Radar Detection of Subsurface Objects Using Correlation Imaging

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The radar detection of objects below a rough surface is an active area of research motivated by the problem of detecting shallowly buried land mines. The primary challenge for this approach is the extremely low signal-to-noise ratio between the return from the buried object and the reflected return from the rough surface. The weakness of the former is due to the low dielectric contrast between the buried object and the enclosing soil, as well as the lossiness of the soil medium. The strength of the latter is due to the random roughness of the surface. In this work, correlation imaging is employed to separate the return from the rough surface from that originating from the object by correlating radar measurements made at multiple angles. We incorporate a probabilistic weighting function (filter) to further enhance the effectiveness of correlation imaging, taking into account the random phase variation of the buried object return due to the rough surface.

The electromagnetic scattering is computed using a dyadic Greens function which describes the scattering from a half-space medium with planar boundary, and spherical objects embedded below this boundary. An approximate solution is obtained using a perturbation technique to yield expressions for the scattered field as a function of the viewing geometry (incident and scattering angles), object placement, and soil dielectric properties. The rough surface height variation is assumed to have a Gaussian distribution.

To evaluate the effectiveness of the correlation processing, we simulate the response of a monostatic Synthetic Aperture Radar with a linear viewing geometry that illuminates each ground patch from different angles. The samples from each patch are then used to measure the correlation:

$$C(\vec{r}_p) = \sum_{m=1}^{N} \sum_{n=1}^{N} E_p(\vec{k}_m) E_p^*(\vec{k}_n) e^{2i(\vec{k}_n - \vec{k}_m)} W(\vec{k}_m, \vec{k}_n)$$

where $\vec{r}_p$ is the patch location, N is the number of radar positions, $E_p(\vec{k}_m)$ is the electrical field received from the pth patch due to excitation from the mth source position, and $W(\vec{k}_m, \vec{k}_n)$ is the weighting function.

Our previous results showed that this approach was effective at reducing the clutter to allow detection of buried objects when the modeled scattering response is computed to first order. In this work, we extend the scattering model to consider second order scattering terms so that the return from the buried object after scattering from the random surface is taken into account. This term contains small variations in both the magnitude and the phase of the buried object return, and reduces the correlation between independent measurements. To compensate for this, a new weighting function is applied based on the assumed statistical properties of the rough surface. For a Gaussian surface, the weighting function has a normally distributed phase term that is centered at the assumed object depth, z_0. Results are presented that show the robustness of this approach to inaccuracies in the assumed depth and the width (σ) of the probability distribution.