"I See Buried Things"

by William A. Bartling

Borrowing from young Haley Joel Osment's haunting confession in the movie *The Sixth Sense*, earth scientists sport a special talent, one uncommon in the broader technical population: "We see buried things." It's what we do; it's what we are good at. We stand tall here in Houston and elsewhere, look straight down and proclaim with great confidence what lies miles below our feet.

Half a world away from Houston, a Humvee transporting American soldiers rolls along an empty road, its passengers carefully monitoring all directions. Then, without warning or a visible antagonist – boom! A buried roadside bomb, unseen and undetectable, detonates, laying waste to the Humvee, its passengers and anyone nearby.

These deadly improvised explosive devices (IEDs) lie buried along the roads throughout Iraq, posing a constant threat to our troops. Geophysics sees to the great depths where oil resides, and, using the right tools in the right way, can also see things shallow and small. A buried roadside ordnance, a booby trap under a building, buried caches of weapons – geophysics can detect things of great interest and importance to troops doing their best to navigate around and through harm's way. A modified form of the geophysical remote-sensing technologies used to find oil can enable our troops to avoid these threats, render them useless and take a key weapon out of the hands of the insurgent army. A program to develop this capability has been initiated, and we have made excellent progress, but the military has yet to deploy it in combat. In fact, many of the army's own have come up with similar ideas.

Cloning Excellence

A colleague who works in defense technologies was asked, while traveling, to deliver a spontaneous presentation on high-performance computing in the oil and gas industry. A couple of frantic phone calls later, he located me, and I delivered a set of slides with key talking points on seismic processing and visualization to his e-mail box halfway around the world. These processes were the best examples of high-performance computing in the industry and an area I am very familiar with.

My colleague is also an Army Air Reserve pilot who recently spent time on active duty in the Middle East, experiencing firsthand the challenges facing the troops. One of the most harrowing is this unseen enemy – buried ordnance waiting for its wary but blind victims.

Upon returning from his journey, he asked me a single pointed question with no attempt to hide or disguise his agenda: "You can see underground, can't you?"

After we filled white boards with seismic theory, acquisition designs, the hypothetical direct application to the IED problem and a history of proposing such solutions, he had come to a new insight. The geophysicist's ground-penetrating eyesight could serve his mission to protect soldiers against explosives concealed beneath a light blanket of earth. He then asked, "What can you tell from these data?" The answer: We can tell if something is there and, if something is, where and what it is.

This idea is not new. It was first proposed to the Defense Special Weapons Agency in the mid-1990s to design a remote way to detect and visualize buried threats and activities, such as weapons manufacturing. At that time we called it Lawn Darts, since the hardened, wireless-enabled geophones we envisioned were to be launched from cannons, implant themselves in areas of interest, listen passively for noisy subterranean activity and transmit data back to command central. The project was restarted when U.S. troops entered Iraq in 2003, but with the first phase of hostilities behind us and better access to the region, the focus shifted from passive to active imaging. Both methods require sensor engineering and modification to data-processing schemes to find what we are seeking.

The idea matured last year into a field trial proposed to the army (still pending at Fort Huachuca, Arizona) to test if the method, operated by soldiers in the field, can find small things at shallow depths. Upon a successful test, the method will be hardened, produced and deployed for use.

Geophysics to the Rescue

Geophysical technology has been polished by a century of unforgiving scientific scrutiny. The question posed now is what geophysics can contribute to this new military challenge.

A first-order approach is apparent, given our knowledge, tools and expertise for subsurface imaging. But this time the search is not miles deep; no imaging targets are cleverly tucked under the sheltering wing of a salt body or complicated by rapidly and erratically varying physical properties. The targets are within range at least of a backhoe, if not a strong man with a shovel, buried under just a few predictable, understandable and discernable layers of young sediment. There is no need for supercomputers or expensive field-acquisition systems. No well-equipped, air-conditioned high-rise offices, no systems administrators and no legions of exceedingly qualified processing professionals are necessary.

Rather, a couple of soldiers in a Humvee lay out a line of geophones, fire a combat rifle into the ground for a high-resolution seismic source, push a few buttons on a laptop to answer the question "threat, no threat or not sure" and immediately act on feedback that can save their lives and those of their fellow soldiers.

Vaporware? Hardly

Delivering high-resolution, shallow subsurface imaging (subterranean target detection, in the nomenclature of the army) builds on well-honed expertise. Thriving in a mixture of hazy data, a century of experience, scientific conjecture and imagination, earth scientists peer underground using powerful technologies to reassemble contorted acoustic waveforms into coherent 2-D and 3-D images.

The early years of reflection and refraction seismology used guns and sledgehammers as high-frequency sources and short lines of geophones to record refracted energy through near-surface strata. Modifications of these early efforts, upgraded with modern computing and algorithms, are being adapted to IED detection, and the army has no shortage of rifles to serve as high-frequency seismic sources. As part of the Fort Huachuca pilot, geophysical contractors, led by an experienced government systems integrator, have been engaged to deliver the customized product, one that can easily be managed by soldiers in harsh or conflict-ridden environs.

