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WISDOM Subsurface Imaging for Inhomogeneous Media and Complex Propagation Scenarios

Dirk Plettemeier (1), Christoph Statz (1), Yun Lu (1), Wolf-Stefan Benedix (1), Yann Hervé (2), Alice Le Gall (2), Charlotte Corbel (2), and Valerié Ciarletti (2)

(1) Technische Universität Dresden, Germany (christoph.statz@tu-dresden.de), (2) LATMOS/UVSQ, Guyancourt, France

The fully polarimetric ground penetrating radar (GPR) WISDOM is part of the 2020 ExoMars rover payload. It operates as a stepped-frequency continuous-wave radar at frequencies between 500 MHz and 3 GHz yielding a centimetric resolution and a penetration depth of about 3 m in Martian soil. Its prime scientific objective is the detailed characterization of the material distribution within the first few meters of the Martian subsurface as a contribution to the search for evidence of past life.

The antenna of WISDOM consists of two crosswise arranged two-element Vivaldi arrays. It exhibits a wide bandwidth ratio of 6:1 and is built using ultra-lightweight composite materials. Due to the crosswise arrangement four transfer-functions can be recorded: two co-polar and two cross-polar. The antenna pattern exhibits a small beam at the E-plane and a wide beam at the H-plane.

A GPR works by transmitting a generally known signal (electromagnetic waves) in the observable zone of the subsurface below the antenna. The transfer function of the observed zone is then recovered from the received signal. The propagation kernels are usually known for homogeneous, non-dispersive media and under far-field assumption, where the transmitted signal (before entering the target zone) is not modified by e.g. the medium, measurement hardware and the wave propagation itself, e.g. due to dispersion.

In the inhomogeneous GPR case, however both transfer function and transmit signal are typically unknown, e.g. due to coupling of antennas and ground. Therefore, the received signal can be expressed as a bilinear function over the transmitted signal and the transfer function of the medium. This problem is typically known as blind deconvolution problem. Since the structure of the signal is strongly location-dependent, instead of the precise signal domain a proper location-independent spanning domain is required, where the received signal can be represented in a compressible manner.

This spanning domain can be obtained by characterizing the WISDOM antenna in the free space and some primary scenarios, as well as analyzing the influence of the imaging method applied to the data. A high-resolution image for the polarimetric data analysis can be obtained if the transfer function is successfully recovered from the generated spanning domain.

The approach was tested on laboratory measurements and data obtained during field tests, and shows promising imaging performance.