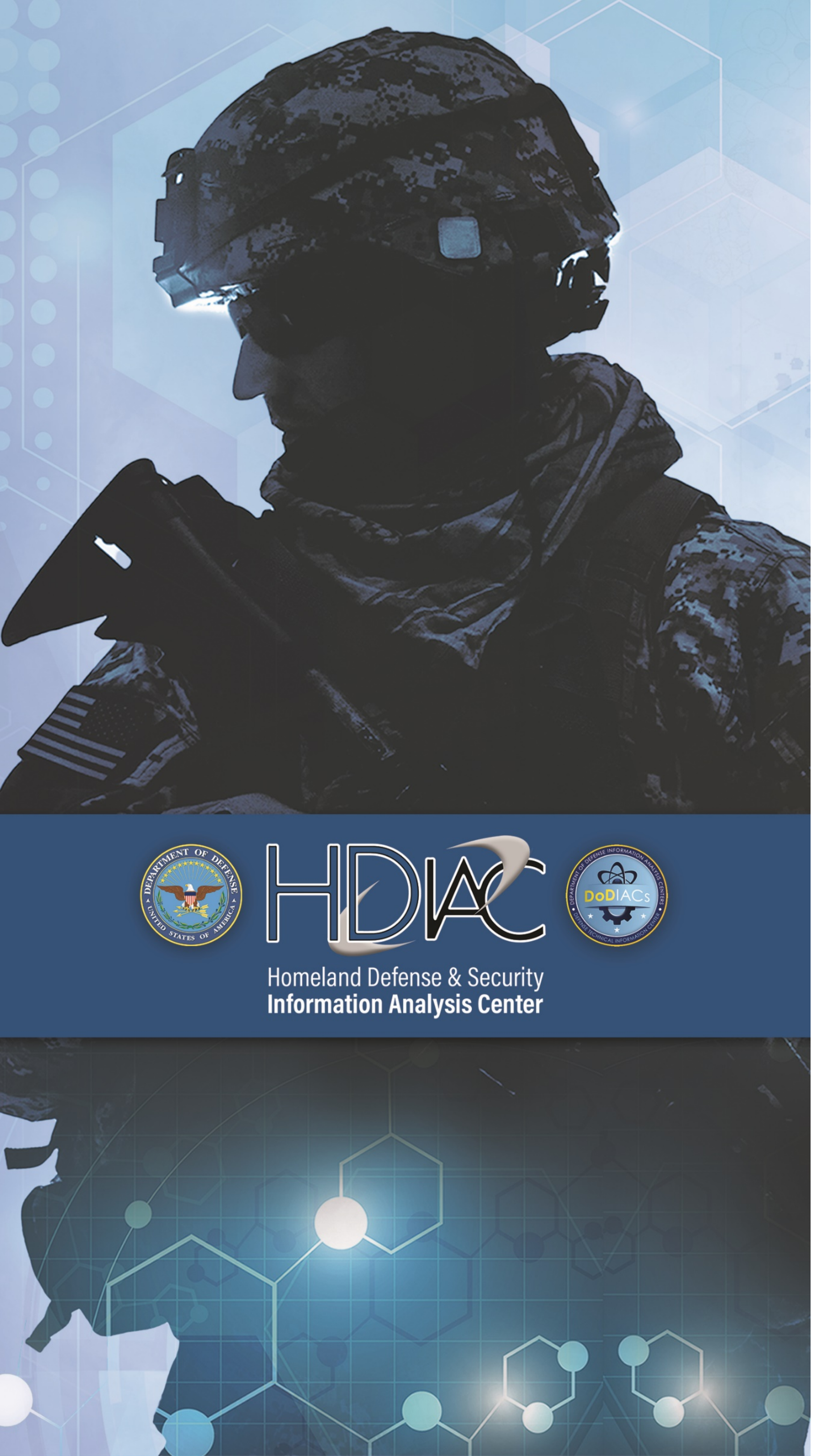

Technical Inquiry 2018-3691

Developed by:
HDIAC
104 Union Valley Rd
Oak Ridge, TN 37830

HDIAC Contract Number:
FA8075-13-D-0001

Distribution A: Approved for public release. Distribution unlimited.

