Detecting Improvised Explosive Devices

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To help counter the improvised explosive devices (IEDs) used by insurgents in Iraq and Afghanistan, DoD has been developing improved systems to detect and neutralize buried IEDs and mines. For more than a decade, IDA has provided objective analyses of systems designed to detect buried objects as they were tested at various government sites. One of these systems recently completed a successful assessment in Afghanistan.

Detection Systems

The most mature sensors for mine and IED detection include metal-detector coils, infrared (IR) cameras, and ground-penetrating radars (GPR). Depending on the type and depth of the target, each of these systems has advantages and limitations.

- Metal detectors can detect targets deeper than a GPR can, but cannot reliably detect low-metal targets.
- GPRs can detect metal and low-metal targets, but do not perform as well against deeply buried targets.
- IR cameras can provide contrast between targets and the surrounding soil, but are ineffective during thermal crossover points (dawn and dusk).

Most GPRs designed to detect shallow targets work at frequencies between 200 MHz and 5,000 MHz. The lower frequencies allow radar energy to penetrate the soil, and the higher frequencies provide the resolution needed to discriminate targets from clutter. A response in the radar return depends on the contrast in dielectric properties of the target and the surrounding soil. Soil moisture plays a critical role in detection. It can enhance the contrast between the target and the soil, but can also hinder the radar waves' penetration of the ground, thereby degrading the GPR's detection capabilities.

Comparing different GPR systems has been a challenge because performance depends on factors such as target type, target burial depth, soil conditions, and algorithms. Ideally, competing systems should be tested side by side under the same conditions, though this is rarely achieved due to differences in program schedules. To help overcome this barrier, IDA developed software to compare the raw data collected from many GPR systems and compute performance metrics as a function of several key parameters. By using the raw data and building a graphic user interface (GUI) in which algorithms can be applied to the data one step at a time, we were able to compare different systems at the same processing point. This enabled separating sensor performance from total system performance.

Figure 1 shows the output of IDA's GPR sensor analysis tool when applied to three different developmental GPR systems. The target of interest was a plastic-cased low-metal anti-tank mine buried 1 inch deep. White pixels correspond to high ratios of signal to clutter, based on an IDA-developed metric. The data images are essentially bird's-eye views of the ground, with the x-axis corresponding to meters down-track and the y-axis corresponding to meters across-track. White arrows indicate the location of the target in the data. The data image generated by System 1 has the highest signal-to-clutter ratio. The target appears as a white ellipse of pixels. Using System 2, the target is visible as a smaller white circle, but there are many other white circles that give rise to false alarms. For System 3, the target is barely visible and appears only as a few faint pixels. System 1 was an early model of the GPR that would become the Husky Mounted Detection System (HMDS).

Comparing Performance

To conduct timely performance assessments of mine and IED detection devices, IDA developed the Mine and IED Detection Assessment and Scoring (MIDAS) tool. This suite of software computes detection probabilities, false-alarm rates (FARs), and

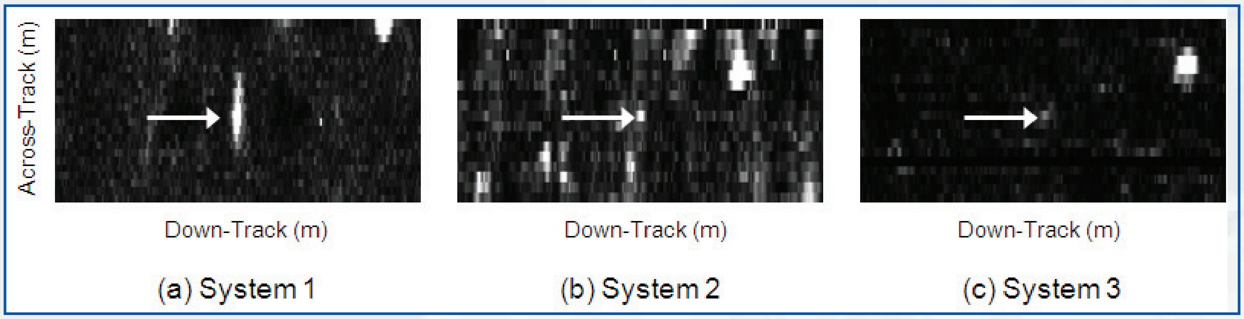

Figure 1: Outputs of IDA's sensor analysis tool for three developmental GPR systems.

system biases. It creates receiver-operating characteristic (ROC) curves as well. IDA researchers have participated in the HMDS Algorithm Working Group—where MIDAS is used to track algorithm improvements.

Figure 2 compares ROC curves for two different GPR systems. ROC curves show the trade-off between probability of detection (P_D) and false-alarm rate (FAR). Ideally, a system would provide a P_D of 1.0 and a FAR of 0 (corresponding to the top-left corner of the graph). System 1 performs far better than System 2. At a FAR of 0.001 m^{-2}, System 1 has detected nearly all the targets, but System 2 has detected only ~40% of them. ROC curves such as these are one of the primary measures our researchers use to assess the detection performance of mine and IED detection systems. In addition to comparing systems, ROC curves can shed light on performance as a function of target type and burial depth, as well as determine which algorithm is most effective.

