The influence of soil properties on landmine detection

Kazunori Takahashi, Holger Preetz, and Jan Igel

Electrical and magnetic properties of soils show a correlation with performance of sensors used for landmine clearance operations.

Humanitarian mine removal efforts must contend with frequent false alarms. Metal detectors, commonly used for landmine identification, uncover not only landmines but also any objects containing metal. Thus, every find must be checked via excavation. Fortunately, ground-penetrating radar (GPR) can potentially distinguish landmines from junk metals by analyzing their signatures. While GPR in combination with a metal detector (called a dual sensor) has been tested, the performance of metal detectors and the discrimination capabilities of dual-sensor GPR must be thoroughly evaluated before deployment in clearance operations.

Since both devices employ electromagnetic techniques, they are influenced by the magnetic and electrical properties of soil. To evaluate this influence, we measured magnetic and dielectric properties of four soils: laterite (an iron-rich, strongly weathered, reddish clay loam), magnetic sand (an artificial mixture of engineered magnetite and coarse sand), humus A (a humus loam originating from loess, a wind-deposited silt), and humus B (a loamy humus forest soil with a high stone content). We characterized the magnitude, frequency dependence, and spatial variation of the soils’ magnetic susceptibility, electrical conductivity, and dielectric permittivity.

Magnetic susceptibility, particularly its frequency dependence, is the most influential property on metal detectors. Conversely, while susceptibility can influence GPR, the effect is negligible if it is not extremely high. Spatial variations in dielectric permittivity, however, are expected to significantly influence GPR. GPR measures reflections from a target, and the reflectivity is mainly controlled by contrasts in permittivity. Permittivity variations in heterogeneous soils can thus make the identification of a target difficult. In contrast, permittivity has almost no influence on metal detectors. Finally, electrical conductivity can, in principle, influence both methods. However, it needs to be very high to affect the responses of metal detectors and GPR as much as susceptibility and permittivity.

We compared the magnetic and electrical properties of the four soils with sensor performance. On test lanes with these soils, operators tried to detect and identify randomly buried landmines and metal pieces (see Figure 1) with metal detectors and dual sensors. To evaluate these blind tests, we calculated the following performance measures: probability of detection (POD: how many mines were detected by a metal detector), false alarm rate (FAR: how many false alarms were produced by a metal detector), FAR reduction (how many false alarms by a metal detector were reduced by the additional use of GPR), and POD loss (how many mines detected by a metal detector were misidentified as false alarms by GPR). Table 1 summarizes the measurements.

Because of the very high magnitude and frequency dependence of magnetic susceptibility, we expected laterite to be the most difficult soil for metal detectors. In contrast, humus A showed a very low magnitude and frequency dependence, and thus it was categorized as neutral. Magnetic sand showed a very high level of magnetic susceptibility. However, it was expected to have only a moderate impact on metal detectors because of continuation on next page.
Table 1. Qualitative evaluation of measured soil properties and comprehensive estimation of soil impact on the performance of detectors.

<table>
<thead>
<tr>
<th></th>
<th>Laterite</th>
<th>Magnetic sand</th>
<th>Humus A</th>
<th>Humus B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute level of magnetic susceptibility</td>
<td>Very high</td>
<td>Very high</td>
<td>Very low</td>
<td>Very low</td>
</tr>
<tr>
<td>Frequency dependence of magnetic susceptibility</td>
<td>Very high</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Spatial variation of magnetic susceptibility</td>
<td>Small</td>
<td>Small</td>
<td>N/A</td>
<td>Very large</td>
</tr>
<tr>
<td>Absolute level of electrical conductivity</td>
<td>Low</td>
<td>Very low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Spatial variation of electrical conductivity</td>
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<td>Very small</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Absolute level of dielectric permittivity</td>
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<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Spatial variation of dielectric permittivity</td>
<td>Large</td>
<td>Very small</td>
<td>N/A</td>
<td>Very large</td>
</tr>
<tr>
<td>Impact on metal detector</td>
<td>Very severe</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Neutral</td>
</tr>
<tr>
<td>Impact on ground-penetrating radar</td>
<td>Moderate</td>
<td>Neutral</td>
<td>Severe</td>
<td>Very severe</td>
</tr>
</tbody>
</table>

Laterite magnetic sand Humus A Humus B

the low frequency dependence. For GPR, humus B was expected to be the most difficult soil because of the large spatial variation of the dielectric permittivity. Magnetic sand, on the other hand, showed very small spatial variation. We therefore classified it as neutral and expected a very clean landmine signature.

Figure 2, which plots the performance measures with respect to soil characterization, clearly shows the influence of soil properties on sensor performance. The performance measures of each soil are plotted in the order of estimated soil difficulty. For metal detectors, the POD (positive feature) decreases and the FAR (negative feature) increases with soil difficulty. This indicates that metal detector performance decreases in soils characterized as difficult. For GPR, the FAR reduction (positive feature) is almost constant over all the soils. However, the POD loss (negative feature) increases with soil difficulty. Overall, the discrimination performance of GPR drops in the soils characterized as difficult. These results demonstrate that soils can be characterized for demining sensors by soil property measurements and analysis.

In summary, the performance of demining sensors in specific soils can be assessed by analyzing the magnetic and electrical properties of the soils. Comparing the soil characterization with the performance of demining sensors reveals a clear relationship. However, our current soil classification is qualitative. We are currently working on a quantitative characterization, which will help to more accurately estimate detector performance. We believe that this work will improve the safety and productivity of landmine clearance operations.

Figure 2. Performance of (a) metal detector and (b) ground-penetrating radar plotted with respect to the estimated soil impact. Soil on the left side is considered to be easy and on the right side to be difficult for each detection technique. The error bars show 95% confidence bounds. POD: Probability of detection. FAR: False alarm rate

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Author Information

Kazunori Takahashi
Tohoku University
Sendai, Japan

Kazunori Takahashi received his PhD from Tohoku University in geoscience engineering. After working at the Federal Institute for Materials Research and Testing (BAM), Germany, and the Leibniz Institute for Applied Geophysics as a research scientist, he joined the Graduate School of Science, Tohoku University, where he is currently an assistant professor.

Holger Preetz and Jan Igel
Geoelectrics and Electromagnetics Department
Leibniz Insitute for Applied Geophysics
Hannover, Germany

Holger Preetz received his diploma in physical geography from Johann Wolfgang Goethe University, Frankfurt am Main, Germany, and his PhD from Martin Luther University, Halle-Wittenberg, Germany. He has been working on soil influence on sensors for the detection of landmines and unexploded ordnance at the Leibniz Institute for Applied Geophysics.

Jan Igel received his MSc in geophysics from Karlsruhe University (2001) and his PhD in geosciences from Johann Wolfgang Goethe University (2007). He is a research scientist at the Leibniz Institute for Applied Geophysics in Hannover and is working on electromagnetic methods.

References

