TECHNICAL NOTE

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Disturbances in the Soil: Finding Buried Bodies and Other Evidence Using Ground Penetrating Radar

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ABSTRACT: Ground penetrating radar (GPR) is an efficient and effective means to search for buried evidence, whether it be a clandestine grave, formal burial, or certain missing articles from a crime scene. The procedures for GPR used by the U.S. Army Central Identification Laboratory, Hawaii (CILHI), are the result of several years of experimentation on a variety of ground surfaces in Hawaii, Southeast Asia and the mainland U.S. This remote sensing method does not usually provide direct information that there is a body or other specific object beneath the ground. Most of the time the GPR has been used to determine where a target object is not located. The key feature of GPR is that it can detect recent changes in shallow soil conditions caused by the disturbance of soil and the intrusion of different material.

Using the methods described here, the investigator should be able to determine the precise metric grid coordinates for a subsurface disturbance, as well as the approximate size, the general shape, and the depth of the buried material. Success will vary with soil conditions. The conditions suitable or not practical for using GPR are summarized. This remote sensing technology can have wider use in crime scene investigations due to the recent introduction of more user-friendly software and more portable hardware.

KEYWORDS: forensic science, ground penetrating radar, remote sensing, archaeology

GPR has been used by the CILHI since 1992. The field procedures developed by the author are based on extensive experimentation and testing in a variety of soil contexts such as large sand dunes, foothill farm plots in Vietnam, mixed sandy clay deposits in tropical jungles, upland deep volcanic soil, and hard caliche surfaces. Training of personnel has been done in Hawaii on sandy soil near a pine forest and at a coastal state park with buried walls and other rock alignments. The result of the training and testing is a fast and accurate method for using GPR that is applicable to many forensic situations. The method and its practical limitations are presented here with a minimum of geophysical terminology.

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Historical Background

GPR has been used to find a wide variety of objects buried by human beings. One of the early uses of GPR was during the Vietnam War to find nonmetallic land mines and tunnels (1). A shift to human-induced environmental problems occurred during the 1970s. GPR became effective in finding buried utility lines, landfill debris, deposits of contaminated fluids, highway voids, unexploded ordnance and other material (2). The Soil Conservation Service in 1978 began extensive soil mapping of the United States using GPR (3). Applications of GPR became diverse, with the design of the technology, as well as the details of field operation and analysis, usually dependent on the problem being investigated and the obscuring soil (4,5). There are deep and long range applications such as the detection of mineral resources, mapping of ice field structures, locating dry river beds beneath the Sahara, and remote sensing of desert regions from satellites. Some of the successful applications of GPR in archaeology have been the detection of eroded burial mounds in Japan (6), remote sensing of the inside of a pyramid (7), and imaging the location of adobe walls, floors, pits, and artifacts at prehistoric sites in the American Southwest (8).

GPR can sometimes locate unmarked burials. Vaughn (9) was moderately successful in locating graves at a 16th century Basque whaling station in Canada. Bevan (10) found graves at nine locations in the U.S., with varying quality of results. Mellett (11) was successful in finding graves at four kinds of sites in the eastern U.S.: historical cemeteries up to 200 years old; plots for the indigent poor of this century; a clandestine burial that occurred in 1982; and a Native American burial site from circa AD 800. Burns et al. (12) were successful in a search for a clandestine grave. France and her colleagues in Colorado conducted research with a variety of methods, including magnetic surveys, electromagnetics, GPR, cadaver dogs, and other approaches. Their findings are that "*GPR surveys offer the investigator the most useful tool to delineate possible graves.*" (page 1452, 13)

GPR is one of the techniques applied in Southeast Asia to the search for Vietnam War era isolated burials, buried ordnance, and incident-related artifacts from aircraft crashs. Numerous surveys have been done to verify witness testimony concerning the approximate location of isolated burials. GPR alone has not been successful in finding such purported burials. Confirmation that burials are not present has been done by archaeological excavation (14). The author has also used GPR in the U.S. to survey large land areas where suspected burials might be found, such as a volcanic soil palm grove on Oahu and several acres of caliche surface in central Texas.

GPR does not directly find skeletal or fleshed remains, unexploded ordnance, or large pieces of buried metal. The technology does allow determination of both vertical and horizontal location information. It is an excellent means in many contexts to rapidly and precisely locate the presence or absence of a subsurface disturbance (15).