The design calls for many small teams to quickly deploy the sensors. The rifle source is then fired, and equipment in the back of a Humvee captures the seismic records and performs preliminary data processing. The system must quickly and clearly tell the soldiers if there is an anomaly and, if there is, whether it has characteristics consistent with an IED threat. Threat characteristics would include depth of burial, proximity to roads, size and shape of the object and any anomalous density information that can be derived. (As an example, C-4, a type of plastic explosive, is about 25 percent less dense than moist sand, and a metal container filled with weapons will also show a positive density anomaly.)

If the result is an absolute positive detection, remedial and avoidance actions are initiated and the threat is averted and neutralized. If the result is an absolute negative, the unit moves on. In ambiguous states, more sophisticated measures must be invoked that could range from better processing of the data at the command center to ordering additional, more sensitive recordings, such as ground-penetrating radar. The challenges for sensor and software engineers are to make the system quick and easy to use in the field by non-experts and to calibrate the results so the recording team has to do only minimal interpretation. Only green, red or yellow lights (safe, dangerous, don't know) are necessary.

The data and processed results are transmitted to the command center, where they are continuously cataloged and integrated into a multidimensional composite and real-time management of the battle theater. The growing

A U.S. Army soldier surveys a damaged Humvee vehicle following a roadside bomb explosion in the Iraqi capital.

database of surveys, plus data from other sources (air photo, multispectral satellite, etc.), creates a full picture of the area, patched together piece by piece as new data are acquired. Each microsurvey adds to the collective knowledge of the world 10 meters below the soldiers' boots, just as exploration composites merge multiple 3-D data sets around oilfields.

In a report last July, *Business Week* likened this tactic to applying a "king-size stethoscope" to listen for both reflected and self-generated sounds, deployed in the field and operated by troops. Or as Paul Temple, a senior manager at Silicon Graphics Inc., told the *San Francisco Chronicle* in August 2005, "Instead of geophysicists using the technology, we want to make it soldier friendly. The intent is to take those sensors around an area of the battle space they consider hot, shoot an explosion and take the information to the Humvee."

These questions are simple compared to imaging a sub-salt trap. In a science where one's imagination and curiosity are the limiting factors, we are flush with sound, technological approaches to solving this IED problem. Reflection and refraction seismology are but two options that are being pursued. Refraction surveys have long been shown to be highly effective in delineating shallow features such as top of groundwater, tunnels and other man-made objects. In fact, discussions are well under way to adapt this same methodology to monitor the southern border of the United States, where a network of tunnels is known to exist (but details of their locations and extent are missing) to transport people and contraband into the country. Rather than stationing border patrol personnel randomly at known tunnel portals, this method maps the extent of the tunnels, listens for activity and alerts the patrol where to go to meet whoever is moving through them.

Other approaches come from gravity anomalies, such as the Falcon airborne gravity measurement system commercialized by BHP Billiton for detecting mineral deposits from magnetic surveys, and from already proven methods such as ground-penetrating radar for estimating clusters of shallow caves and tunnels. Advanced processing methods, virtual-team interfaces and other computational and communication methods that link people together around their data as they need it can augment the assimilation of these data in the command centers, where the operations are managed and planned.

Where Are the Challenges?

No one will deny that technical know-how in appropriate disciplines resides in our fields and laboratories. No one can deny that the energy industry has tackled some of the hardest problems we can conceive. The investments to develop the foundational technologies have been made. While this problem of real-time theater management comes with challenges of its own, they are small compared to the scientific innovations of our past.

But we also have a history of excruciatingly long lead times to popularize new technological breakthroughs. Our military, however, operates with a great sense of urgency, and although they are careful and certain in their decisions because lives do depend on them, they will accelerate progress and finalization as much as is possible.

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As implied in the *Business Week* and *San Francisco Chronicle* articles, the concept is under development by a few companies, and implementation options will be tested this year.

The significant hurdles that remain include adapting complex analysis to hardened, field-based systems run by unskilled personnel in hostile environments. We may also find, should our role in Iraq come to an end, that this vital research will again be abandoned and left unfinished.

The Payoff

Since the war began in March 2003, IEDs have accounted for at least 894 of the 1,735 military deaths by hostile fire and more than 9,200 of the more than 16,500 wounded, according to Pentagon figures through Jan. 21. Knight-Ridder reported in an article published last year that as of June 2005 more than half of the 255 American soldier deaths in the first six months of the year were from IEDs – roadside bombs among the most popular – up from 26 percent in 2004. These devices are getting cruder and more lethal, with many of them now composed of 155-millimeter artillery shells strung together. A top priority of the army is identifying and neutralizing what has become the biggest killer of troops. It is high time to complete the testing and start deploying subterranean target detection to save lives using our proven geophysical methods. The escalating impact of roadside bombs is an urgent cry to action, and action now – action that is uniquely in our hands. The tests that are under way should be accelerated to get version 1.0 to the field, with updates and upgrades on the development schedule.

The problem is evident. We have a solution. Let's get it done. ◆

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