

Electromagnetic soil properties variability in a minefield trial site in Cambodia and its effect on the detection of mine-like targets with a dual-sensor system

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ABSTRACT

In this paper results are presented of a study on the performance of a dual-sensor landmine detector and its dependency on soil moisture. The detector was used on a trial site in the K5 mine belt in Cambodia. Soil samples were taken from the trial lane, as well as GPR measurements. The data obtained from these soil samples and field measurements are integrated into a model for soil moisture content that is correlated with the land mine detector performance.

Keywords: GPR, modeling, landmine detection, performance.

INTRODUCTION

The principal tool that deminers use in their operations is the metal detector. However not every metal detector alarm is caused by a landmine, especially in combat areas where shells and shrapnel are present, or close to villages where metallic clutter can be the result of nearby civilization. These non-mine metallic parts increase the false alarm rate of metal detectors dramatically, thus slowing down the work of the deminers since they have to dig out every metal detector alarm as if it was a real mine. At the moment, a reduction in the false alarm rate is among the most important requirements in demining technology.

Recently developed dual-sensor detectors aim at a better discrimination between the clutter and the real mines, i.e. reduction of the false alarm rate. A typical dual-sensor mine detector contains a metal detector and a small ground penetrating radar (GPR) unit. The metal detector is sensitive to the presence of metal, while the GPR is sensitive to changes in electromagnetic properties of the soil and its contents. In an ideal case the metal detector will give an alarm in the presence of metal, either due to a mine or to metallic clutter, and the GPR will help to discriminate the clutter from the mine by giving an alarm when used on top of a fairly large object with substantially different electromagnetic properties than the surrounding soil, such as a stone, a thick root, or a mine. In principle the only objects that will result in alarms from both detectors are mines due to their metal content and the different electric conductivity of the explosive and the air gap inside in the mines. Metal detector alarms that do not coincide with a GPR alarm are due to metallic clutter, and GPR alarms not coinciding with metal detector alarms are due to e.g. a stone or big root.

In order to make a conceptually difficult to understand device as a GPR easy to learn and use for the deminers, a series of compromises have been accepted and assumptions have been made in the use of the detector. To begin with the detector does not show the results of the GPR sweep on a screen, but it generates a sound similar to that of a metal detector. The known hyperbolic arrival time curve of a single buried target on a GPR screen has been translated to sounds that the deminer can listen to without having to distract his attention from the demining lane. The pitch of the sound grows deeper with deeper targets. In this way the deminer can have an idea of the position and depth of a potential mine. The possibilities the deminer has to adapt the device to different soil types are limited and these options take broadly into account the soil conditions. In this paper the consequences of these assumptions are investigated and the performance of a dual-sensor mine detector as a function of the lateral or vertical variations of the soil moisture content is studied.

The initial goal was to perform measurements at three sites where the dual-sensor detector was on trial: Cambodia, Bosnia and Angola. From those measurements we expected to deduce a general idea of how soil changes affect the

performance of dual-sensor detectors. Due to reasons beyond our control it was not possible to take measurements at all three sites, but only in Cambodia.

FIELDWORK

The dual-sensor detector trials were done in the K5 mine belt in the north-western region of Cambodia, close to the Thai border. In a previously demined area several blind test lanes were arranged. In these lanes the deminers were training daily in the use of the dual-sensor detector. Over a period of several days their performance was recorded so that areas with higher occurrence of false alarms could be identified by the trail team.

The dimensions of the trial lane used for the research reported here, were 12.50 x 1.60m. Simultaneously with the blind tests, GPR profiles were made along the lane at 0.2 m, 0.8 m and 1.4 m from the left long side of the lane (upper side in Figure 1). Cross profiles were taken every two meters. The soil samples were taken along the GPR survey line at 0.2 m every two meters (see [Gorriti 2006]).

On the trial lane mine-like objects and metallic clutter were buried. The mine-like objects are plastic, metal and wax imitations of mines that give a response for the metal detector and the GPR of the dual-sensor detector that is very similar to that of real mines. The clutter consisted of small metallic fragments: nuts of 8 mm length and bolts of a few millimeters in diameter. This metallic clutter is supposed to be invisible to the GPR present in the dual-sensor detector, due to its small size. Apart from that the soil contained many roots and stones, objects that can act as a natural source of (non-metallic) clutter for the GPR. However, from this point on, when clutter is mentioned in this paper, it refers to the intentionally placed metallic objects as nuts and bolts.

