Non-Destructive Evaluation after Destruction: Using Ground Penetrating Radar for Search and Rescue.

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Abstract

Ground penetrating radar (GPR) has been used both for non-destructive evaluation (NDE) and for search and recovery for many years. However, dragging antennas over unstable surfaces to locate buried objects or victims is always difficult and sometimes risky. This new device makes non-destructive search and *rescue* possible by leaving the antenna stationary, thus making the least motions detectable through several meters of concrete.

The innovation has been in the areas of clutter reduction through hardware and software improvements and in advances in automated target detection. False detection rates in real-life situations are constantly being evaluated, but in "rubble pile" tests and simulations, the True Positive / False Negative results are currently about 90% / 5% in over 200 tests of varying degrees of difficulty. The low false positive rate is significant. Rescuers have stated that one key benefit of this device is not only its ability to locate life, but also its ability to declare an area fallow, so that they can move on to more likely locations. Since time is always critical, negative information is just as important as positive information. Non-destructive evaluation of destroyed civil structures using GPR is proving its effectiveness in this niche application.

Résumé

Le radar pénétrant (GPR) a été utilisé pour l'évaluation non destructive (NDE) et pour la recherche et le rétablissement pendant beaucoup d'années. Cependant, traînant l'excédent d'antennes des surfaces instables pour localiser les objets ou les victimes enterrés est toujours difficile et parfois risqué. Ce nouveau dispositif rend la recherche non destructive et la délivrance possibles en laissant l'antenne stationnaire, de ce fait faisant aux mineurs des mouvements traversant discernable plusieurs mètres de béton. L'innovation a été dans les domaines de la réduction d'image de fond par des améliorations de matériel et de logiciel et dans les avances de la détection automatisée de cible. Des taux faux de détection dans des situations réelles constamment sont évalués, mais dans des essais et des simulations « de pile de blocaille », véritables résultats négatifs positifs/faux sont actuellement environ 90%/5% dans plus de 200 essais des degrés variables de difficulté. Le bas taux positif faux est significatif. Les sauveteurs ont déclaré qu'un avantage principal de ce dispositif est non seulement sa capacité de localiser la vie, mais également sa capacité de déclarer une jachère en secteur, de sorte qu'ils puissent passer à des endroits plus probables. Quand le temps est critique, l'information négative est comme importante juste que l'information positive. L'évaluation non destructive des structures civiles détruites employant GPR prouve son efficacité dans cette niche application.

Keywords

GPR, RUBBLE, BUILDING COLLAPSE, AVALANCHE.

2 Introduction

Non-destructive GPR surveys of concrete are usually planned over coffee. The site is typically a smooth, stable surface with well constrained depths in homogeneous media. The data are often taken back to a lab for processing and evaluation, so that data can be presented and a solution proposed.

After an earthquake has destroyed these structures, however, none of these methods will work. The altered conditions require a different set of real-time tools, usually involving rescue dogs and thermal cameras, and now for the first time, GPR. New developments have shown that GPR is a robust tool in the non-destructive evaluation of structures destroyed by earthquake, avalanche, mud-slides etc. for the purpose of search and rescue. Whereas a normal GPR survey might move an antenna over a bridge to create a map of the structures beneath, this new application leaves the antenna motionless on a collapsed bridge in order to locate anything that moves underneath. GPR, typically used to prove structural safety, now is being used to probe unsafe structures for the purpose of safe rescue.

Search and recovery (not search and rescue) has been a niche application for GPR over its 40+ year history. [1][2] GPR has often been used to isolate regions of interest for recovery of human remains after a disaster. [3]

Unique properties of GPR make it an effective tool in the rescuer's arsenal looking for living victims as well. [4][5] Its low frequency penetration permits detection of faint chest-wall motion through meters of rubble. GPR does not get tired, it does not need silence, and it does not rely on line-of-site detection. If a rescue dog finds a scent, the smell may have traveled dozens of meters from the actual victim, who may not even be alive. A GPR locator looks specifically for life, via breathing or motion, and then reports the depth to the victim within seconds for teams to start the rescue.

And of course one of the most important benefits of the GPR locator is its ability to non-destructively locate. Using a pole or other means, a sensor can be placed atop an unstable structure without risk to the rescue team or victim. The operator can stay a safe distance, using a PDA to control several sensors wirelessly, up to 100m away.

