Soil characterisation and performance of demining sensors

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Abstract

A field trial for the evaluation of detection performances of demining sensors including metal detectors and dual sensors was carried out in September 2009. During the trial, geophysical measurements were also conducted for characterising soils in the test lanes. The measured and deduced soil properties include: soil texture, humus content, magnetic susceptibility, electric conductivity, dielectric permittivity and water content. Considering these measurements and the impact of the properties on sensors, a comprehensive and qualitative characterisation of the test soils with regard to detection performance was provided for both metal detector and dual sensor. The trial results in terms of detection performance agree with our prediction of soil impact. It indicates that performance of landmine detectors can qualitatively be predicted by some geophysical and pedological analysis which can be performed not only inside a mined area but also at an adjacent representative area with the same soil type. Further, the applicability of the guideline "CWA 14747-2: Humanitarian Mine Action – Test and Evaluation – Part 2: Soil Characterization for Metal Detector and Ground Penetrating Radar Performance" has been demonstrated.

1. Introduction

Soil properties play an important role for performance of demining sensors such as metal detectors and dual sensors. Electrical engineers, geophysicists and soil scientists have been working on this issue in order to assess the performance of sensors and, further, the effectiveness of the techniques in various soil types. A guideline has been made for characterising soil properties for metal detector as well as for ground-penetrating radar (GPR) which is a part of dual sensor being used in humanitarian demining [1]. In order to demonstrate the characterisation and influence of soil properties on demining sensors, Leibniz Institute for Applied Geophysics (LIAG) has carried out geophysical and pedological investigations during the ITEP dual sensor test in Germany in 2009 [2][3]. This paper briefly reviews the influence of soil properties on metal detector and GPR in general, and then the measurements of these properties in the trial are reported. An estimation of soil influence on the detection methods is made based on the measurements, and relationships between the estimation and test results in terms of the detection and discrimination performance of detectors are also discussed.

2. Influence of soil properties on demining sensors

A. Magnetic susceptibility

Magnetic susceptibility is considered to be the most influential property on metal detectors, whereas it has no influence on GPR. In general, the absolute level affects frequency-domain (CW; continuous wave) metal detectors and its frequency dependence has more influence on time-domain (impulse) detectors [4]. Soil with a high magnetic susceptibility and frequency dependence creates additional response to metal detectors. This response from soil can be misinterpreted as a metal detection or can disturb response from landmines. As a result, it can be a cause of false alarms or even missing mine detections. Most of modern metal detectors have a ground compensation function which aims to reduce soil influence. The measurement of magnetic susceptibility at a location and at one or two frequencies can be made in the field quickly and easily. Measurements at two frequency is often enough to observe the frequency dependence because it is usually linear. The measurement of the complete frequency dependence at numbers of frequencies needs to be carried out at a laboratory with a fragile instrument.

B. Electric conductivity

Electric conductivity is considered to be an influential property on metal detectors only if it is extremely high [1]. Such a high conductivity is related to salt water and can be found in some coastal areas but is very uncommon in other areas. However, it has influence on GPR even if it is not extremely high. The property is mainly related to the attenuation of electromagnetic energy, meaning that a radar signal cannot propagate a long

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distance in a high conductive medium. The measurement of electric conductivity at a location can easily be carried out in the field.

C. Permittivity (dielectric constant) and water content

Permittivity, also called dielectric constant, is the most influential property on GPR [5] and it is directly related to the water content of soil. It mainly defines the propagation velocity of radar signals. Since the reflectivity of radar signals is controlled by the contrast of permittivities, the property can cause both positive and negative influence. The measurement of permittivity at a location can easily be carried out in the field.