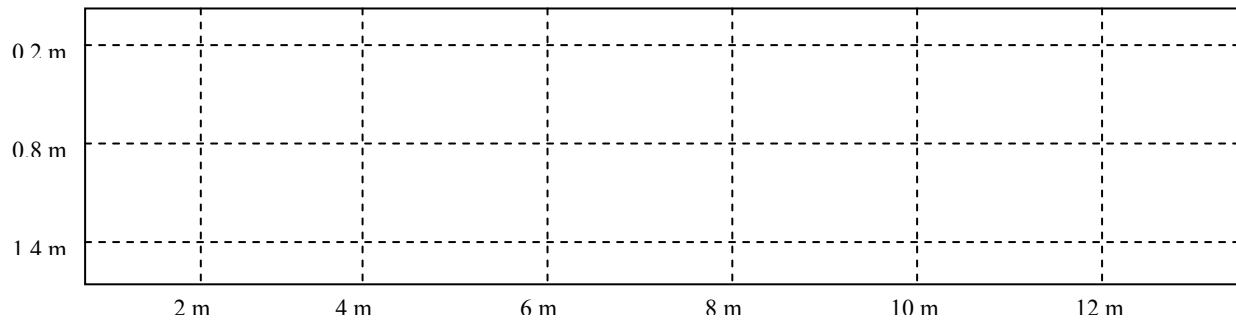


Figure 1: Landmine detector trial lane. Dashed lines represent the locations where the GPR profiles were taken.

The GPR equipment for acquiring soil profiles used in this campaign was a NJJ-95A Handy Search GPR from Japan Radio Company. This particular equipment is very small, easy to transport and to use. It is equipped with a CF card for electronic storage of both GPR and position data. Figure 2 shows the Handy Search radar in action during the measurements and Figure 3 shows an example of a real time read out on the radar's LCD screen.

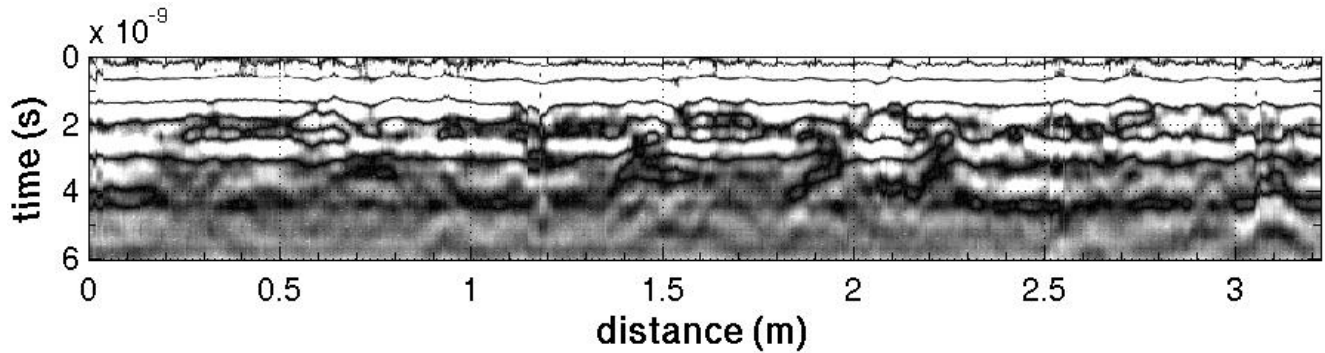


Figure 2: Measurement results shown on the display of the NJJ-95A Handy Search during use on the trial lane (profile at 0.2 m).



Figure 3: NJJ-95A Handy Search radar being used in the trial lane (profile at 0.2 m).

DATA ANALYSIS

After the soil samples were taken to the laboratory and analyzed, a clear moisture content boundary was found at 5cm depth between two layers in the uppermost 20 cm of soil [Gorriti 2006]. There is a direct relation between the upper layer moisture content and its permittivity. The upper layer is subject to the weather changes as tropical rain or strong heat from the solar radiation which causes great variation in moisture content in this layer over short periods of time.