How well things work in theory and in practice are always two different questions. The purpose of this paper is to collect and present the results of lab tests and real-life usage so far. Since nothing has yet been presented on this new technology, it might be helpful to evaluate the efficacy of a GPR Search and Rescue locator and to present shortcomings in need of improvement.

3 Test Methods

Successful detection of trapped victims under rubble depends on a huge assortment of variables. They can be classified in five main categories:

1. *Signal generated by the victim*: large or small motion, hyper vs. hypo-ventilation rates.
2. *Attenuation through the debris pile*: wet/dry/mud conductivity variations, metal rebar density, air pocket size and configuration.
3. *External Noise*: walkie talkie interference, grass/tree/human motion detected behind the antenna despite shielding.
4. *Internal Noise*: Effectiveness of shielding, "quietness" of electronics, bit depth, filter choices.
5. *Algorithm performance*: The ability of the detection algorithm to pull signal out of the noise.

In order to constrain these variables, most preliminary testing required repeatable conditions, like a "standard" person walking toward and away from the antenna in the same hallway, or sitting motionless in a chair, breathing at different distances from the antenna. A few examples of these methods are given in sections below. A faraday cage was built to help in quality control during production.

Thousands of tests have been performed that have helped steadily improve detection performance. Figure 1 shows the main departure from traditional GPR that makes it work. The standard image on the left appears uninteresting until background removal reveals a person walking toward then away from the antenna four times. This is the starting point for detection. But unless that antenna hardware is unusually quiet, all smaller motions will become buried in noise.

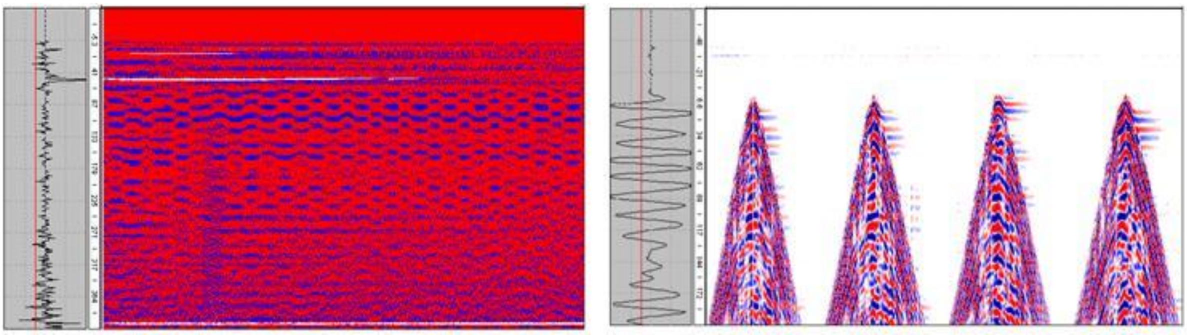

Figure 5. *Typical GPR B-Scan on the left and after background removal on the right.*

3.1 Equipment Tested

The Search and Rescue tools that were tested are developed by Geophysical Survey Systems Inc. (GSSI) and distributed by UltraVision Security Systems Inc.. It essentially packages a 270MHz center frequency GPR antenna together with the controller boards and wireless antenna needed to operate it from a PDA.

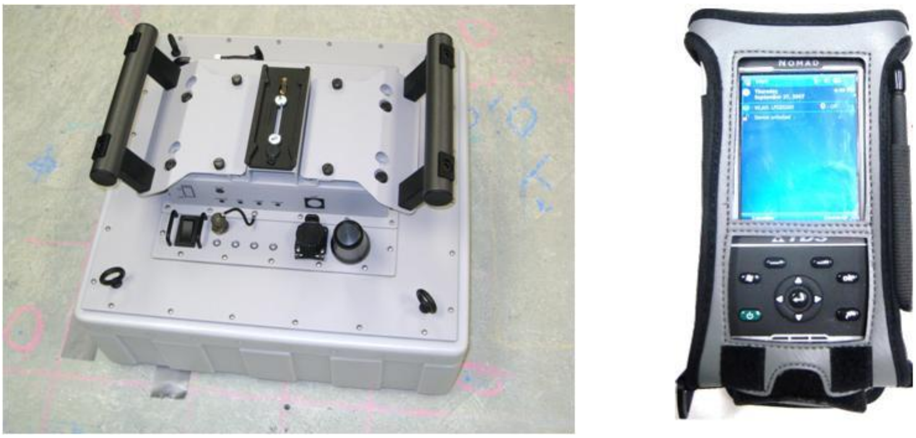

Figure 2. *A Search and Rescue locator with the PDA controller.*

3.2 Movement Tests in Air

If background removal is too long, previous motion gets smeared into future scans. This is especially visible when turning and moving away from the antenna, as can be seen in Figure 1. The smearing effect from long background removal times need to be cleaned up either by an active filter, or by "intelligently" ignoring them in the detection algorithm. As one might expect, the pitfall with selecting a short background removal is that slow or slight motions would get attenuated into extinction.