The Technology

A GPR operation consists of a portable GPR machine, a power source such as a 12-volt car battery, an antenna in a box that can be pulled across the ground surface, 30 to 60 meters of thick insulated cable, and a machine operator with general knowledge of local soil conditions. The GPR system referred to here is the Subsurface Interface Radar (SIR) System-3 manufactured by Geophysical Survey Systems, Inc. During operation the SIR control unit sends a signal though the antenna box (transducer) into the soil (Fig. 1). When a soil boundary is detected, the signal is electronically processed and sent to the real-time graphic recorder (Fig. 2). A digital tape recorder with GPR software can be added to this system. The operator has to know the kind of soil at the survey area and how deep the target object might be buried. For most applications, depth will be a key factor in determining the type of antenna used.

Most forensic applications can be done with antennas of either 300, 500 or 900 Megahertz (MHz) center frequency. The very short pulse antenna (900 MHz) is effective with small and near-surface targets, such as buried ordnance and (presumably) corpses. The 500 MHz antenna is useful for ground disturbances in the range of 0.5 to about 3.5 meters depth, which can include most of the items of interest in a forensic field investigation. The 300 MHz antenna is suitable for depths up to about nine meters in certain soils under ideal conditions (e.g., low moisture and low clay content). The higher the frequency of radar pulse the shallower the signal will penetrate, but the higher the resolution. The findings in this report are based on the use of the 500 MHz antenna.

The GPR antenna will transmit a signal into the ground. The radar machine will evaluate the strength and time for reflection of the signal, measured in nanoseconds. The size of the disturbance that includes the target and its electrical properties at the upper and lower boundaries will affect the strength of the signal, generally how dark or light it will show on the printout. The depth of the soil boundaries will affect the time it takes to go down and back. An area that has been dug up and had something placed in it will (usually) have less density, different soil mix, and different electrical properties than the surrounding undisturbed soil matrix. A review of recent literature (1990 through July 1995) indicates that for shallow and midrange targets such as human burials, GPR is the preferred remote sensing method:

> *"Virtually every type of grave creates a constant in electrical parameters which is detectable with GPR. This includes the parameters of a body, the parameters of any enclosure of a body, and also the contrast in soil parameters created by the excavation and backfill. Even a small urn with cremation ashes creates a detectable contrast."* (page 1813, 1)

The GPR antennas do not transmit only straight down, but also send signals to the sides and to the front. As the antenna approaches a soil disturbance, the detection will begin when the line of sight between antenna and disturbance is approximately 45 degrees. Disturbances with large metal objects will be detected sooner, since the radar signal cannot penetrate metal. As the antenna gets closer to the disturbed soil the reflection time will get shorter (Fig. 3). The appearance of the radar reflections for a buried object (e.g., the disturbance that includes it) will print out as being in a bigger area than is actually the case and will often look like a series of piled-up sine waves or bell-shaped curves. The target object itself is located at the point of the top of the shallowest curve, whatever its shape. This means that it is not necessary to walk over every bit of surface of a project area. Testing and adjustment with the 500 MHz antenna indicates that spaced intervals one to two meters apart are quite sufficient. Such spacing will detect most soil disturbances in which someone has placed a body, a metal object, or many other kinds of evidence.

FIG. 2—*The GPR machine in operation. Observers are monitoring the printouts while closely watching the sled puller (Fig. 1).*

FIG. 1—*The radar antenna sled is pulled over the project area that has been stripped of nearly all vegetation. The 500 Megahertz sled (with electronic remote signal) weighs about twelve pounds. It is being used with 60 meters of cable.*

3A.

3B.