In Figure 4 a trace of the Handy Search radar from the 0.2 m profile is shown. The environment producing this trace is modelled with the FDTD modeling package GprMax. In Figure 5 the result of the model is shown for the current soil configuration. In the model a 5 cm layer on top of a 20 cm layer is used. The relative permittivity in the bottom layer is set to 10 and in the top layer it ranges from 10 to 16, following the values found in laboratory measurements [Gorriti 2006]. The traces are calculated for the different upper layer permittivities. Figure 5 clearly shows that there is a relation

between the increasing amplitude of the second maximum of the GPR trace and the increase in upper layer permittivity. This is related to the increasing permittivity contrast between the two layers.

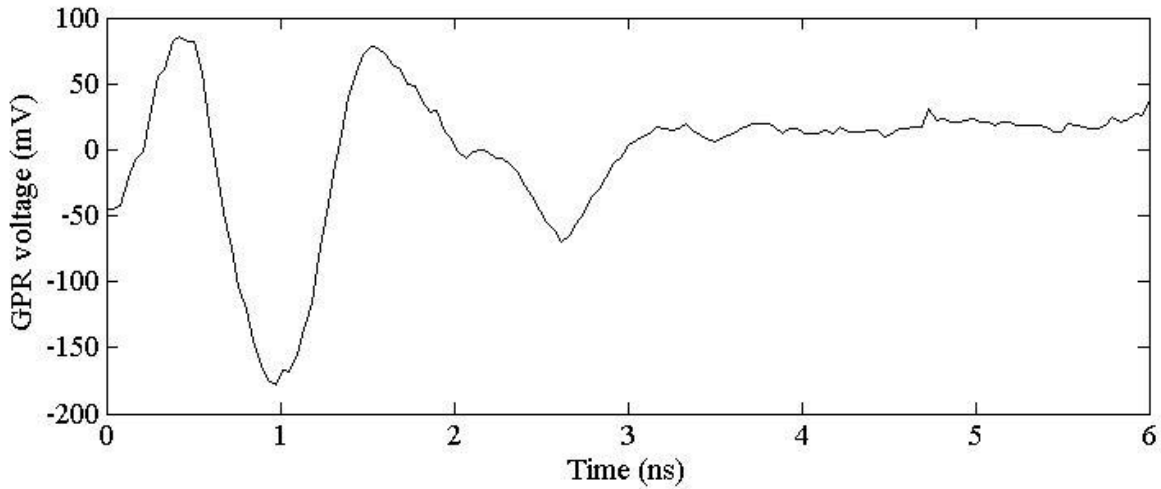


Figure 4: NJJ-95A Handy Search trace.

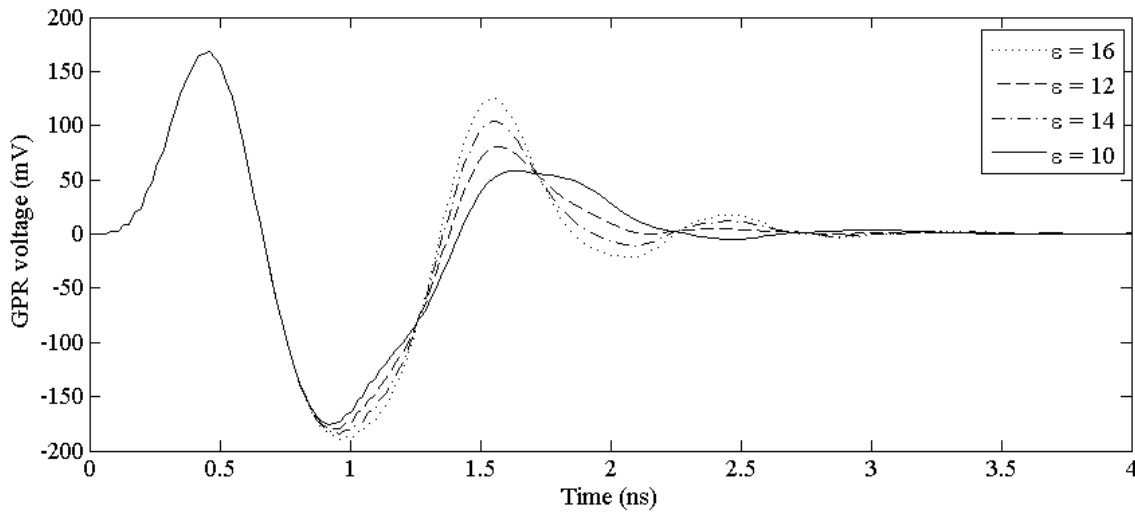


Figure 5: Modeled GPR trace for four values of the relative permittivity of the upper 5 cm of soil.

