Airborne ground penetrating radar: practical field experiments

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ABSTRACT

The performance of ground penetrating radar (GPR) under conditions where the ground coupling of the antenna is potentially compromised is investigated. Of particular interest is the effect of increasing the distance between the antennae and the ground. In this paper, a field trial approach is used and the study is intended to complement a related theoretical model study. Preliminary results suggest that~~,~~ in the case of moderately conductive survey conditions, it is possible to conduct meaningful GPR surveys with an antenna raised up to 2-3 wavelengths off the ground. Advanced GPR and imaging processing could possibly be used to extend this height even further. The findings of this study lend support to the concept of deploying GPR systems on mobile platforms, including low-altitude airborne vehicles.

Key words: GPR, coupling, airborne

INTRODUCTION

The use of ground penetrating radar to probe the near-surface has increased substantially in recent years; this can be attributed to the technological advances that have been made in the areas of hardware, software and interpretation capabilities. Earth scientists are also continually finding novel and innovative applications for GPR and in doing so the limitations associated with the traditional application of the technique are often challenged. The reasons for experimenting with non-traditional applications may vary, but common themes are productivity and logistics: Ways of overcoming logistical obstacles (for example, survey sites that are difficult to access on foot) and of acquiring data more productively (for example, where large survey areas need to be covered) are often sought.

One way of increasing GPR productivity is to employ multiple sensors simultaneously. Another way might be to deploy the radar sensor(s) on a mobile platform such as a customised vehicle. The use of mobile platforms may also enable surveys in areas where ground crews are not able to operate effectively or safely.

The concepts of using multiple sensors and mobile platforms are not novel and have been exploited for many years, especially in applications such as road surveying (Diamanti & Redman, 2012; Hugenschmidt, 1998) and landmine detection (Zyada, 2011). In the field of mining geophysics, however, these concepts are not widely applied. Traditionally, mining companies have been perceived to be slow adopters of new geophysical technologies, but in recent times the local mining industry has shown the opposite to be true. The key driving force behind this mindset change is thought to be the ever increasing focus on safety. To illustrate this, many platinum mines in South Africa are using GPR on a regular basis to assess hangingwall conditions in their underground developments. The use of borehole radar to detect geological structures ahead of mining is also on the increase.

One particular application that has received some attention recently, not just locally, but also in other mining regions, is that of detecting near-surface structural features in areas that are scheduled for open cast mining. The features of interest may be intrusive dykes and faults, or cavities that develop above deteriorating old workings. All of these scenarios can be associated with potentially unsafe mining conditions and their early identification would be highly advantageous. However, due to unfavourable surface conditions such as vegetation, agricultural activity, uneven topography, mining activities and/or safety concerns it may not always be feasible to conduct routine ground geophysical surveys. Ideally, geophysical techniques that offer high-resolution mapping of the near-surface and which can be employed on mobile platforms need to be applied. Potentially suitable mobile platforms may be remote-controlled roving vehicles or even unmanned aerial vehicles.

In this paper the possibility of employing GPR as described above is investigated and the focus is specifically on the effect of varying the key survey parameter of sensor height above the ground. An empirical approach is followed, involving a series of controlled field experiments. In these field experiments the sensor height is varied through a range of discrete values. The associated impact on GPR performance is assessed semi-quantitatively.

It should also be noted that the concept of airborne GPR is also not new; however most of the documented efforts have been over snow and ice terrains (Heilig, 2008; Vaughan, 1999), which represent ideal GPR conditions due to the fact that these materials are effectively transparent to radar signals . In our case we are interested in applying GPR over moderately conductive terrains.

The ultimate aim of these experiments is to provide guidelines in terms of the limits of applicability when conducting GPR surveys with raised antenna configurations over moderately conductive ground.

METHOD AND RESULTS

A suitable test site with a known target was identified: the site is located on the CSIR campus in Pretoria and the target is a storm water pipe, buried approximately 0.5 m below surface. The cylindrical concrete pipe has an inner diameter of 37 cm and is air-filled; the target therefore represents a sub-surface cavity. The host material is a dry sandy soil with grass cover.

