EXPERIMENTAL VALIDATION OF RADAR FORWARD AND INVERSE SCATTERING MODELS FOR LAYERED NONSMOOTH MEDIA

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Problem Definition:

There are many current and potential applications for the use of low frequency radars in remote sensing of soil moisture and vegetation, subsurface characterization, and nondestructive testing. To retrieve the quantities of interest from radar measurements, inversion algorithms have to be used, which are typically based on iterative adjustments of parameters of the respective forward scattering models. Development of forward and inverse scattering models and their validation continue to be active areas of research. Often, these inverse models are validated using synthetic data obtained from the same forward models that are used in the inverse models under test. Therefore, the results from such validations can be limited and even misleading. Experimental validation is the most convincing approach for gaining confidence in both the forward and the inverse scattering models. The purpose of this work is to evaluate the validity of forward and inverse scattering models we have recently developed [1], [2], for multilayered media with non-smooth interfaces, which can be representative of bodies of water and layered soil structures. It is also aimed to advance the state-of-the-art for short range low frequency radar hardware and its calibration and field measurement techniques.

Methodology:

The system developed in this work is a proof of concept tower based pulse radar system operating at several frequencies. The pulse width, which determines the bandwidth and therefore the range resolution of the system, can be varied from 20 ns to 150 ns. The frequencies can be chosen between 130 MHz and 1.1 GHz depending on particular experiment requirements; the baseline configuration has three distinct bands centered at 140 MHz (VHF), 435 MHz (UHF), and 1 GHz (L-band). Generally the system is used for characterization of surface and subsurface properties of layered media, and in particular, it is intended for retrieval of parameters of three-layer media with non-smooth interfaces. Assuming the medium under the first interface is lossy, the response from the 2nd interface is negligible if the frequency is high enough. Therefore, higher-frequency measurements (1 GHz range for the current system) are used in conjunction with inverse scattering models to characterize parameters pertaining to the 1st interface. Once this step is complete, measurements taken at the lower frequencies are used to characterize the unknown parameters pertaining to the 2nd interface.

The inversion algorithm validated in this work relies on multiple forward model evaluations making the accuracy and robustness of the forward model of great importance. While the forward model has been tested and validated against other existing numerical models for a number of specific cases, experimental validation is needed to provide a more convincing evidence of the accuracy and applicability of the forward model. The experimental validation of the forward model is a challenging task as all of the parameters that go into the forward model must be obtained with high accuracy for every case of validation. The experimental validation of the inverse scattering model requires that several independent radar measurements be collected that span a large range of variations of unknown parameters. To obtain a unique solution the number of measurements should be no less than the number of unknowns in the inversion algorithm. Given the fixed number of frequencies (3) and available polarizations (4), if more data points are required for each scenario, they have to be collected by using multiple incidence angles. The radar system developed here is capable of producing such a data set.

There are a number of challenges in designing and operating short range low frequency radars. These challenges include antenna choice, radar hardware and calibration. In general, resonant antennas do not perform well for pulse based systems – the pulses are smeared which greatly decreases the quality of the measurements. Traveling wave antennas have much better pulse transmission characteristics but are generally several wavelengths in size – a requirement that can render them impractical at low frequencies. While short ranges allow for the much lower power levels to be used the hardware timing requirements are toughened to the nanosecond level. Electromechanical switches which have superior RF and power handling characteristics cannot be used at these speeds. Solid state switches can operate at these speeds but in addition to inferior RF performance can only handle about +20 dBm of power. The system used in this work is recently built new generation low frequency radar intended to achieve a better performance and replace older radar.

Calibration is normally performed by placing a bright known target (usually a corner reflector) in the bore sight of the antenna. Since standard corner reflectors are several wavelengths in size at VHF their size becomes impractically large. In this work three calibration procedures are used: electronic, sky and target. To calibrate out the effects of the electronic variability the transmit signal is fed to the receiver bypassing the antenna through a well calibrated attenuating load. To compensate for the transient response of the antennas, the sky calibration is performed. The radar antenna is pointed to the sky and the trance collected is used to calibrate out the antenna transient response from the subsequent measurements. The absolute calibration is performed using specially manufactured perforated corner reflectors.

Results and Conclusion:

Both forward and inverse scattering models were tested and validated for several environmental scenarios. The models tested showed efficiency and robustness. In addition, a number of technological improvements were made to the design and operation of the new generation of low frequency radars. The experiments in this work include (1) estimation of river channel cross-section (i.e., river depth) at St. Claire River in Michigan, and (2) soil moisture profile characterization at the University of Michigan Matthaei Botanical Gardens. The measurements in (1) are taken while the radar is parked on the river bank. The depths retrieved are validated with the in-situ water depth data collected from a boat using established sounding techniques. To validate the soil moisture retrievals in (2), a network of soil moisture sensors has been installed within the radar footprint. The estimation accuracies, sensitivities, and limitations in each case are investigated, and the utility of multiple-low-frequency radars for these subsurface characterization applications is established.

References:

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