D. Inhomogeneity

Soil properties always vary with location. The changes can be quantified by geostatistical analysis and the parameters correlation length and variability. The former quantity indicates the spatial length of the change and the latter represents the amount of changes. If the correlation length is significantly smaller or larger than the target dimension and the variability is relatively small, the soil can be considered homogeneous. If not, the soil is inhomogeneous and can have additional influence on detectors. For example, a metal detector is compensated at a location and has no response of the soil at this position. However, it is not valid any more at other locations and gets false alarms from the soil if the soil is very inhomogeneous. For GPR, the spatial changes of permittivity generate reflections which can disturb mine signatures and/or create additional responses to the radar. The measurement of the spatial variation of a property can be done by repeating a single point measurements at various locations and some analyses. The measurement can only be performed in the field, because it is impossible to take soil samples back to laboratory keeping the natural spatial pattern of variation.

3. Investigation of test soils in ITEP DS trial 2009

Measurements of the soil magnetic/electric properties mentioned above as well as pedological investigations have been carried out during the ITEP dual sensor trial in 2009 for characterising soils in the test lanes. The details of the measurements and results can be found in [2] and [3]. There were four types of soil prepared in 12 lanes. These soils can be categorised and described as follows:

i) "Laterite" (Lanes 1.1-1.4)
The soil material is a tropical soil formation from the Tertiary period. It stems from a former bauxite pit that is located in medium range mountains of Vogelsberg area, Germany. Its parent rock is basalt. The texture is clay loam with a small stone content (basalt) of approximately 2-5 %.

ii) "Magnetite" (Lanes 2.1-2.4)
The soil material in these lanes is a synthetic mixture of calcareous sand with engineered magnetite. The texture is coarse sand with a low content (2-5 %) of fine gravel.

iii) "Humus" (Lane 3.1)
The parent material of this top soil material is loess and the texture is loam with a low content of fine gravel. Its provenance is in the region of the foothills of the Alps in Bavaria. Its humus content is 2.7%.

iv) "Humus with high stone content" (Lane 3.2-3.4)
High humus content and high stone content which is about 30-40%.

From the grain size analyses, the textures of test soils are determined as shown in Fig. 1 and Table I.

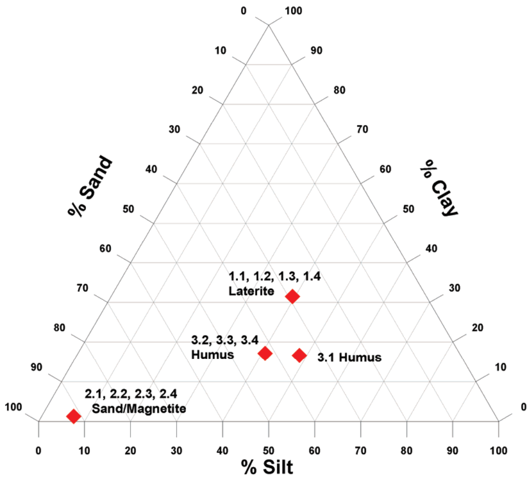

Fig. 1. Texture triangle of test soils.

TABLE I. Soil texture and humus contents of test soils.

	Laterite	Magnetite	Humus	Humus with high stone content
Clay [%]	31.5	1.3	16.6	17.1
Silt [%]	39.4	7.0	48.4	40.7
Sand [%]	29.1	91.7	35.0	42.2
Humus [% of total soil]	0.8	< 0.5	2.7	12.4

Fig. 2 shows the frequency dependence of magnetic susceptibility of the test soils measured in laboratory. Both Laterite and Magnetite have very high absolute levels of magnetic susceptibility and only Laterite shows frequency dependence. Both Humus lanes have very low susceptibility; however Humus in Lane 3.1 has remarkable frequency dependence. Fig. 3 shows the magnetic susceptibility normalised by the mean of each soil as a function of position. It can be observed that the relative spatial variation is very large in Humus with high stone content whereas it is relatively small in Laterite and Magnetite. The measurements are summarised in Table II.

Fig. 4 shows the spatial distribution of electric conductivity measured in field. Electric conductivity is ranging from 0.2 to 15 mS/m in all soils together, which is not high. Humus with high stone content (rightmost figure) seems to have higher relative inhomogeneity than others, however the influence is not serious since the absolute level is fairly low. The frequency dependence of electric conductivity is also measured in laboratory as shown in Fig. 5. Certain amounts of frequency dependency can be observed, but the absolute levels are low and no significant influence on metal detector as well as on GPR is expected.

