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Implications of the choice of the forward model used in the multicomponent imaging of ground penetrating radar data

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Implications of the choice of the forward model used in the multi-component imaging of ground penetrating radar data,

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Introduction

In the past, the imaging algorithms for GPR data were adapted from seismic imaging algorithms. However, important differences between the seismic and radar wave propagation exist, like the vectorial nature of the electric field, the conductivity and the dipole nature of the electric current sources. For imaging of ground penetrating radar data the three important parameters, which have to be taken into account are, in order of importance, the wave speed, the polarisation and the amplitude. For imaging purposes, knowledge of the forward model, which incorporates these three parameters, is indispensable. An important requirement for 3D imaging of ground penetrating radar (GPR) data are closed-form expressions for the forward model, because the exact integral expressions of the total field require too much computing time to be incorporated in a 3D imaging algorithm. Recently, van der Kruk et al. (GPR2000) discussed a multi-component imaging algorithm, which takes into account the polarisation and the complex radiation characteristics. This multi-component imaging algorithm uses more measured electric field components to obtain a bounded operator for the inverse wavefield extrapolator, which eliminates the propagation effects. The forward model used to calculate the scattered data in the foregoing analysis was based on the well-known far-field expressions for the radiation characteristics (Engheta et al., 1982). In this paper the forward model to calculate the scattered data is based on the total-field expressions obtained by the exact integral expressions for the electric field which are evaluated numerically. Both the far-field and the total-field expressions can be used in the forward model which is the basis to determine the inverse wavefield extrapolator. The implications of the choice of the forward model to determine the inverse wavefield extrapolator on the obtained results is discussed.

Forward model

The forward model that is used for the imaging must describe the three parameters, wave speed, polarisation and amplitudes and is given by

$$
\hat{E}_d^\alpha(x^R,\omega) = \int_{x^S \in D^s} G^{EJ}_{\alpha r}(x^R|\omega)\chi^\tilde{\eta}(x^c)G^{EJ}_{r\beta}(x^c|\omega,\omega)^S_j(x^S,\omega)\eta^\beta(x^S,\omega)dV,
$$

where $D^c$ is the scattering domain and Einstein’s summation convention applies to repeated subscripts. The Latin subscript $r$ can take the values $\{1, 2, 3\}$, whereas the Greek subscripts can take the values $\{\alpha, \beta\} = \{1, 2\}$. $G^{EJ}_{r\beta}$ describes the propagation of the vectorial electric field due to a point source $\tilde{J}_\beta$, to the location of the contrast $\chi^\tilde{\eta}$ at position $x^c$. This scatterer can be considered as a secondary source and the propagation from $x^c$ towards the receiver is described by $G^{EJ}_{\alpha r}$. The contrast $\chi^\tilde{\eta}$ is defined as $\chi^\tilde{\eta} = \tilde{\eta} - \eta$, where $\tilde{\eta}$ and $\eta$ describe the properties of the background and the scatterer, respectively. $\tilde{\eta}$ is defined as $\tilde{\eta} = \sigma + j\omega\epsilon$. It can be seen that the forward model is mainly described by the inner product of the two Greens functions $G^{EJ}_{r\beta}$ and $G^{EJ}_{\alpha r}$, which describe the radiation characteristics of the source and receiver antennas.
Radiation characteristics of a dipole on a dielectric halfspace

The radiation characteristics are obtained by evaluating the integral expressions for the total-field and by using the far-field expressions. In Figure 1 the amplitudes of the spherical field components of the total-field are compared with the far-field results in both the $H$- and the $E$-plane at a distance of $R = 1$ m. A circle and an arrow in the origin indicate the direction of the source in the left and right figure, respectively. In the left figure the polarisation of the electric field is parallel to the direction of the source, which is indicated with circles. In the right figure the polarisation of the electric field is indicated with arrows. The far-field expressions do not resemble the total-field in the lower halfspace. A relatively large error between the far-field and the total-field expressions is present near the critical angle.

Resolution function: Imaging of a point scatterer for one frequency

To investigate the performance of the imaging algorithms the forward model to calculate the scattered data is based on the total-field. The imaging was carried out for a conductivity (real-valued) contrast, $\chi(\mathbf{r}) = \delta(\mathbf{r} - \mathbf{r}_d)$ for one single frequency component $f = 500$ MHz, which returns a resolution function. The determination of the inverse wavefield extrapolators is discussed by van der Kruk et al., (SEGJ2001). The obtained imaging results at the depth of the scatterer are depicted in Figure 2 for two scalar imaging algorithms, the SAR (left) and Gazdag (right) imaging algorithm. The scalar imaging algorithms do not show a circular symmetric image of the point scatterer and return for a real contrast a complex valued image. These results show that the scalar imaging algorithms do not compensate for the propagation effects and that the angle-dependent radiation characteristics of the source and receiver antenna still influence the obtained image. In Figure 3 the obtained results are depicted for the multi-component imaging algorithm, which was performed using the far-field expressions (left) and using the total-field expressions (right) to determine the inverse wavefield extrapolator. Using the far-field expressions a small error occurs in the obtained image result, compared with the results which were obtained by using the total-field expressions to determine the inverse wavefield extrapolator. This is indicated by the imaginary part being non-zero. However, even using the far-field expressions to determine the inverse wavefield extrapolator of the multi-component imaging algorithm, a representative image of the point scatterer is obtained, which is better than using the scalar imaging algorithm, because the multi-component still takes into account the polarisation and approximate radiation characteristics.
Figure 2. Real and imaginary part of the resolution function using the SAR imaging algorithm (left) and the Gazdag imaging algorithm (right).

Figure 3. Real and imaginary part of the resolution function using the multi-component imaging algorithm using the far-field expressions (left) and using the total-field expressions (right) to determine the inverse wavefield extrapolator.
Experimental results

Measurements were made with the 900 MHz pulseEKKO system using different polarisations of the source and receiver antennas in a controlled testing environment. In Figure 4, the obtained imaging results are depicted. The far-field expressions were used to determine the inverse wavefield extrapolator and the results give a representative image of the subsurface where different objects are buried.

\[ \begin{align*}
  x_1 & \quad 0 \quad 1 \quad 2 \quad 3 \quad 3.5 \\
  x_2 & \quad 0 \quad 0.5 \quad 1 \quad 1.5 \quad 2 \\
  x_3 & \quad 0 \quad 0.25 \quad 0.5 \quad 0.75 \quad 1
\end{align*} \]

Figure 4. Multi-component imaging results using 900 MHz pulseEKKO antennas.

Conclusions

The use of an adequate forward model is indispensable for imaging purposes. The far-field expressions which are generally used have a significant error compared with the total-field results. This error in the far-field expressions, compared with the total-field expressions, results in a non-optimal reconstruction of a point scatterer when the multi-component imaging algorithm is used. However, still a reasonably circular symmetric resolution function is obtained which gives a representative image of the subsurface. Still, the obtained results are better compared with the scalar imaging algorithms, the SAR and the Gazdag imaging algorithms, because the multi-component imaging algorithm takes into account the polarisation and approximate radiation characteristics. The obtained results indicate that better closed-form expressions, which resemble the total-field values in a better way, can improve the imaging algorithm. Note that knowledge of the radiation pattern of finite length antennas is the final goal to be incorporated in the multi-component imaging algorithm.

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References