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14. ABSTRACT

Through this DURIP project we have successfully purchased an advanced GPR imaging system. A variety of test data sets illustrating the multi-channel capabilities of the radar as described in our proposal have been collected (e.g., 3D, multi-offset, multi-frequency, and multi-component imaging). The results of these initial trials were presented in a poster at the NovCARE conference in Cape Cod last spring (Mangel et al., 2011). Over the 2011 summer we also began a collaboration with the University of Wisconsin-Madison to evaluate applications of the

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Report Title

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Through this DURIP project we have successfully purchased an advanced GPR imaging system. A variety of test data sets illustrating the multi-channel capabilities of the radar as described in our proposal have been collected (e.g., 3D, multi-offset, multi-frequency, and multi-component imaging). The results of these initial trials were presented in a poster at the NovCARE conference in Cape Cod last spring (Mangel et al., 2011). Over the 2011 summer we also began a collaboration with the University of Wisconsin-Madison to evaluate applications of the new GPR system to hydroecology. In addition to advancing basic research, this collaboration has been funded by CUAHSI (Consortium of Universities for the Advancement of Hydrologic Sciences, Inc.) to promote the use of geophysics within the hydrologic community and therefore advances our goals to demonstrate the GPR system as a flexible and powerful tool for academic research. We are currently analyzing the data obtained from two field visits conducted over the summer and expect a paper to be submitted from the work late this fall. We are also beginning to integrate the system into a variety of other projects and teaching activities, including a research project currently funded by the ARO Terrestrial Sciences Program.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Mangel, A.R., K. Robertson, and S.M. Moysey, 2011, Applications of multi-channel GPR data collections at field scales, NovCare Conference, Cape Cod, MA, May.

Number of Presentations: 1.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See Attachment

Technology Transfer

Final DURIP Project Report
Project #W911NF1010365
Project PI: Stephen Moysey, Environmental Engineering & Earth Sciences, Clemson University
Project Title: *A real-time, 3D GPR monitoring system to support basic research for subsurface detection and characterization in complex environments*

Summary
Through this DURIP project we have successfully purchased an advanced GPR imaging system. A variety of test data sets illustrating the multi-channel capabilities of the radar as described in our proposal have been collected (e.g., 3D, multi-offset, multi-frequency, and multi-component imaging). The results of these initial trials were presented in a poster at the NovCARE conference in Cape Cod last spring (Mangel et al., 2011). Over the 2011 summer we also began collaborating with researchers the University of Wisconsin-Madison to evaluate applications of the new GPR system to hydroecology. In addition to advancing basic research, this collaboration has been funded by CUAHSI (Consortium of Universities for the Advancement of Hydrologic Sciences, Inc.) to promote the use of geophysics within the hydrologic community and therefore advances our goals to demonstrate the GPR system as a flexible and powerful tool for academic research. We are currently analyzing the data obtained from two field visits conducted over the summer and expect a paper to be submitted from the work late this fall. We are also beginning to integrate the system into a variety of other projects and teaching activities, including a research project currently funded by the ARO Terrestrial Sciences Program.

Equipment Purchased
The equipment purchased on this project was the same as that described in the proposal, with the exception of the additional purchase of an off-road vehicle (Kowasaki Mule) to be used as a mobile platform for the system. The purchase of the off-road vehicle was possible because we were able to negotiate a reduced price for the GPR system. Details of the purchased system components are given below.

<u>*Component #1: GPR system*</u> *(Sensors and Software)* – this is the main portion of the system that allows for all radar imaging capabilities. Subcomponents purchased as part of the system include:

- pulseEKKO pro gpr (control unit + multi-channel adapter)
- 7 x 500 MHz receivers
- 4 x 500 MHz transmitters
- 1 x 1000 MHz receiver
- 1 x 1000 MHz transmitter
- 1 x low frequency receiver (maintains compatibility with older PE100 antennas)
- SPIDAR network interface controller
- assorted cables, adapters, software, and an odometer wheel

<u>*Component #2: Robotic Total Station TCRP 1201+*</u> *(Leica Geosystems)* – the robotic total station provides precise positioning of the antennas during GPR data collection. Currently we are able to collect positioning data during GPR surveys and merge them into the data during post-processing. A remote for the total station was also purchased that will allow us to merge the position information into the GPR data stream in real-time as the data are collected. We will integrate this capability into the overall system over the coming year.