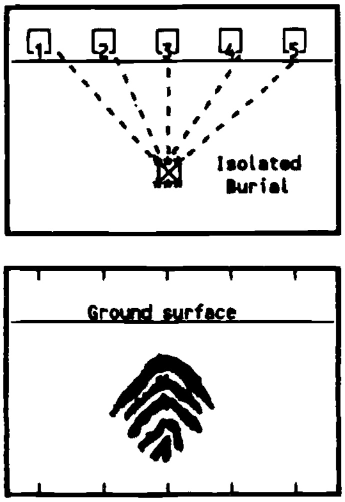

FIG. 3—*How a radar reflection is affected by distance from a buried object. The radar signal projects forward of and to the sides of the antenna sled as well as directly underneath. As the sled goes from Position 1 to Position 3 the signal travel time is reduced. As the sled passes beyond the center of the area of disturbed soil, towards Position 5, the radar travel time is increased (3A). The resulting profile for the disturbed deposit will resemble a set of generally hyperbolic curves (3B).*

Field Methods

Delimit the Project Area

GPR is used for the thorough systematic survey of the subsurface conditions of an area. The investigator will be able to examine printouts of radar reflections that provide a 100 percent coverage of the subsurface and can include depth and horizontal position (grid coordinates). If there has been a recent disturbance of the soil within the depth specified by the investigator, then the data profile can show the strength (intensity) and areal extent of the disturbance, e.g., how much of a disturbance, how deep, and its grid location. How long any disturbance will be detectable in the soil will depend on the composition of the soil, moisture penetration over time, temperature, and other environmental factors. Organic material such as human remains and clothes will decay at different rates, depending on soil and environmental conditions. Parts of intact leather military boots, for instance, are often found at World War II crash sites on various Pacific islands. Even in situations of rapid decay, the soil will have a different chemical composition with different electrical properties that could last for hundreds of years (10).

A control over provenience is possible only if the project area is prepared for a carefully designed survey. Ideally, the project area should be flat and cleared of most surface vegetation. Rarely can such an ideal situation occur. It is recommended that in thick vegetation, if feasible, cut and remove the tall grass, vines, and small brush away from the area to be surveyed. The antenna can then be pulled over the ground at a more even pace, in a straight line, and without tilting or adding electronic "noise" (uninterpretable results). But, GPR cannot be used effectively unless it is possible to pull the antenna sled through an area without a lot of stopping and starting. Trees can be left in place, since the unique profiles of tree roots can be readily seen on a GPR printout. Trees, stone markers, and large heavy objects can be left alone, because the person pulling the sled will simply walk around such obstacles. The operator can mark the location of such interferences on the printout.

The size of the area that can be reasonably surveyed in a day using GPR is quite large. The speed of walking with an antenna sled is two-thirds normal walking pace, or approximately one mile in 30 minutes. If the survey is done with the 500 MHz antenna using one meter wide transects, then a project area 100 by 100 meters can be initially surveyed in less than forty minutes.

Set Up a Grid

It is strongly recommended that an archaeological or civil engineering grid be set up around the entire limits of the area to be surveyed. A grid has three primary functions: as a guide for determining survey lines; as a means for precise determination of location of anything within the project area; and as a convenient reference system by which to produce an accurate map. The following procedural steps are recommended:

1. Visual determination of the farthest reasonable limits of where the target objects might be buried. This is often done on the basis of witness testimony given in the field.
2. Marking the four corners of the project area, usually with stakes. If possible, the project area limits are defined within a rectangle.
3. Clearing a one meter buffer outside of the four sides of the project area. This will allow for the antenna sled to be stopped just outside of rather than within the project boundary.
4. Determining the maximum reasonable depth for the lowest part of the target object that might be in the ground. This will lead to a decision on which type of antenna to be used, usually 900 or 500 MHz.
5. Placing stakes or pin flags at either one meter (900 MHz antenna) or two meter (500 MHz) intervals along the four boundaries. The stakes or pin flags are clearly visible. Bright colors are used to mark the project area, usually red, florescent orange, or another vivid color. It is not necessary to place grid markers inside of the staked boundaries or to spray paint a grid designation on each square.
6. Digging a test pit just outside of the project area that is approximately 0.5 by 0.5 meters in size down to the lowest depth that the target object might have been placed. The GPR machine operator can then look at the walls of the pit and assess density and placement of rocks, moisture, soil layer changes, and general subsurface conditions of soil that has not been recently disturbed.
7. The hole is filled back in. A thick metal object such as metal rebar or a tire iron is placed in the hole before the backfilling. This newly disturbed area with its buried object can be used as a control for the tuning of the radar machine. The soil is compacted only enough that the antenna sled can be readily pulled over the newly disturbed area. Such a control is critical for the successful interpretation of GPR results.