Since in the model the height of the second maximum is directly proportional to the permittivity of the upper layer, the amplitude of the second maximum of the Handy Search GPR measurement data obtained at the trial site is plotted against the profile distance. A curve is expected in these plots proportional to the permittivity profile of the trial lane.

Figure 6 shows a typical profile of the second maximum of the Handy Search GPR signal along the lane (dashed line). This profile contains lots of peaks. The peaks may be due to roots and stones in the soil. In order to extract a general trend that will be usable to correlate this profile with the deminers' performance with the dual-sensor detector a 10th order polynomial approximation is performed (solid line). This solid line shows the trend of the changes in the permittivity contrast between the upper and the lower layers. In the figures 7 to 9 a comparison between this 10th order approximation and the permittivity contrast measured in the laboratory [Gorriti 2006] is made.

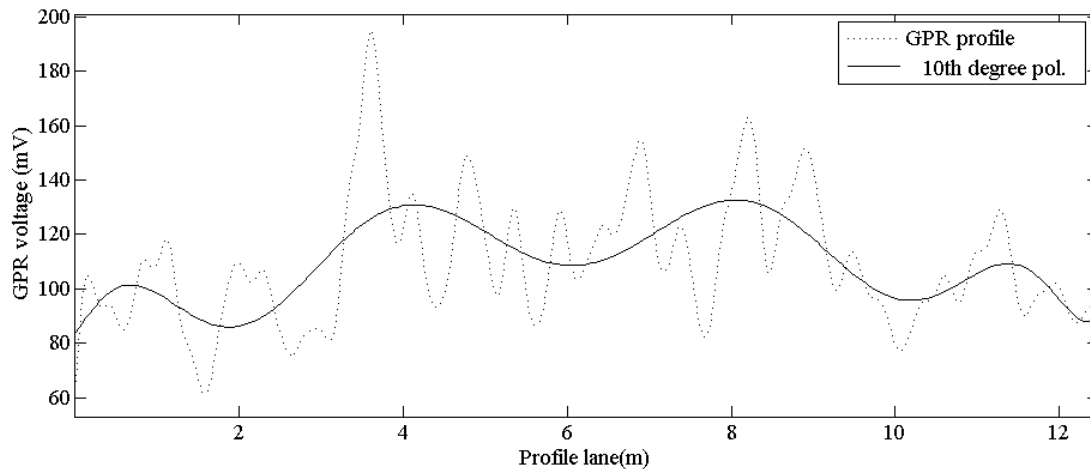


Figure 6: Comparison between the second maximum in the Handy Search GPR profile along the lane and the 10th order polynomial approximation.

Figures 7 to 9 show the Handy Search GPR profiles that will be correlated with the deminers' performance. We focus on the areas where the GPR of the dual-sensor detector gives false alarms. Note the operational procedure for this detector: first the metal detector is swept above the target area; if the metal detector gives an alarm that location is then checked with the GPR. This was done by four deminers in turns. The two most common false alarm causes for the GPR of the dual-sensor detector were due to:

- the intentionally buried metallic clutter (nuts of about 8 mm in length),
- neither a target, nor metallic clutter.

To correlate each of the Handy Search GPR profile measurements with the false alarms in the region adjacent to these profiles, a band of 20 cm on each side of the profile line is chosen and the false alarms occurring in these bands are considered. In the profiles at 0.2 m and 1.4 m a band of 20 cm respectively on the right and left of the profiles is chosen. The reason is that these bands delimit the perimeter of the trial lane. In the following figures the Handy Search GPR profile is superimposed with asterisks and circles that denote the positions of false alarms (asterisks), metallic nuts (circles) and small metallic bolts (squares).