3.3 Breathing Tests in Air

A separate detection method is used to detect breathing, which needs to be 1000 times more sensitive. This method uses a horizontal Fourier transform to look for breathing frequencies. Figure 3 shows someone sitting still at 2,3,5,7 then 8.5m from the antenna in air. Detection confidence is 100%, dipping only when the chair is moved each time.

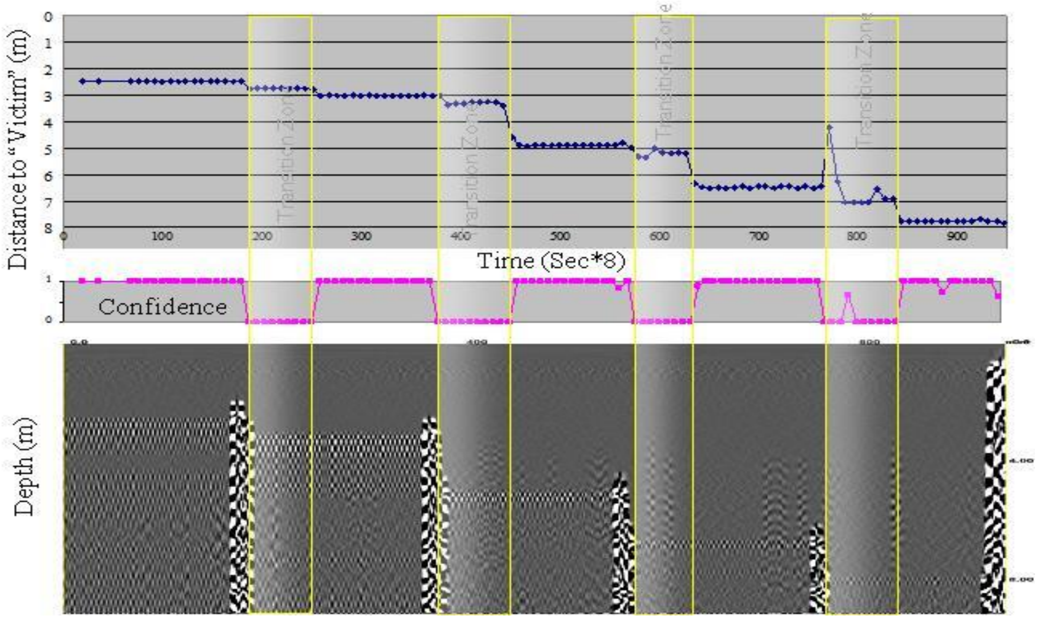

Figure 3. *Upper plot shows the breathing detection distance vs. time. Note a detection lag of about 10 seconds even after the target has moved his chair further away. Lower plot shows detection confidence between 0 and 100%.*

Figure 4, however, shows a similar test, but with the antenna against a solid block of 30cm concrete. Walkie talkie noise was added to demonstrate the problems it can cause. Detection was clean through 5 meters, but false detections increase with added distance and noise.