<u>*Component #3: System Platform*</u> – a small off-road vehicle (Kowasaki Mule) was purchased to allow the system to be deployed over larger-scale areas than would have been possible hand-towing the radar. Over the next year we plan to develop a mounting system for the antennas on the vehicle.

Enhancement of Research & Teaching Capabilities at Clemson

Tests of System Capabilities

We have undertaken a variety of field surveys to test the new GPR imaging system. A typical tow deployment for the system with an 8 antenna configuration is shown in Figure 1. For many applications, accurate estimation of radar wave traveltimes is essential, but through our experiments we have found that the system does not always provide consistent or accurate absolute traveltimes. We have therefore developed a free-air calibration procedure that allows for simultaneous correction of all channels in the system. Since acquiring the system last winter, we have successfully completed demonstrations including 3D reflection imaging (Figure 2), multi-offset profiling (Figure 3), multi-component (polarization) profiling (Figure 3), and multi-frequency profiling (not shown). The system has therefore met performance expectations in terms of providing a wide variety of imaging modes.

Figure 1: The GPR deployed in tow-mode in Wisconsin (left). Demonstration of free-air calibration procedure we have developed to increase traveltime accuracy.

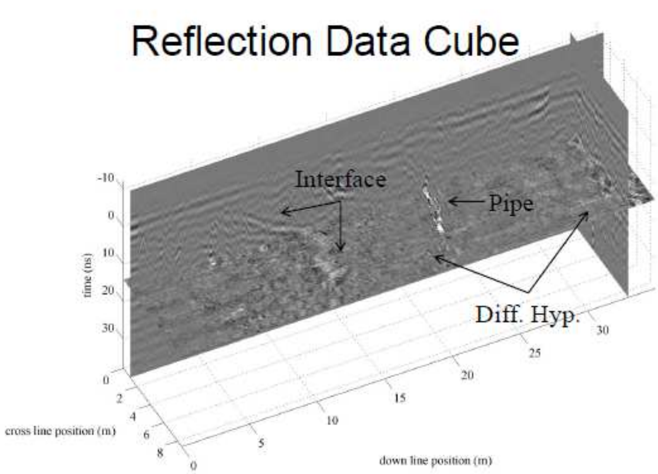
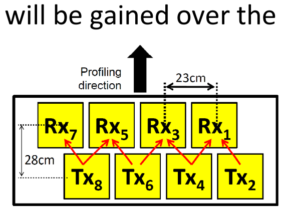
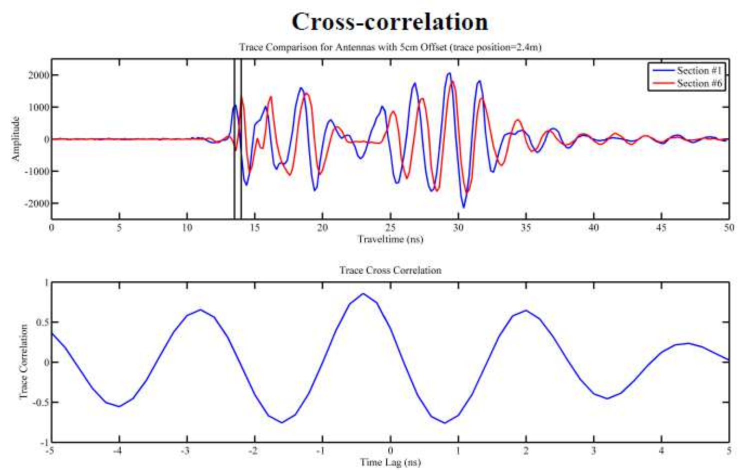


Figure 2: Example of data collected from a 3D imaging survey (left) using the antenna array geometry shown below. These data, which consist of 87,500 traces, were collected over a ~30m x 8m area in 40 minutes, which is a substantial reduction in time compared to single channel imaging. This particular survey was completed without using the robotic total station, so further improvements to survey efficiency will be gained over the next year.



Antenna array – Rx=receiver, Tx=transmitter

Figure 3: Example of traces collected using the multi-offset antenna array shown below. The shift in travel time between the traces (upper figure) can be evaluated quantitatively using cross-correlation (bottom figure). As a result, we expect that we will be able to automate the analysis of multi-offset data collected along profiles to generate high-density cross-sections of wave velocity.