In the upper graph of Figure 7 a voltage profile of the second maximum of the Handy Search GPR traces, approximated to a 10th order polynomial, is shown. In the lower graph of Figure 7 the difference between the top and bottom layer relative permittivities $\Delta\epsilon = \epsilon_{\text{top}} - \epsilon_{\text{bottom}}$ along the lane is given [Gorriti 2006]. The trend in the Handy Search GPR profile follows the $\Delta\epsilon$ profile. In the band of 20 cm on the right side of the 0.2 m profile line several false alarms of the dual-sensor detector occurred. The asterisks in the upper graph denote the locations of the false alarms, and the numbers above the asterisks are the number of false alarms that occurred at that location (no number means only one occurrence). Most false alarms are related to the clutter that was intentionally buried (nuts and bolts, denoted in the figure by circles and squares). The majority of these false alarms occurs around and between the two maximums in the Handy Search GPR profile where the permittivity contrast between the upper and lower soil layer is high. Since the intentionally buried metallic clutter in the lane is supposed to be invisible to the radar, due to its small size, all these false alarm declarations are due to metal detector alarms that coincide with GPR alarms from the permittivity contrast of the two soil layers.

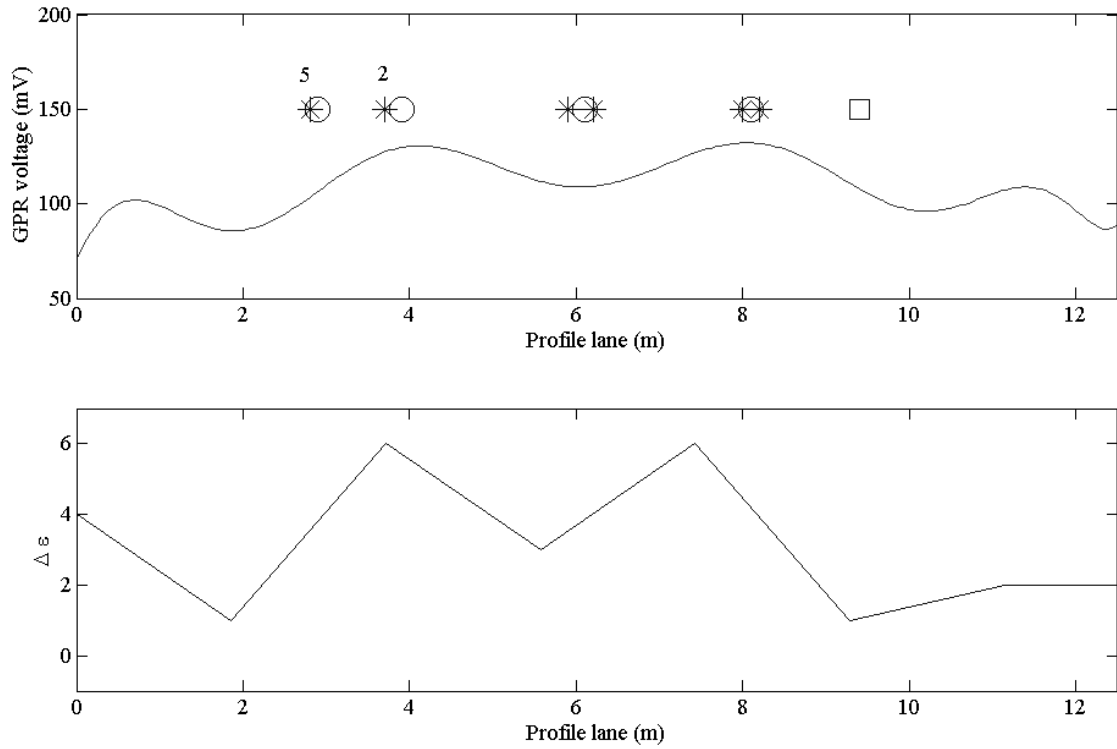


Figure 7: Second maximum of the Handy Search GPR signal along the 0.2 m profile compared with the permittivity contrast.

Figure 8 shows a graph analogous of the upper one from the 0.2 m profile. It gives also the locations of the false alarms occurring in a 40 cm wide band along the 0.8 m profile. Here the false alarms concentrate in the center of the profile and between the 10 m and 12.5 m. In the first case again the intentionally buried metallic clutter is found as the cause of the dual sensor GPR false alarms, while there is no correlation with a high permittivity contrast of the soil layers. The repeated false alarms after 10 m may be due to the area of high contrast between 9 m and 11 m, but in this case no intentionally buried metallic clutter seems to have provoked it. Probably the combination of a very mineralized soil with roots or stones has resulted in these false alarms. No graph of the differences of the relative permittivity if the upper and lower soil layer is available for the 0.8 profile, since soil samples were taken along the 0.2 m profile only.

