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Estimation of Relative Permittivity of Shallow Soils by Using the Ground Penetrating Radar Response from Different Buried Targets

Lorenzo Capineri[1], **David J. Daniels**[2], **Pierluigi Falorni**[1]
Olga Lucía Lopera[3], **and Colin G. Windsor**[4]

[1]Dipartimento Elettronica e Telecomunicazioni, Università di Firenze, Italy
[2]ERA Technology, UK
[3]Signal and Image Centre, Royal Military Academy, Belgium
[4]United Kingdom Atomic Energy Authority (UKAEA), UK

Abstract— Ground penetrating radar (GPR) for landmine detection has reached the stage where portable equipment for field operations is commercially available. Dual sensor systems in which high performance metal detectors (MD) are combined with GPR have been extensively trialled.

The operating conditions for the GPR are strongly affected by the electromagnetic characteristics (magnetic susceptibility and complex relative permittivity) of the soil. These can change in space (soil inhomogeneities) and also in time (environmental factors like moisture, temperature). These variations are the main reasons why the GPR systems need either manual or auto-calibration before their use as a mine detector.

This paper describes an assessment of methods that can be used by operators in the field for the estimation of the relative permittivity (ε_r) of the soil at shallow depth. The estimation of ε_r is obtained indirectly by the propagation velocity $v = c/\sqrt{\varepsilon_r}$, where c is the speed of light in vacuum.

Experiments were carried out using the MINEHOUND dual sensor system jointly developed by Vallon GmbH and ERA Technology at the test site of the latter. Different metal targets were buried at different depths in a soil defined as ballast. The time-of-flight was estimated from data acquired in a 10 second scan above the target.

The MINEHOUND antenna uses two linearly polarised parallel elements separated by 8.3 cm, one transmitting and the other receiving and has a centre frequency of 1 GHz. The equation of the minimum time-of-flight from the target reflection (antenna over the target centre) is:

$$TOF_{\min} = \frac{2}{c}\sqrt{\left(\frac{S}{2} - \frac{S}{2}\frac{Z_0}{Z_0+h}\frac{1}{\sqrt{\varepsilon_R}}\right)^2 + h^2} + \frac{2}{c}\sqrt{\varepsilon_R}\sqrt{\left(\frac{S}{2}\frac{Z_0}{Z_0+h}\frac{1}{\sqrt{\varepsilon_R}}\right)^2 + Z_0^2} \qquad (1)$$

where Z_0 is the target depth, h is the antenna height from soil surface.

The received signals also contain another reflection from the air-soil interface that, with the bistatic antenna configuration, corresponds to the following time-of-flight equation:

$$TOF_{Air-soil} = \frac{2}{c}\sqrt{\left(\frac{S}{2}\right)^2 + h^2} \qquad (2)$$

By suitable processing of the experimental data the difference of the various times-of-flight (Eq. (1)–Eq. (2)) can be evaluated and the value of ε_r can be estimated. Note that Eq. (1) is non-linear for the unknown ε_r. The effect of the variability of h during the sweep also needs to be considered, because it impacts on the uncertainty of the estimate of ε_r.

In this paper we assess which of several different metal targets provides the best calibration target for a measurement procedure in the field:

1. metal pipe
2. metal sphere
3. metal planar reflector

The analysis includes the following points:

- Radar response
- Influence of burying procedures on soil properties
- Cost and availability