Overview

A member of the Joint Improvised-Threat Defeat Organization requested information concerning technologies for the detection and identification of improvised explosive devices (IEDs) along the surf zone using autonomous or semi-autonomous means.

HDIAC analysis revealed a method of surf-zone IED detection through integration of several existing technologies. This novel design is the most promising solution, as no formalized technology capable of surf-zone IED detection currently exists.

The solution conceptualized by HDIAC Analysts and Subject Matter Experts enhances the onboard ground penetrating radar (GPR) of an existing rotary UAV IED detection (RUIED) system to facilitate imaging through water and/or sand. Enhancements accomplished with varying GPR frequencies via signals processing algorithms enable the identification of objects concealed at various depths in sand and/or water in the surf zone. Additionally, applying convolutional neural networks (CNNs) to GPR images obtained from the modified RUIED system would allow for IED detection in an autonomous or semi-autonomous manner.

RUIED System

Engineers at the University of Massachusetts Lowell (UML) demonstrated their RUIED system for accurate subsurface IED detection up to 10 cm below the surface. This system utilizes surface electromagnetic (EM) reflectivity obtained through a GPR system.

This GPR system utilizes processed measurements at multiple frequencies, relative elevations, line-of-sight angles, and signal polarizations with multiple synthetic aperture radar (SAR) algorithms. Figures 1 and 2 demonstrate the imaging of a ground sample detected through gravel and rock at depths between 7.5 and 15 cm. For imaging beyond 10 cm, RUIED produced lower object resolution. However, UML engineers note that further refinement and development of the SAR processing algorithms will clean up the multiple scattering present at depths beyond 10 cm [1].

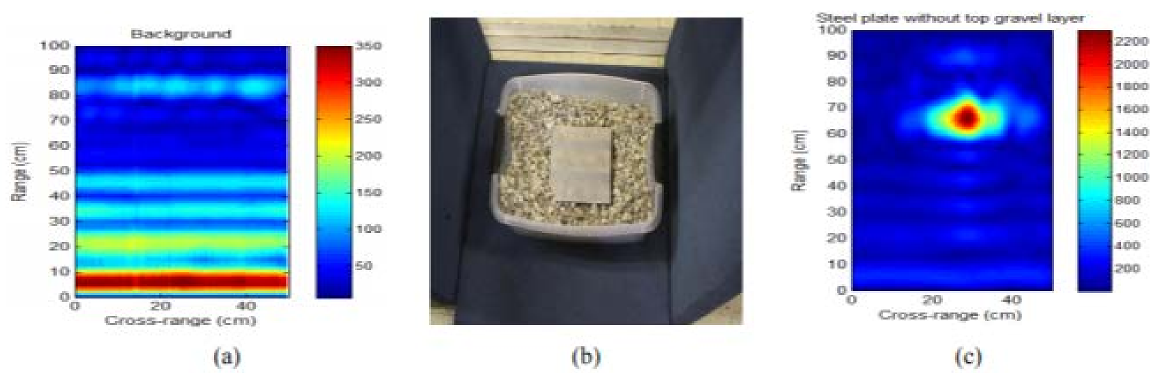

Figure 1: (a) Background without target; (b) Metal target on ground sample; (c) SAR imaging of the scanning area [1].