Conduct the Survey

It takes a team of five to most effectively conduct a large scale GPR survey: a GPR machine operator; someone who will pull the sled antenna and use the remote trigger switch on the handle at metric grid intervals; a person to control the cable that connects the antenna sled to the GPR machine; and two observers who hold a string line to keep the sled on a straight transect within the grid. As few as two persons are needed for the survey of a small area. The survey is ready to begin when the sled is behind one grid line, the GPR machine is tuned to the site specific soil context, and a guide line is in place on the surface at the first row. A large area survey can proceed as follows:

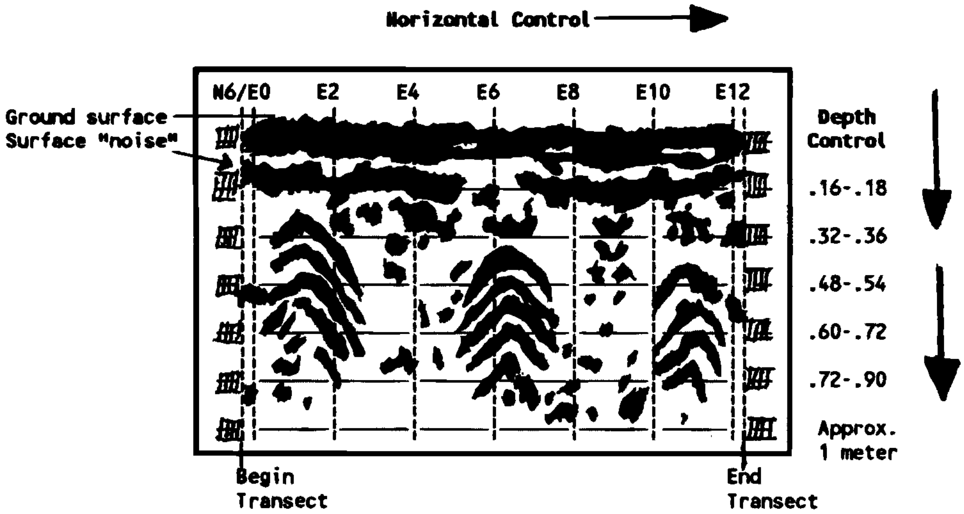

FIG. 4—*The basic characteristics of a radar profile. Showing are three disturbances, each less than two meters across. The depth lines are automatically placed on the printout. The grid lines come from the remote control beeper signals sent by the sled puller. The center profile shows the clearest signs of disturbance. Grey scale differences in strength of signal are not shown.*

1. The sled puller, upon signal from the operator, will begin the first transect. As the sled reaches the start of the grid the puller will send two short signals with the remote button. These signals will be printed as vertical lines at the start of the transect on the printout.
2. A single beep is transmitted as every single or every other metric stake is passed, at the point perpendicular to the sled.
3. At the opposite end of the transect another double beep is transmitted to mark the completion of the transect.
4. The sled is then hand carried back to the starting line, one or two meters away from the previous transect. The string guide line is also moved over.
5. The process is repeated. It is not recommended that the survey be conducted back and forth within a project area. The printouts from adjacent transects are not comparable if the profiles were obtained in opposite directions.
6. The last transect is just inside the last row of stakes. The operator will have labeled the beginning of the printout for each transect with the following bits of information: transect number, in sequence; cardinal direction of transect (e.g., "S to N"—south to north); and the beginning grid coordinates (e.g., N0/E1, then N0/E2, etc.).

Do a Cross-Survey

Another series of transects is surveyed at 90 degrees from the first set. The subsurface of each grid square can then be viewed from two directions.

In-Field Analysis

The GPR cannot indicate whether a disturbance of a particular size is or is not the target object. The profiles can under the right conditions, however, rapidly eliminate large sections of a project area from further consideration. The objective of a GPR survey is to tell the investigator where to dig or not to dig. The real-time printouts for several transects can be aligned and studied in the field. Each printout can have two sets of lines running through the profile. The evenly spaced interval lines running horizontally across the profile are an indication of depth, particularly if the control pit was used in the calibration of the machine. The other set of lines runs vertically down the printout, either partially from the top of the profile or down the entire length. These pulse lines were the result of the remote signals made by the sled operator as each grid stake was crossed. This provides horizontal control over the data (Fig. 4).