GPR profiles were acquired perpendicularly across the known strike of the linear target as this would produce an easily recognisable hyperbolic target response. Data were acquired using a Rock Noggin 1000 MHz system with shielded antennas. The transceiver was mounted on a Noggin SmartCart and in-line positioning was achieved with the aid of an odometer wheel.

The profiles were repeated several times, varying the survey parameter of sensor height (h) as outlined in Table 1:

Sensor height (h)	***Sensor height in number of wavelengths***
On ground	0
8 cm	~0.75
12.5 cm	~1
15.5 cm	~1.3
32 cm	~3

Table 1. 1000 MHz profiles acquired for different values of sensor height (h)

The approximate wavelength values in Table 1 are based on a moderately conductive soil with assumed electrical properties of $\varepsilon \approx 7$-10; $\sigma \approx 0.05$-0.1 mS/m ($\rho \approx 100$-200 Ωm).

A sequence of output radargrams corresponding to Table 1 is presented below in Figure 1. All the radargrams were processed by applying basic GPR processing steps, which included a time zero correction, a dewow filter and the application of an automatic gain control (AGC) function. No migration was applied so as to preserve the hyperbolic character of the target reflections.

In the resulting radargrams, the target reflection can be seen as a small hyperbolic reflection at an x-position of ~4.9 m and a depth of ~0.5 m.

As the antenna is raised off the ground the target reflection still clearly manifests on the radargrams up to a sensor height of approximately 1.3 wavelengths (15.5 cm). Data wasn’t acquired for an h-value between 1.3 and 3 wavelengths, but at ~3 wavelengths the target anomaly appears to be somewhat less prominent, but still distinguishable. The last radargram in Figure 1 shows that with some additional processing – aimed at supressing unwanted background reflections and emphasising the target reflection – the observed contrast and image quality can be enhanced sufficiently to enable target detection at sensor heights of approximately 3 wavelengths.

CONCLUSIONS

The results suggest that the effect of raising a GPR antenna up to approximately 1.5 wavelengths from the ground appears to have little effect on the detectability of near-surface targets. At a sensor height of ~3 wavelengths, a slight deterioration in performance was observed, but it was shown that through strategic processing, target features could still be easily detected.

Suitable automatic detection algorithm could potentially be employed if target responses with specific characteristics are being sought.

The results from this experiment are likely to be frequency independent. If so, a low frequency GPR system – say a 50-100 MHz system could be deployed effectively several metres above ground level. This inference is supported by a numerical model study reported on elsewhere at this conference.

These findings suggest that it may be feasible to conduct low-altitude airborne GPR surveys in areas where surveys on foot are not possible or logistically challenging. If the maximum sensor height proves to be of the order of a few metres (for example, for a low-frequency system) the airborne platform may have to be a small-scale, unmanned aerial vehicle (UAV).

Follow-up experiments using lower frequency – and possibly also unshielded – antennas are recommended to test the inferences made to date.

