of events over a short time span. Tests of this nature showed the system was capable of capturing up to 30 acoustic events within 6.2 seconds, with a mean difference from truth of 0.5 meters 2D RMS with a standard deviation of 0.2 meters.

TRACS has also been used to capture localizations on live munitions containing upwards of 80 sub-munitions (similar to the data set shown in Figure 8). Timing tests have also shown the system to produce time tags that are accurate to within three milliseconds.

Ultimately, the operator need only review the final report output, which contains localization, time, classification, and residuals for all events captured in order to get a clear picture of how the weapon performed. Post-mission processing typically takes place within one hour for a single discrete event or within four hours for a multi-munition event.

Testing at Yuma Proving Grounds

The TRACS system was delivered to the Electronics Division at the Yuma Proving Ground (YPG) in March 2009. At YPG a two-person team deployed and surveyed the system in approximately one day.

Following system set-up, YPG conducted a scoring accuracy test of TRACS using multiple C4 charges at air and pre-surveyed ground locations. The test was executed over approximately three hours, after which realtime processing was performed.

Test operators obtained real-time results within two hours with 3D detonation locations generated to within 1.6 meters for all but two cases. They then downloaded the full bandwidth data from each sensor and performed post-mission processing the next day. The post-mission results, presented in Table 2, demonstrated sub-meter 2D and one meter 3D scoring accuracy for these controlled tests. Timing information was not provided for the detonations, but TRACS system statistics indicate timing of each detonation was determined to within 0.9 milliseconds.

The inconsistent results for the two air detonations remain in question. Although the optical theodolite used as "truth" possesses limited accuracy, particularly for determining coordinates for a continuously moving air burst detonation, this alone does not account for the observed error. Additional testing and analysis is planned to resolve this discrepancy.

In addition to testing the scoring accuracy of TRACS, YPG also conducted a series of demonstrations to determine the effective communications ranges of the system components, the utility of the CCS and RCCS to effectively operate the system from a remote location, the utility and effectiveness of the real-time and post-mission data processing and analysis software, and a review of the operations and maintenance manual for the system. Final acceptance of the system was accomplished in May of 2009 following a weeklong hands-on training program.

Planned Improvements

Operational testing of the TRACS system has identified several elements that we plan to improve to increase the system's utility and performance. Operational modifications include the addition of a "trigger" operating mode to mitigate the amount of acoustic data stored, thereby expediting data downloading and processing. We anticipate that a trigger-operating mode would also increase TRACS's multi-day operation from the 48-hour continuous operation period currently supported.

Performance modifications include

Small Caliber Weapon (GPS Surveyed Truth +/- 10cm)	
Realtime Accuracy 2D Delta (m)	Post-Mission Accuracy 2D Delta (m)
0.59	0.403
0.98	0.392
0.97	0.593
0.72	0.615
0.64	0.436
0.57	0.454
0.51	0.359
0.44	0.354
2.07	0.298
1.29	0.277
1.09	0.313
0.96	0.299
0.45	0.331
1.47	0.333
3.31	0.210

Table 1. Summary of TRACS testing results in Austin, Texas

System Target Ordnance Events					
Air Detonations Theodolite Truth (+/- 1 m)		Single Ground Detonations GPS Surveyed Truth (+/- 20 cm)		Simultaneous Ground Detonations GPS Surveyed Truth (+/- 20 cm)	
2D Delta (m)	3D Delta (m)	2D Delta (m)	3D Delta (m)	2D Delta (m)	3D Delta (m)
0.64	1.04	0.85	N/A	0.54	N/A
2.55	4.15	0.37	N/A	0.85	N/A
0.59	10.04	1.12	N/A	0.59	N/A
				0.40	N/A
				0.34	N/A

Table 2. Summary of TRACS testing results at Yuma Proving Grounds

the modeling and filtering of supersonic acoustic events to improve the ability of the wavelet processor to identify leading edge signatures and thus improve the 3D scoring accuracy of air burst detonations. Another performance modification under study is the ability to discriminate unique acoustic events for dispensed munitions where significant numbers of munitions are detonated in a small spatial and temporal area.

Two likely concept of operations modifications that would improve the ability to localize each unique dispensed munition event: altering sensor placement to significantly vary the range of each sensor relative to the impact field and reducing the temporal spacing within the LLS algorithm. These pending modifications will expand the utility of the system and improve scoring reliability and accuracy.