The perpendicular (cross) transects allow for an evaluation of the shape and size of a buried object or disturbance. Consider a radar profile taken of a narrow linear trench in which remains or a long barrel rifle had been placed. Suppose that the antenna sled was pulled on the surface directly across (perpendicular to) the trench. That profile will be quite different than a profile obtained when the antenna path was along side of or closely parallel to the length of the disturbed area. Similarly, the pit for a extended human burial is about 1.8 meters long but only about 0.5 meters wide. Running the radar in two directions over such a disturbance will provide very useful information about the general size and shape of whatever might be in the disturbed area. Two-directional views of grids will also aid in narrowing down which areas of disturbed soil are of a size that might actually contain the target object and are worth excavating.

TABLE 1—*General factors affecting soil electrical conductivity.*

Principal Factor	Application/Comment
(1) Amount of clay and sand	Depth and resolution quality increases as percentage of clay decreases and percentage of sand increases.
(2) Porosity and degree of water saturation	Effect is noticeable but often minor and can be controlled if the maximum depth to be observed is shallow.
(3) Amount and type of salts in solution	High amount of soluble salt is bad, a low amount is good for radar penetration and reflection.
(4) Scattering	The effects of trash, small pieces of metal, and other intrusions that cause the radar signal to be degraded and dispersed.

TABLE 2—*Success areas for GPR in possible forensic contexts.*

Good Depth/High Resolution	Attenuated signal/Poor Resolution
1. Sandy dunes or hills	1. High clay content soil (but use to find high clay areas)
2. Gravel	2. Shale
3. Peat	3. Swamps
4. Upland volcanic deposits (tuff, loam, pumice, etc.)	4. Caliche (but conduct survey to find noncaliche disturbances)
5. Upland coastal plains in eastern U.S.	5. Silt deposits
6. Karst (voids within)	6. Coastal marine
7. Urban areas for objects buried in walls or under pavement	7. Some lacustrine deposits
	8. Glacial till/rocky soil in prior glaciated areas
	9. Coral deposits (Hawaii)

Discussion/Summary

The use of the 500 MHz antenna with a GPR system allows for the rapid survey of a large project area with high resolution of results. However, GPR is not useful in some soils, particularly those that will absorb the radar signal, i.e., those that have high electrical conductivity. Tables 1 and 2 summarize the findings regarding the use of GPR. Table 1 pertains to antennas with frequencies of 500 MHz or higher and summarizes findings of the Soil Conservation Service, U.S. Department of Agriculture (16). Table 2 is based on the trial and experimentation with GPR by the author over the last three years and by other investigators over the last 30 years (5,8,16–20). Some kinds of soil are better than others for obtaining useful GPR profiles. However, that does not mean a survey should not be conducted in a poor soil context, particularly if the objective is to find a recently created shallow disturbance.

Success of a GPR survey will primarily depend on three factors: the clear delineation of the survey objective by the investigator; the composition of the soil at the project area; and the experience of the GPR operator. The older GPR technology provides real-time printouts in gray scale, ranging from black for metal to various shades of grey to nearly white for a void (e.g., loose soil with air pockets). The manufacture of the SIR System-3 was discontinued in 1994. The current technology, such as a SIR System-2, is lightweight and much easier to use, although not appreciably cheaper (about $30,000 for a complete system). It comes with a color television monitor and software which aids in interpreting data obtained by the GPR machine. Recording of usable profiles is made easier for rough and steep terrain. Transects can also be done back and forth, since alternate profiles can be recorded upside down. Software designed for use with Microsoft Windows was introduced in 1995. There is also a print program that allows the user to insert GPR printouts into other documents, such as Microsoft Word. It has digital storage and retrieval. The sled antennas, however, have not changed. The procedures for carefully and systematically conducting a GPR survey are the same regardless of the generation of technology used to record and present data.

A GPR survey, if carefully planned, can be a rapid, efficient and effective means of determining whether or not a human-made subsurface disturbance is present. If there is a soil disturbance, the GPR profiles will provide to the investigator the general size and shape of the disturbance, its approximate depth, and its precise grid location. The field methods discussed in this report are recommended as an efficient yet comprehensive non-intrusive means to search for objects of interest in forensic investigation.

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