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Enabling subfield scale soil moisture mapping in near real-time by recycling L-band GNSS signals from drones

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Accurate measurement of soil moisture (SM) at high spatiotemporal resolutions is one of the critical challenges of site-specific precision agriculture. Traditionally SM is measured manually or using □□ □□□□ SM probes scattered in the field. Although these observations are generally accurate and reliable up to the sensitivity level of the SM probe, it is very time-consuming, costly, and inefficient for large heterogeneous fields to acquire high-resolution SM measurements. Over the last several decades, microwave remote sensing approaches have become popular for measuring spatially distributed SM. Several space-borne missions, such as SMAP and SMOS, have been launched to provide surface SM measurements globally. Although all current satellite missions and their SM products are critical for many large-scale research and studies, their coarse spatial resolution (about 40km) makes it impractical for precision agriculture applications.

To enable subfield scale soil moisture mapping in near real-time, our team has recently developed an unmanned aircraft systems (UAS) -based multi-sensory system with Global Navigation Satellite System (GNSS) reflectometry (GNSS-R), a multispectral camera, and a LIDAR. A down-facing GNSS antenna with a ground plane blocks the direct GNSS signals, and it collects reflected carrier-to-noise density ratio (C/N0) measurements from multiple specular points on the ground for each visible GNSS satellite. The multispectral camera provides spectral images in blue, green, red, red edge, and near-infrared (NIR) bands. The LIDAR offers a 3D representation of the surface and vegetation. Such a comprehensive dataset has been collected in a field under different management practices for the last three years. The study field was organized with a split-plot arrangement and was planted with corn and cotton as the main crops. We have performed 581 flights over the study field and collected more than 4 TB of data, including visual and multispectral images and LIDAR point clouds. More than 2.5 million L-band reflection samples have been collected over the field. In addition, □□ □□□□ SM and intense manual SM observations over the field have been collected as ground truth information.

Observed GNSS-R data is dependent not only on the SM but also on the vegetation, surface roughness, topography, soil texture, GNSS satellites' positions, transmitter characteristics, receiver orientation, and flight parameters through a combination of linear and nonlinear relations. To learn such a relationship, we developed a machine learning (ML) model using multiple sensory input features for high-resolution, low-cost, and easily accessible SM mapping for precision agriculture. In this study, we will present the multi-year field campaigns and the development of the ML framework with convolutional and fully connected neural network layers for SM mapping that can utilize multiple imageries jointly with other physical and microwave data and calculate features relevant to SM. During the model development, site and time-independent cross-validation methods are used for better model generalization and performance evaluation.