Conclusion

Trident Research has adapted its TARGT ocean-based acoustic scoring system technology — described in an *Inside GNSS* article (August 2006) — to successfully provide sub-meter 2D and one-meter 3D munition scoring in a land-based environment. The TRACS system provides a highly portable, one-person deployable, land-based capability for the accurate scoring of single and multiple ground- and air-burst munitions.

The system has been accepted and successfully used by the U.S. Army Yuma Proving Ground to support weapons testing of multiple types of military ordnance. This off-the-shelf capability provides a rapid and low-cost alternative to conventional weapons testing methods. TRACS is highly adaptable to a broad range of test environments and provides a new tool for weapons program offices in evaluating the performance of new weapons, particularly weapons using dispensed submunitions.

Manufacturers

The TRACS real-time remote sensor incorporates the AC12 GPS receiver from **Ashtech SAS**, Carquefou, France; a Wi-Sys WS3977-DH GPS antenna from **PCTEL, Inc.**, Bloomingdale, Illinois, USA; an AW900mT RF Transceiver from **AvaLAN Wireless Systems, Inc.**, Madison, Alabama, USA; an A09-HASM-675, **MaxStream, Inc.**, Lindon, Utah, USA; a WXT-510 MET Sensor from **Vaisala Oyj**, Helsinki, Finland; an SDCFX3-16384-901 Extreme III 15GB CF card from **SanDisk Corporation**, Milpitas, California, USA; an MPA205 microphone, **BSWA Technology Co., Ltd.**, Beijing, China; and a SensorTech SQ21 hydrophone, **Sensor Technology Ltd.**, Collingwood, Ontario, Canada.

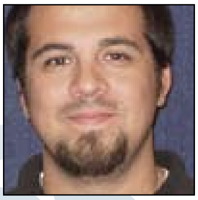
The TRACS instrumentation shelter contains a DL-V3 GPS/GLONASS receiver and a GPS-702-GG antenna manufactured by **NovAtel, Inc.**, Calgary, Alberta, Canada; an AvaLAN Wireless AW900xT radio; and an Antenex FG9026 RF antenna from **Laird Technologies**, Chesterfield, Missouri, USA.

The TRACS remote command and control system incorporates a TR2021 computer (comprising an Intel Core 2 Duo 2.4 GHz; 4GB PC2 8500; 250 GB Storage; DVD+R) from **Trident Research LLC**, Austin, Texas, USA; an AW900xT radio and AW15 Yagi antenna from **AvaLAN Wireless Systems, Inc.**

Authors

Miguel A. Cardoza has worked for more than 25 years in systems engineering and program management for federal, state, and foreign governments in both the university and private industry sectors. In that time he has led the design, development, and fielding of multiple instrumentation systems in the area of weapons testing and training, with emphasis on real-time, remote, distributed sensor systems. Cardoza received his bachelor and master degrees of science in aerospace engineering from the University of Texas at Austin, and is a graduate of the Advanced Program Management Course from the Defense Systems Management College, at Fort Belvoir, Virginia. He has authored numerous technical papers and patents on real-time military instrumentation systems and is the founder and president of Trident Research LLC.

Dr. Jeffrey A Cook has developed prototypes of tactical and instrumentation systems for real-time environmental surveillance, remote sensing, data telemetry, automated classification, and casualty assessment for multiple federal and state governments. He has developed and validated field prototype systems for ballistic missile and air-dropped bomb scoring. Cook has designed, fabricated, and demonstrated "sparker"-based acoustic sources, including geophysical-scale units and small units for simulation testing of bomb scoring systems. Cook was the lead scientist for the TRACS system development for U.S. Army Yuma Proving Ground. He received his Ph.D. in physics from the University of Texas at Austin and is currently a senior research scientist for Trident Research LLC.



William Adamez has worked for more than 10 years in software engineering and IT management for the Department of Defense in both the university and private industry sectors. In that time he has participated in the design, development, and fielding of a number of military instrumentation systems for the U.S. Navy, Army, and Air Force. Adamez was the project lead for the TRACS system development for the U.S. Army Yuma Proving Ground. He received his bachelor of arts degree in geographic information sciences from the University of Texas at Austin and his masters of Science degree in management information systems from the University of Phoenix. He has also co-authored patents on real-time military instrumentation systems and is presently a senior software engineer at Trident Research LLC. IG