Fig. 6 shows the spatial variation of permittivity (dielectric constant) and the converted water content measured with a TDR (time-domain reflectometry) probe in field. Laterite and Humus have higher permittivities (higher water content) than Magnetite and the higher permittivity is expected to cause higher reflectivity of landmines. However, the spatial variations in these soils are also very large and the variation is supposed to create radar response which can falsely be interpreted as mines. On the other hand, Magnetite has a very small spatial variation of permittivity and very "*clean*" mine response is expected in this soil. Table III shows the summary of the permittivity measurements.

Considering measured soil properties, the impact of soil on the performance of detector is estimated as shown in Table IV. For the classification, thresholds of magnetic susceptibility as well as its frequency dependence for metal detector performance as defined in [1] and [6] are taken into account. However, such thresholds are not established for GPR and the estimation is made according to our interpretation of the analyses.

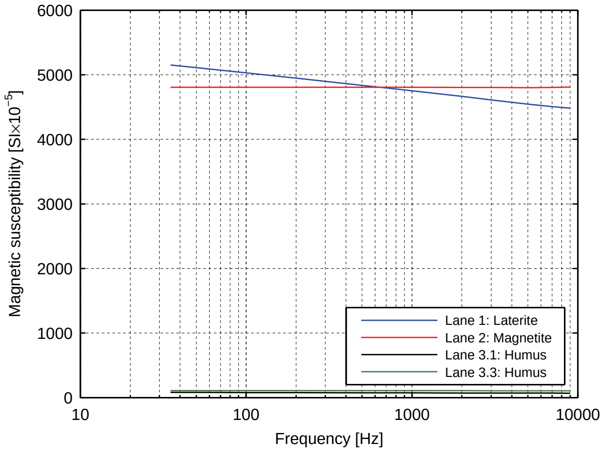

Fig. 2. Frequency dependence of magnetic susceptibility.

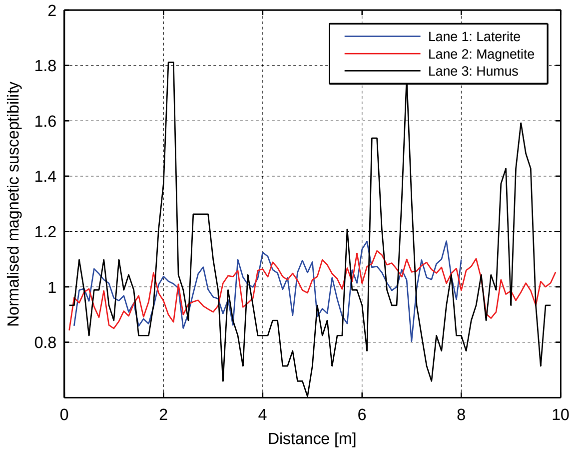

Fig. 3. Spatial variation of normalised magnetic susceptibility.

TABLE II. Summary of magnetic susceptibility measurements.

	Laterite	Magnetite	Humus	Humus with high stone content
Absolute value	Very high	Very high	Very low	Very low
Frequency dependence	High (6 %)	Very low (0.1 %)	High (7 %)	Very low (1 %)
Spatial variation	Small (8.4 %)	Small (7.4 %)	-	Large (38.9 %)