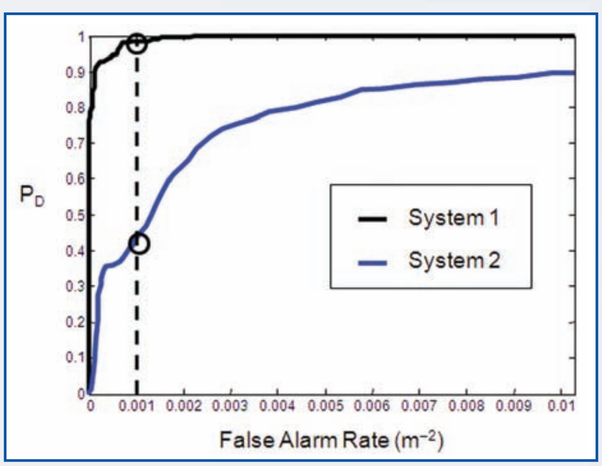

Figure 2: ROC curves for two GPR systems.

A Sample Test

Recently, HMDS was evaluated in Afghanistan. HMDS consists of a down-looking GPR designed to automatically detect buried mines and IEDs in roadways. Figure 3 depicts HMDS as deployed in Afghanistan. The 4-panel, 51-channel GPR is mounted at the front of a Husky vehicle, which has a V-shaped hull to deflect IED blasts. The vehicle's single occupant monitors a GUI within the cab while conducting route-clearance missions. The GUI provides real-time visualization of the GPR data, while an algorithm alerts the operator with an audio alarm if a target is detected. With the vehicle stationary and the GPR over the suspected target, the operator presses a button causing the marking bar to paint the ground over the target for the explosives ordnance disposal teams.

Before fielding, HMDS was tested to determine whether it was compatible with a set of jamming technologies that would ultimately operate in proximity to the GPR. IDA designed a test and used MIDAS to compare the detection performance as a function of separation distance between HMDS and the jamming systems. We analyzed the raw GPR data and developed metrics to determine if HMDS was being interfered with. IDA identified the minimum separation distance at which detection performance was unaffected by jammer noise. In addition, we found that the Husky vehicle itself provided significant shielding when the jamming system was following HMDS. By quantifying the effect, IDA provided the information needed to operate both systems optimally when they are used for route-clearance missions in Afghanistan.

Figures 4 and 5 show HMDS GPR data with and without jammer noise present. The black line in Figure 4 is the radar response in the absence of jammer noise. The x-axis can

Figure 3: HMDS in Afghanistan.

be thought of as depth, where for increasing time sample number, the radar is penetrating deeper into the ground. Other than the peak that occurs when the radar wave reflects off the ground, the response is flat. The blue line in Figure 4 is the radar response that occurs when the jammer is relatively close to HMDS. Note that the response in the presence of the jammer is not flat. Instead, the noise produces peaks and valleys in the GPR data. Our researchers used the standard deviation of the late-time radar response as a metric for determining the extent of noise in the GPR data. Figure 5 reveals what the radar effectively sees under the ground. Figure 5a corresponds to the case when no jammer was present, while Figure 5b corresponds to the case when a jammer was nearby. The ground response appears as a white-black horizontal band, and the target as an inverted hyperbola. The peaks and valleys of the blue line in Figure 4 appear as an alternating pattern of light and dark pixels in Figure 5b. The noise caused by the nearby jammer is primarily confined to channels 1–12 in the HMDS data. The responses in channels 13–50 are largely unaffected by the jammer due to the Husky's aforementioned shielding effect, on which the GPR is mounted.

IDA continues to support the ongoing assessment of HMDS as soldiers use it to clear roadways of mines and IEDs. Data collected in theater and sent back to the United States are being analyzed so that the system can be improved. For example, we are now examining why the system's false-alarm rate is higher in theater than in tests in the United States.

Summary

The IED defeat challenge has existed since makeshift land mines and explosive booby traps first came into use. Today, IEDs are