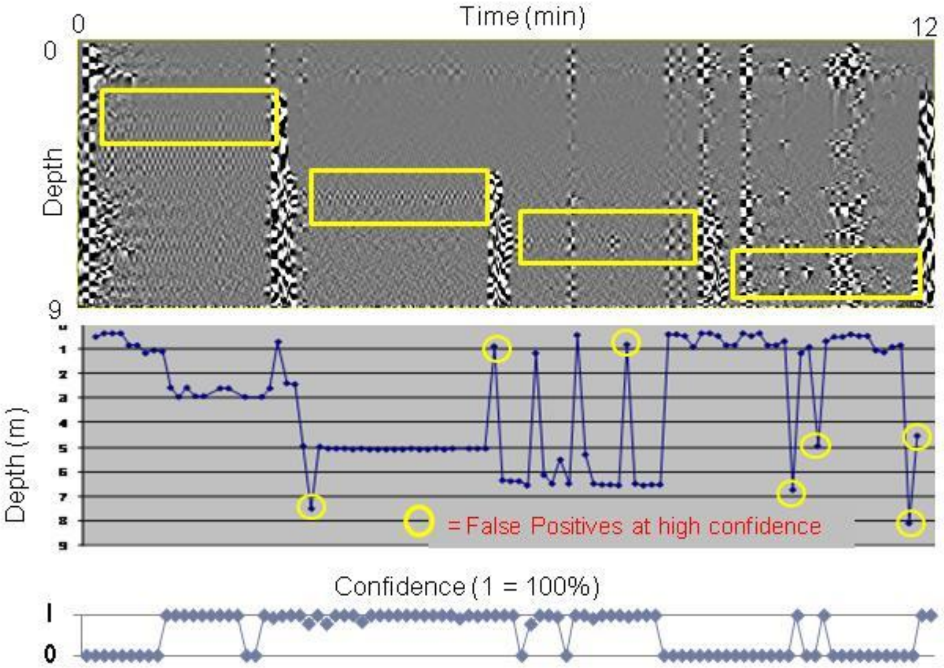

Figure 4. *More difficult conditions create problems for breathing detection. Note the general increased clutter as well as the walkie talkie burst noise on the right.*

3.4 Motion/Breathing in Rubble Piles

A solid concrete slab is not a rubble pile. This may actually be a good thing, since the antenna cannot always lie flat against a surface, and air gaps actually make signal paths easier.

Figure 5. *Different test in debris piles around the world can only simulate the conditions one might find in an actual emergency. These tests in debris piles used to train dog sniffing teams. The "breathing dummy" was helpful in repeatability testing. The device could successfully detect breathing in both locations.*

The equipment has been tested extensively in debris piles by teams in the US, Japan, China, Israel and Africa. Feedback has been collected by Search and Rescue teams from several of these sites in addition to our own testing at Federal Emergency Management Agency (FEMA) sites in Massachusetts and Virginia (Fig. 5). Results have been encouraging.

Table 1*: Test results of motion under concrete slabs in a debris pile.*

	20cm concrete slab 1.5m away		20cm concrete slab 3m away		25cm concrete slab 4m away	
Results	# Tests	%	# Tests	%	# Tests	%
True Pos	46	96%	67	87%	44	88%
False Pos	1	2%	7	9%	6	12%
False Neg	1	2%	3	4%	0	0%

One series of motion tests (Table 1) shows a detection success rate of about 90%. In this test through concrete slabs, the detection limit was found to be at 4m through 1m of rebar re-enforced concrete. Noise tests determined that interference from gas generators was acceptable at distances greater than 5m, cell phones at 8m and 2-way radios at 30m. Subsequent noise cancelling software improvements have cut these distances about in half.

Testing from day to day is not always repeatable due to weather or "noise". Arms waved might have a completely different radar cross section depending on travel path, moisture content, body size etc. And if variability under such controlled conditions proves difficult, imagine trying to accurately assess results from a real situation, especially since most of the anecdotal information may come from users poorly trained to recognize such problems.

4 Real Search and Rescue

Of course we are fortunate that there is not more real-life data to draw from, but at least two cases have been reported of use in emergencies.

4.3 Kenya Building Collapse, Jan 2006

The team arrives after 17 hours to find no signs of life. Although they could locate workers through three walls 8m away, the results are inconclusive. There were no false positives, but no survivors were located either. [6]

4.4 SzeChuan Earthquake, May 2008

Immediately after the earthquake, several LifeLocators were brought by fire departments around China. Over 50 rescues have been confirmed using the radar. [7][8] Most reports are vague, but on May 14^{th}, one Radar team found 50 year old Xianying Huang buried in the rubble of her collapsed 6 story apartment building located in Nanba Village, Pingwu County. Ms. Huang was pinned immobile under approximately 3-4 meters of concrete and other debris for almost 57 hours before her breathing was detected.

About 10 files were examined due to claims of false detections. About half of them clearly showed motion, either by someone walking into the area, or tree motion overhead. The other half contained some noise artifact, perhaps radio noise or cell phone noise. Sadly, one clearly showed a breathing victim about 2m down that must have been missed in the digging.

5 Conclusions

Both tests and real conditions have shown that GPR can successfully be modified to be a useful tool for real-time non-destructive Search and Rescue. Data is limited, but actual performance limitations seem to have as much to do with operator error and environmental noise as with detection ability. At the end of the day, the system is saving lives, which is all that matters.

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