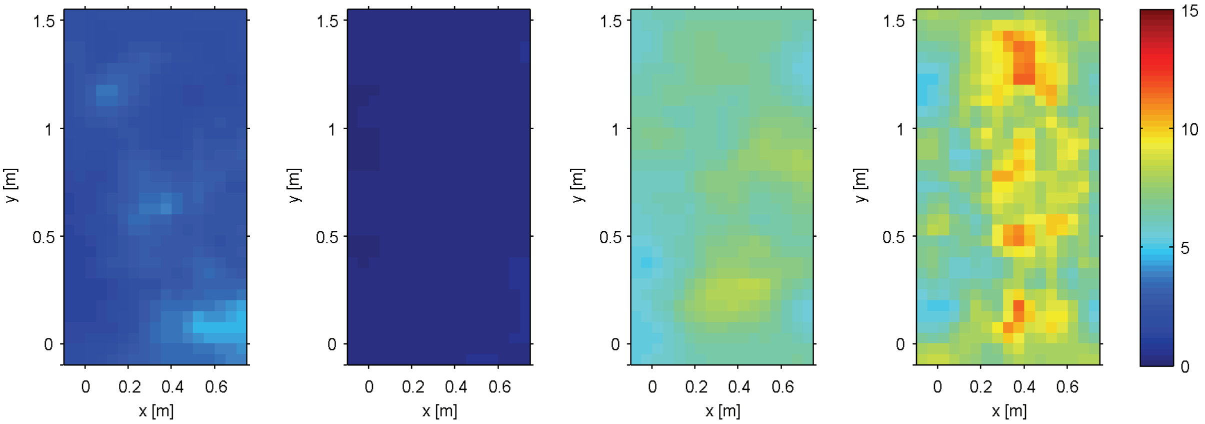

Fig. 4. Spatial distribution of electric conductivity in mS/m at a depth of 5 cm. Left to right: Lane 1 (Laterite), Lane 2 (Magnetite), Lane 3.1 (Humus) and Lane 3.2 (Humus with high stone content).

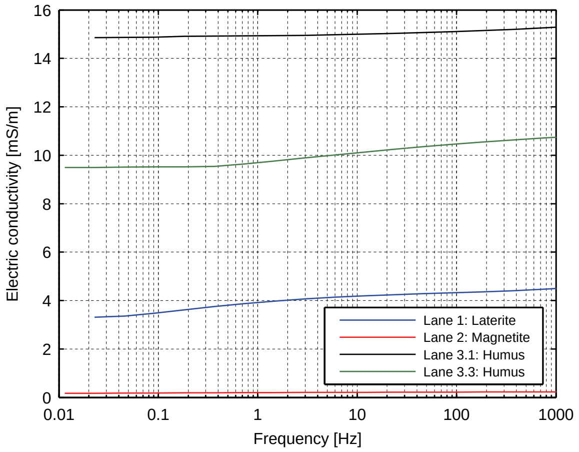

Fig. 5. Frequency dependence of electric conductivity.

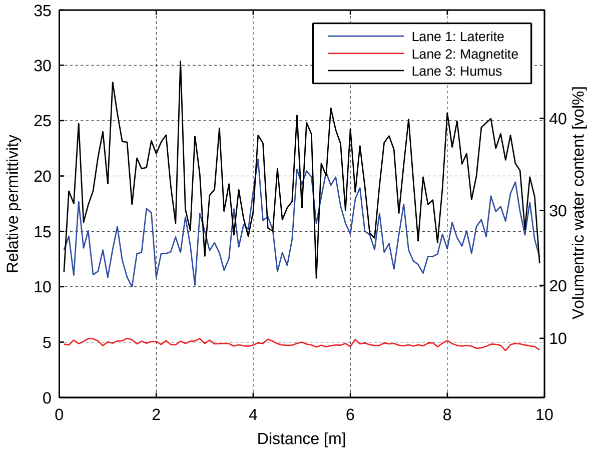

Fig. 6. Spatial variation of permittivity (dielectric constant) and water content.

TABLE III. Summary of permittivity measurements.

	Laterite	Magnetite	Humus
Mean	High (14.9)	Low (4.8)	High (20.1)
Correlation length	1.35 m	-	0.63 m
Coefficient of variation	Large (18 %)	Very small (4 %)	Large (19 %)

TABLE IV. Estimated impact of soil on the performance of detectors.