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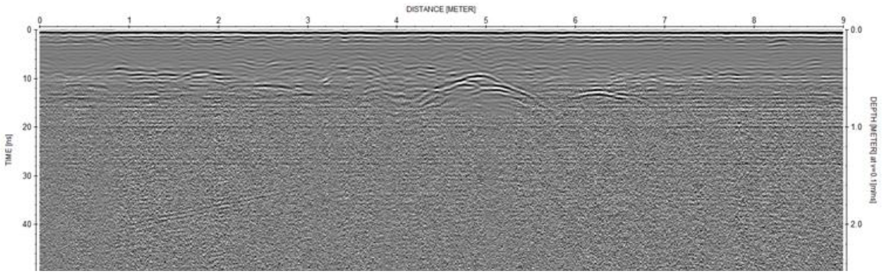
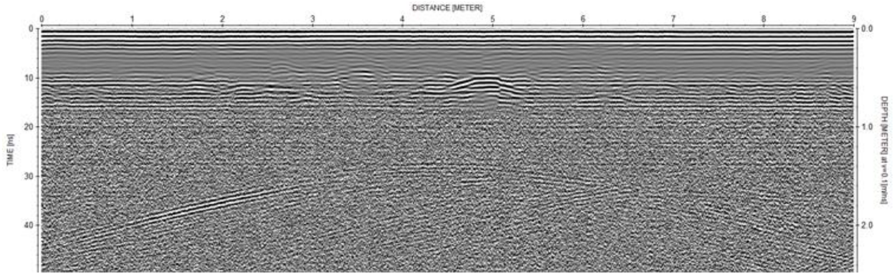
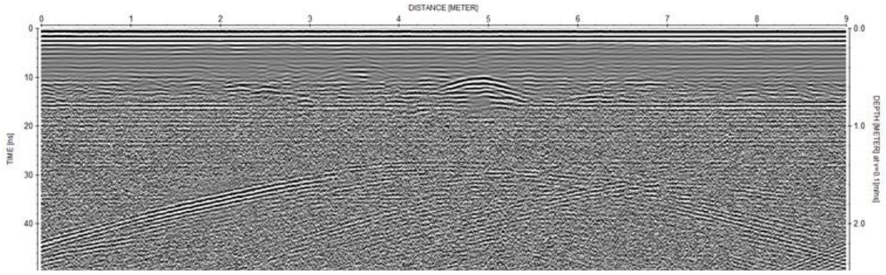


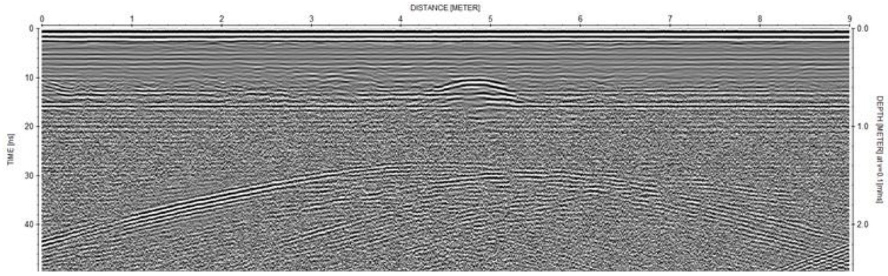
h = 0 cm



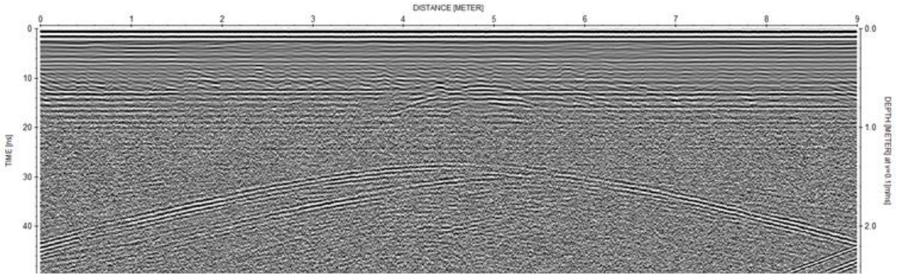
h = 8 cm



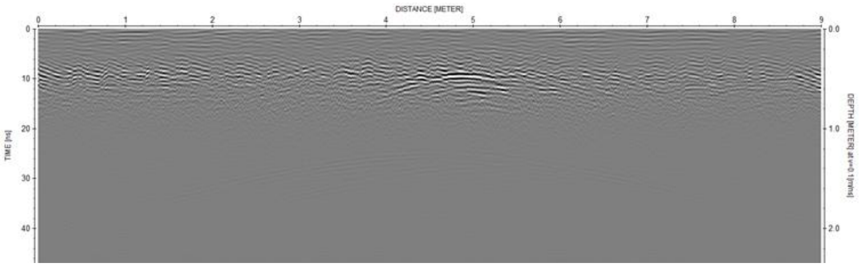
h = 12.5 cm



h = 15.5 cm



h = 32 cm



h = 32 cm (with additional processing)

Figure 1. GPR results over buried air-filled pipe for different sensors heights