Airborne GPR surveys via tomographic imaging: an analysis of the reconstruction capabilities

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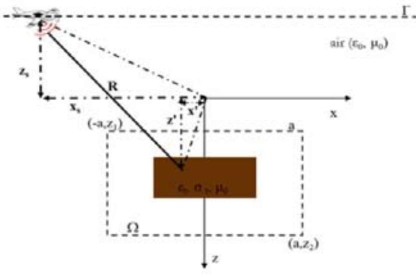
GPR systems installed on helicopters or spotter planes represent effective monitoring tools to cover surface and underground characterization of wide areas. In this respect, the paper discusses the on field reconstruction capabilities resulting from the joint exploitation of a novel sounder system and a tomographic data processing approach. The sounder system was built by CORISTA in collaboration with the Italian Space Agency, which promoted and founded the project. It is a pulsed radar working at 163 MHz and transmits a 10 MHz linearly frequency modulated signal (chirp) by using DDS (Direct Digital Synthesizer) technique. The transmitted peak power is about 200W over a 3 μ sec pulse length. The system exploits a log periodic antenna with four elements, GPS and an INS are used for storing position and altitude information. The data processing is faced by means of a microwave tomographic reconstruction approach, which is based on a simplified scattering model. In particular the Born approximation is adopted to formulate the imaging as a linear inverse scattering problem. The effectiveness of the system is shown by means of the tomographic images corresponding to the first trial surveys made with the sounder installed on a helicopter of the Italian Air Force.

A TOMOGRAPHIC MODEL FOR AIRBORNE GPR IMAGING

According to the Born approximation and the ray based model the relation to be inverted is given as:

$$E_s(x_s,z_s,f)=\int_{-a}^{a}\int_{z_1}^{z_2}\frac{\exp(-j2\beta_0 R)}{R}\chi(x',z')\,dx'\,dz'. \qquad (1)$$

In eq.(1), $E_s(x_s,z_s,f)$ is the back-scattered field measured in the observation point (x_s,z_s) at the working frequency f, $R=\sqrt{(x_s-x')^2+(z_s-z')^2}$ denotes the distance from the antenna to the generic point (x',z') in $\Omega=[-a,a]\times[z_1,z_2]$, β_0 is the free space wave-number and χ is the contrast function



Sketch of the reference scenario.

After a discretization of the problem, a matrix relationship is achieved between the scattered field data and the contrast

$$\underline{\mathbf{E}}_S=\underline{\mathbf{L}}\chi$$

where $\underline{\mathbf{E}}_S$ is the data vector of MxF complex elements data vector (M = # Tx/Rx positions, F= # frequencies); $\underline{\chi}$ is a N dimensional vector of complex elements, where N is the number of pixels in the investigation domain.
A truncated SVD (TSVD) based approach is adopted as regularized inversion scheme to ensure a stable solution

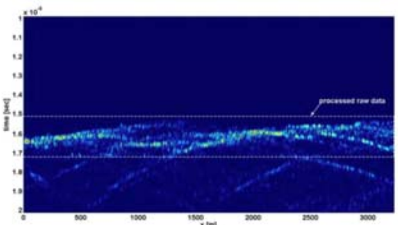
The following pre-processing steps are needed to pass from the GPR raw measurements to input data suitable for the inversion approach:

1) **inverse Fourier transform of the measured frequency domain radar traces is computed to achieve the synthetic radargram;**
2) **gating of the synthetic radargram by forcing to zero those parts which are external to the time window (this identifies the spatial domain under test);**
3) **alignment of the radargram zero-time with the adopted time-window. This time fixes the helicopter platform height in the adopted reference system;**
4) **Fourier Transform of the synthetic radargram to achieve the required frequency domain data.**

VALIDATION AND PERFORMANCE ASSESSMENT IN A REAL CASE

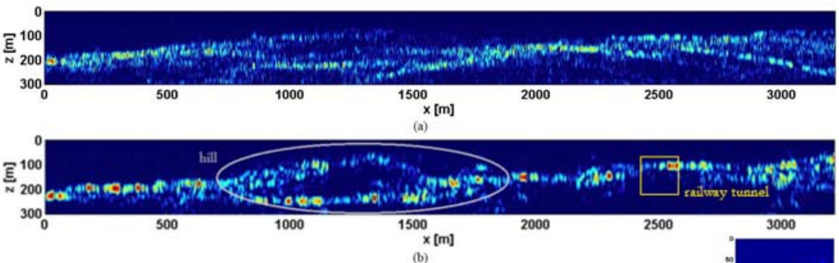
To verify the capability of the sounder to detect buried targets, a survey was performed 11th October 2011 on a hill country located in the Visciano town, Campania, Italy. This area is worth to be considered as test site due to the presence of a hill and a railway tunnel.

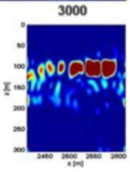
Aerial view of the surveyed hill country, located in the Visciano town, Campania, Italy. The red line represents the 3216m long GPR trajectory, the gray circle localizes the hill and the dot yellow line identifies the railway tunnel.



Overall synthetic raw data radargram

The deployed antenna is a log periodic one with four elements. This antenna has a 7dBi gain and a beam width of 68 degrees, with a front-back ratio of 15-19 dB. The antenna is mounted on a helicopter of the Italian Air Force and works as transmitter and receiver. The receiver acts with a minimum range gate delay of 4 μ sec (for the measurement survey here presented a delay of 10 μ sec was used) with a receiving time window of 81.5 μ sec.





(c)

(a) Zoom of the radargram corresponding to the processed time window;
(b) Tomographic reconstruction (the image displays the normalized modulus of the regularized contrast function χ, as obtained by means of the TSVD);
(c) Zoom on the railway region of the tomographic reconstruction.

The tomographic image has been obtained by processing subsets of 201 radar traces spaced 1m one to each other, by taking into account the effective 10MHz wide working frequency range and by assuming a frequency step Δf=0.3MHz. Moreover, the antenna is supposed to be 2250m far from the upper side of the investigated domain and a free space medium has been assumed as a background scenario. The threshold of the TSVD filters out the singular values whose magnitude is lower than -10dB with respect to the maximum one.
The tomographic image is cleaner and clearer compared to the raw data and permits to identify the hill, under which the presence of an elongated and flat interface can be inferred. However, due to the complexity of the scenario, from a global image it is very hard to gain information about the railway tunnel. By the way, its presence can be inferred by zooming the tomographic image.

CONCLUSIONS

The first reconstruction results gained by means of the sounder promoted and founded by Italian Space Agency and built by the CORISTA, thanks to the use of the microwave tomographic approach developed by IREA have been presented. This linear inverse scattering approach, specifically tailored to process radar data from airborne platforms, allowed to tackle the realistic case of long scanning trajectories acquired by relevant platform height. As future activity, we will address a more extensive analysis with different kinds of scenarios and also in presence of "reference targets".

14th International Conference on
Ground Penetrating Radar (GPR 2012)
Tongji University, Shanghai, China
June 4-8, 2012