	Laterite (Lane 1.1-1.4)	Magnetite (Lane 2.1-2.4)	Humus (Lane 3.1)	Humus with high stone content (Lane 3.2-3.4)
Metal detector	Very severe	Moderate	Neutral-Moderate	Neutral
GPR	Moderate-severe	Neutral	Moderate	Very severe

4. Soil characterisation and sensor performance

The estimation of soil influence on detector performances are compared to the test results. Fig. 7 shows the probability of detection (POD) and false alarm rate (FAR) of stand-alone metal detectors in total in each test soil. The horizontal axis shows soil types used in the test and the order is sorted from influential soil (or "*difficult*" soil) to less influential soil (or "*easy*" soil) according to the rating for metal detectors in Table IV. The blue bars showing POD are increasing and the red bars showing FAR are decreasing from left to right. It indicates that POD is low and FAR is high in difficult soil, and POD is high and FAR is low in easy soil. The similar representation is made for dual sensors in Fig. 8. In the figure FAR reduction and POD loss which indicate the performance in discrimination are plotted in the order of the difficulty of soil for GPR (the definitions as well as the meaning of FAR reduction and POD loss can be found in [3] and [7]). While the FAR reduction by GPR (blue bars) does not vary so much in different soil types, POD loss (red bars) is decreasing. It means that POD loss is high in "*difficult*" soil and it is low in "*easy*" soil when FAR reduction is kept constant. Therefore, our estimation of soil influence on detector performance shown in Table IV agrees with the test results and validates the geophysical investigation methods used.

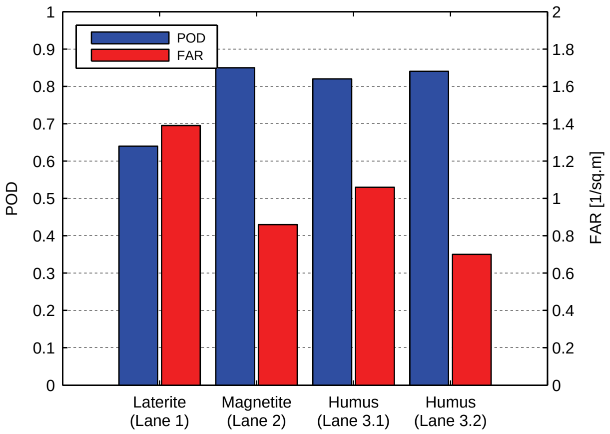

Fig. 7. POD and FAR of stand-alone metal detectors in total in each soil. Soil on left-hand side is difficult and right-hand side is easy soil for metal detector.

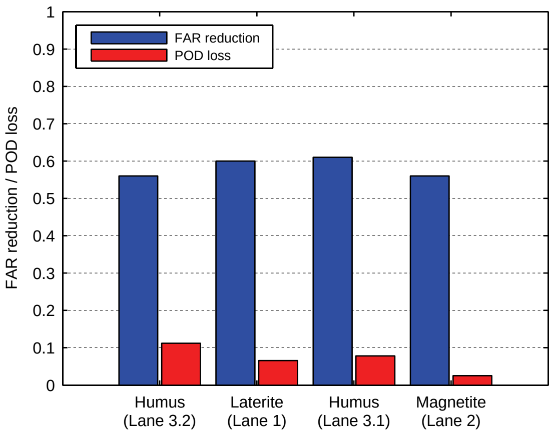

Fig. 8. FAR reduction and POD loss of a dual sensor in each soil. Soil on left-hand side is difficult and right-hand side is easy soil for GPR.

5. Conclusions

The relationships between soil properties and test results of demining detectors have been demonstrated in this paper. The soil characterisation based on the influence on metal detector and dual sensor estimated from pedological and geophysical measurements agrees with the test results; low POD and high FAR in difficult soil and high POD and low FAR in easy soil for metal detector; high POD loss in difficult soil and low POD loss in easy soil for dual sensor whilst FAR reduction is kept constant.

The fact that our estimation of soil influence agrees with the test results indicates that the performance of landmine detectors can qualitatively be predicted by some geophysical and pedological analyses which can be performed not only inside a mined area but also at an adjacent representative area with the same soil type. The influence of the soil properties on metal detector and GPR and the characterisation of soil according to the properties are described in the guideline "CWA 14747-2: Humanitarian Mine Action – Test and Evaluation – Part 2: Soil Characterization for Metal Detector and Ground Penetrating Radar Performance [1]", therefore the results also demonstrate the applicability of the guideline.

6. Reference

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