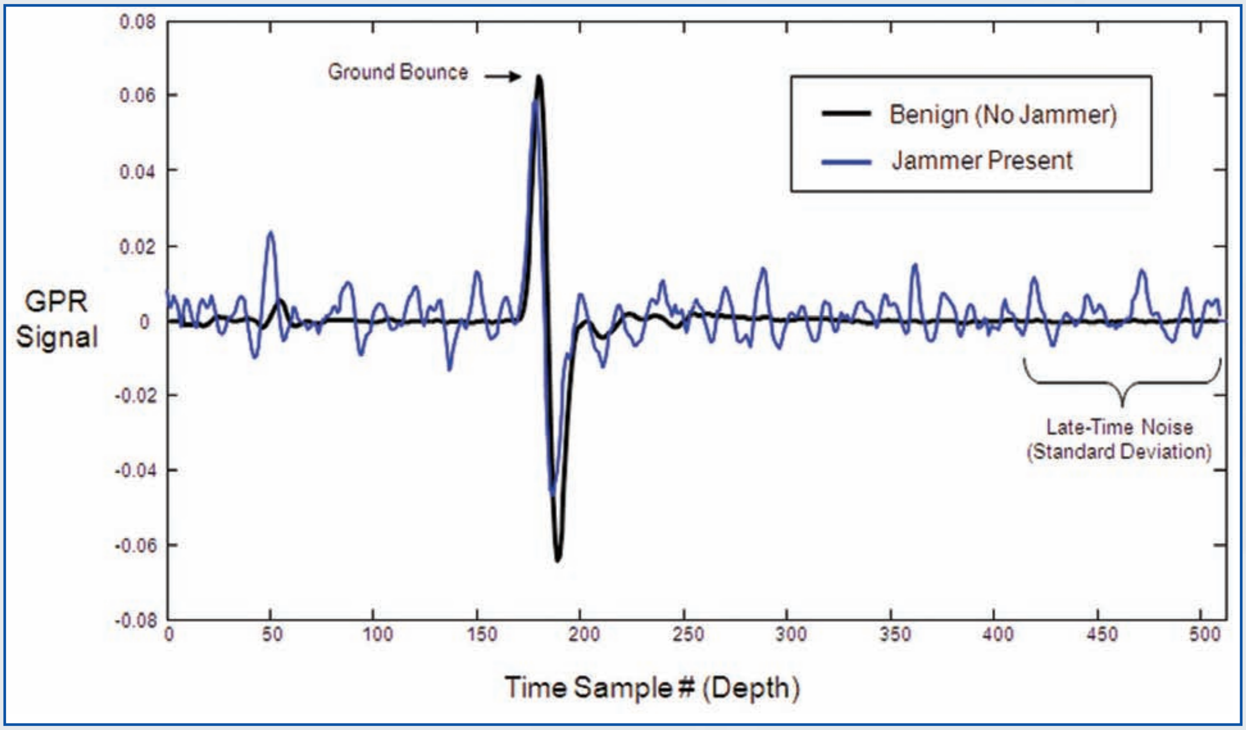

Figure 4: HMDS GPR data, radar response.

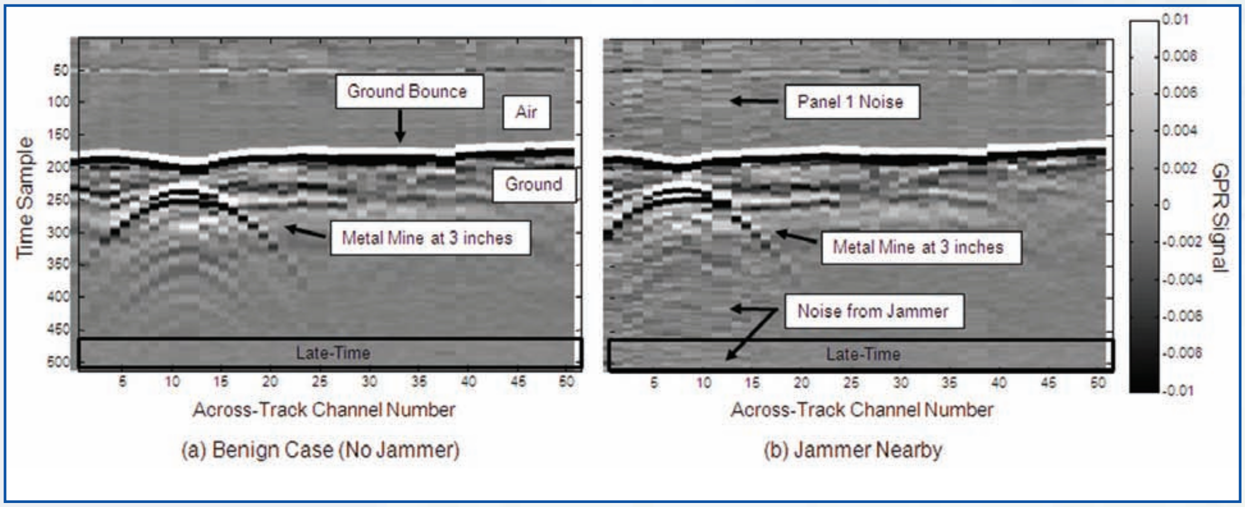

Figure 5: HMDS GPR data, radar response.

used regularly by insurgents, and grow more sophisticated and more dangerous each year. The IED war is one of constantly changing tactics, technologies, and countermeasures in which neither side keeps an advantage for long. Sustained, rigorous, independent, and timely analyses are required to continue improving U.S. troops' capabilities for detecting mines and IEDs. Our researchers help provide that analytical capacity.