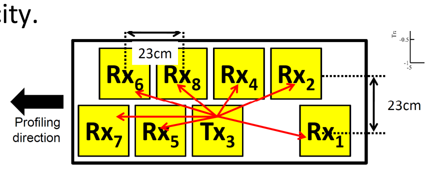
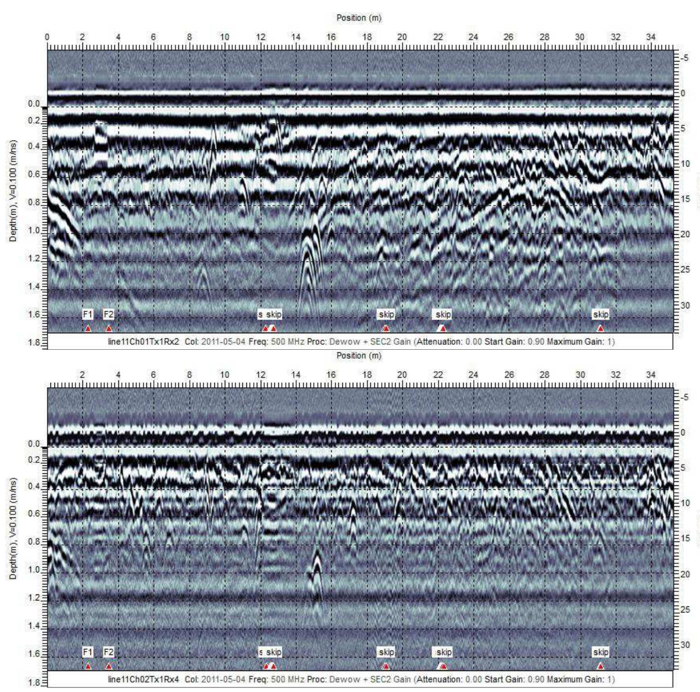
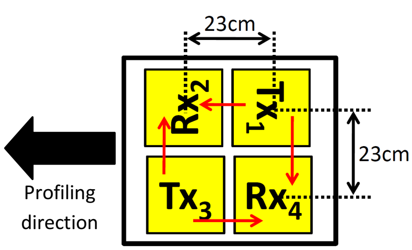


Figure 4: Examples of data collected in multi-component polarization mode (antenna array shown below). Note that both sections were collected simultaneously, but emphasize different features because of differences in geometry between incident waves and target objects. Full multi-component data is likely to be particularly useful for improving classification of difficult targets.





ARO Funded Research – Improved Landmine Classification

We have begun integrating the new system into our automated GPR imaging system, which is being used in a project currently funded by ARO Terrestrial Sciences Program. The objectives of that project are to improve landmine classification algorithms by accounting for changes in hydrologic state during operational detection and classification efforts. The new system will allow for improved integration of the GPR with the motion control system developed in that project to automatically collect data. We also anticipate that we will be able to use the multi-channel imaging capabilities of the new GPR to enhance 3D data collection speed during dynamic wetting events.

CUAHSI Funded Research - Use of GPR in Ecohydrology

We have received funding from CUAHSI (Consortium of Universities for the Advancement of Hydrologic Sciences, Inc.) to evaluate and promote the use of multi-channel GPR in hydrology. Specifically, we are investigating the potential of the system to map water content variations at a restored stream site that plays an important control on the evolution of plant communities. The current hypothesis at the site is that variations in water content are controlled by localized changes in soil structure that decrease the upward movement of groundwater to the root zone, thereby leading to enhanced drying of the soils in these regions. Variations in water content are already being monitored by the heat-pulse method along a distributed temperature sensor (DTS) transect. We chose to test the GPR at this site to provide additional spatial data to assess the posed ecohydrologic hypothesis, while simultaneously allowing us to compare the GPR versus DTS data. We have conducted two field trips to the site to collect data under seasonally wet and dry conditions and are currently processing the data.

Teaching Enhancement – Archeological Geophysics

During the spring of 2012 the new GPR system and data generated from it will be used to enhance undergraduate and graduate teaching in the course GEOL409/609 – *Environmental and Exploration Geophysics*. The radar will be deployed in the lab portion of the class to give students hands-on experience with multi-channel GPR. We are currently planning that some of these lab sessions will be held in conjunction with the Field Methods course for archeology majors taught by Dr. Melissa Vogel, thus also exposing a new generation of archeologists to subsurface imaging technology.

Research presentations produced by this project:

Mangel, A.R., K. Robertson*, and S.M. Moysey, 2011, Applications of multi-channel GPR data collections at field scales, NovCare Conference, Cape Cod, MA, May.