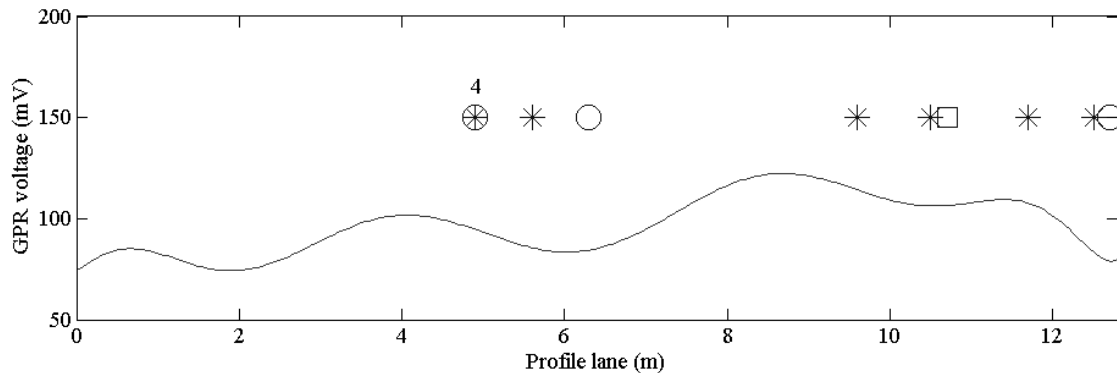


Figure 8: Second maximum of the Handy Search GPR signal along the 0.8 m profile.

Finally in Figure 9 the second maximum of the Handy Search GPR signal taken at 1.4 m is shown. In this side of the lane the false alarms occur very close to where the metallic clutter was buried. In this band no clear correlation between the false alarms and the GPR profile is found. All these false alarms are due to metallic clutter except those occurring at 6.8 m: here a mine-like target was declared incorrectly as clutter.

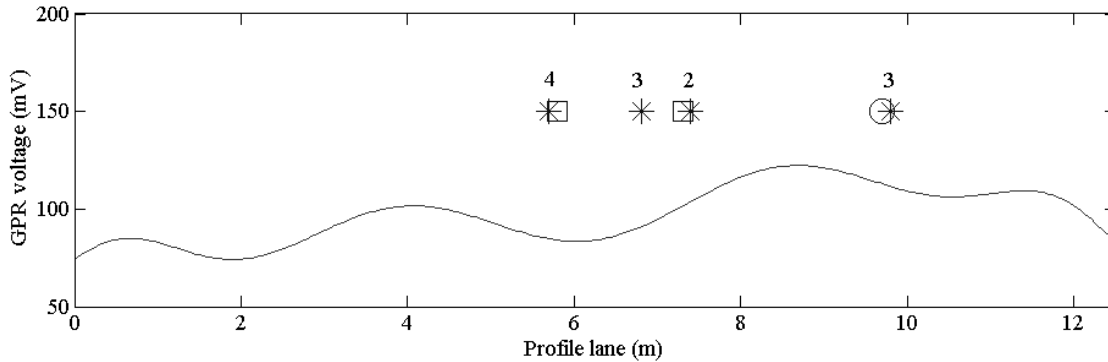


Figure 9: Second maximum of the Handy Search GPR signal along the 1.4 m profile.

CONCLUSIONS

In this paper a correlation between the spatial variations of the soil permittivity and the performance of a dual-sensor landmine detector is investigated. Unfortunately not all the initially planned data could be collected, and it is thus difficult to extract general conclusions that would be applicable to other types of soil at different locations.

In a trial lane where deminers were trained with the dual-sensor detector, GPR measurements were made and soil samples were taken that were analyzed later in the laboratory.

A GPR model is made to support the assumption on the relation between the soil permittivity in a two layered model and the amplitude of the GPR pulse. Based on the results of this model, amplitude profiles of the GPR measurements are related to the permittivity contrast between soil layers. In a number of cases a correlation is found between the two-layer permittivity contrast, the presence of intentionally buried metallic clutter and the locations where false alarms of the dual-sensor detector occurred. Unfortunately the amount of recorded data is not enough to draw more solid conclusions on the correlation between the soil permittivity and the false alarm rate of this type of dual sensor detectors.

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