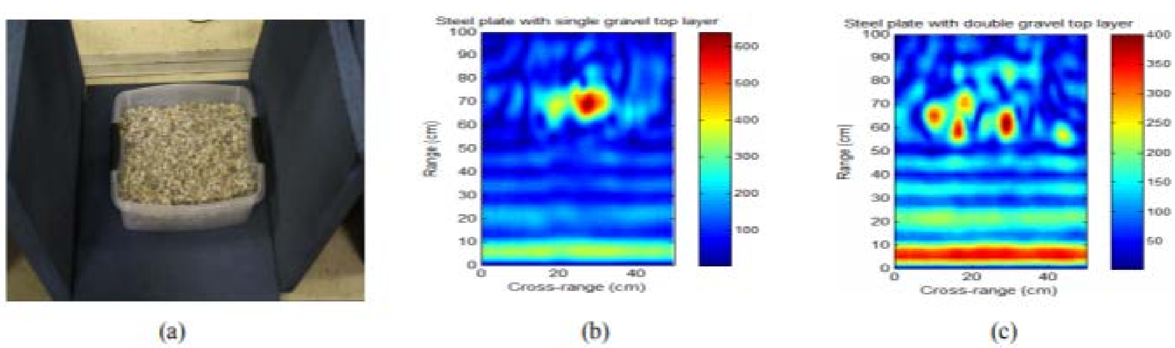

Figure 2: (a) Target buried with ground sample; (b) SAR imaging when the target is buried at 7.5 cm depth; (c) SAR imaging when the target is buried at 15-cm depth [1].

Figure 3 provides images of the RUIED prototype.

Figure 3: Full-scale RUIED prototype under operation [1].

Signals Processing for GPR Imaging through Water and/or Sand

While UML's RUIED platform was developed specifically for IED detection in a roadside setting, GPR has verifiable success in mapping underwater topography and sub-sediment regions. As early as 2000, the U.S. Geological Survey (USGS) demonstrated GPR as a suitable method for generating accurate subsurface maps from above the surface of a river [2]. Figure 4 demonstrates a selection of the findings from the USGS experiment.

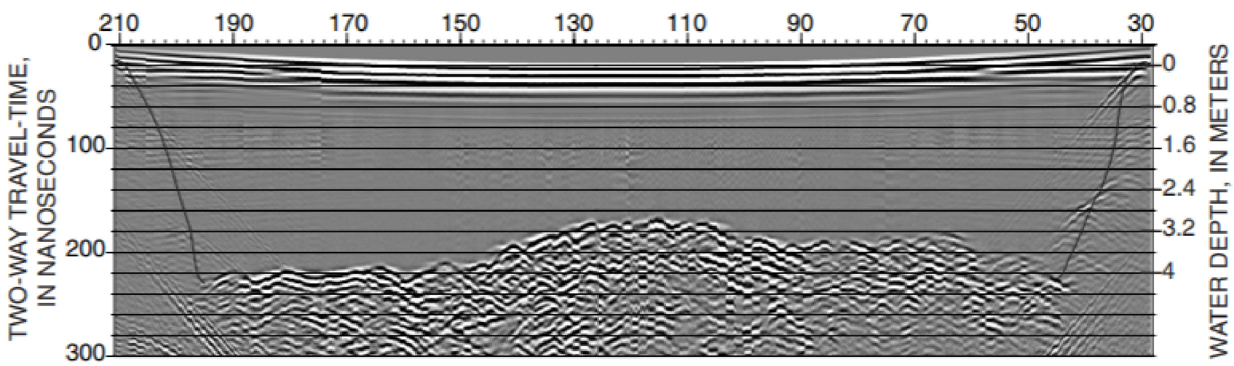

Figure 4: Ground penetrating radar river-bottom reflection record collected across the Skagit River, Mount Vernon, WA (USGS Stream gaging station 12000500). Processed data after filtering and static trace shifting [2].

However, GPR imaging of surface level IEDs (a few inches below the surface) requires vastly different frequencies than riverbed topography imaging. To resolve this challenge, the proposed detection system would employ a signals processing method for scanning at different frequencies, similar to a system by researchers at the University of California, Santa Cruz (UCSC).

UCSC researchers used an, "optimization problem solver, the Expectation-Maximization Algorithm, to define the weights to be used to combine multiple GPR frequency scans over the same target area [3]." This approach allows for "cleaner" GPR imaging across the surf zone, where the through-imaging substance (whether gravel, sand, or water) varies [3].

IED Characterization Methodologies

The final element of the proposed surf-zone IED detection platform is a method to identify IEDs from GPR data. This crucial component would limit false positives for the modified RUIED system that would otherwise result from various objects in the surf-zone, such as rocks or debris shaped like IEDs. There are two methodologies for IED characterization available that, when combined, fill this gap.

Cross-Section GPR Imaging for IED "Profiling"

The first method, recently developed by researchers at University College London (UCL), distinguishes IEDs from naturally occurring objects by creating a standardized IED "profile" from a cross-sectioned GPR image. For surf-zone IED detection, the key difference between an IED and a naturally occurring object (like a large rock or piece of driftwood) is that natural objects are solid, dielectric items that do not house the electronic components needed in an IED. While a top-down, non-cross-sectioned GPR image of an object cannot always distinguish an IED from another object, a cross-section of the GPR image can verify the presence of internal assemblies within a target object for the characterization of an IED [4].

Characterization Using Convolutional Neural Networks (CNN)

This second method from researchers at the Polytechnic University of Milan uses CNN, a deep learning algorithm, "for the analysis of GPR B-scans (i.e., 2D images of vertical underground slices) [5]" to identify IEDs. This approach reliably identifies objects of interest with 85-95 percent accuracy after training only on "synthetic" GPR B-scans [5]. This methodology could enhance the cross section GPR imaging method described above, "training" it in the accurate differentiation of IEDs from naturally occurring objects and facilitating the autonomous or semi-autonomous characterization of IEDs in the surf zone.

Conclusion

While no comprehensive solution for surf-zone IED detection was discovered, HDIAC identified various components that, when integrated, function as a platform for autonomous or semi-autonomous IED detection in a surf-zone. This platform consists of a RUIED system modified with Expectation-Maximization Algorithm for GPR scanning at multiple frequencies, coupled with either a cross-section imaging approach or CNN analysis of GPR data for IED identification and characterization.

Development of this system is available through an HDIAC Core Analysis Task (CAT). Such a task would identify requirements for integrating these existing components into a fully functional and robust system. This task would also address challenges related to the integration of cross-section GPR images and CNN algorithms for IED characterization and differentiation from naturally occurring objects. Finally, it would develop, test, and evaluate a prototype and develop solutions for ruggedizing a modified RUIED, optimizing appropriate flight paths, ranges, and speeds to facilitate suitable coverage for IED detection and identification.

We request your feedback on this Inquiry: www.hdiac.org/inquiry assessment form

References

1. Qin, Y., Twumasi, J., Le, V., Ren, Y., Lai, C., & Yu, T. (2016, May). Roadside IED detection using subsurface imaging radar and rotary UAV. SPIE Defense and Security. doi:10.1117/12.2223445
2. Haeni, F., Buursink, M., Costa, J., Melcher, N., Cheng, R., & Plant, W. (2000, April). Ground-penetrating radar methods used in surface-water discharge measurements. Paper presented at GPR 2000: The 8th International Conference on Ground Penetrating Radar. doi:10.1117/12.383618
3. Tilley, R., Sadjadpour, H., & Dowla, F. (2017). Combining ground penetrating radar scans of differing frequencies through signal processing.
4. Lombardi, J., Griffiths, H., & Balleri, A. (2018, April). Landmine internal structure detection from ground penetrating radar images. *2018 IEEE Radar Conference (RadarConf18)*. doi:10.1109/RADAR.2018.8378733
5. Lameri, S., Lombardi, F., Bestagini, P., Lualdi, M., & Tubaro, S. (2017, September). Landmine detection from GPR data using convolutional neural networks. *2017 25th European Signal Processing Conference (EUSIPCO)*. doi:10.23919/EUSIPCO.2017.8081259