Grid Size Optimization for Soil Moisture Estimation Using UAS-based GNSS Reflectometry

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The agriculture industry consumes 70% of the world's available freshwater, making efficient water use essential to ensuring sustainable practices. Precision agriculture, through accurate soil moisture (SM) measurements, can play a pivotal role in optimizing irrigation, reducing water wastage, and conserving critical resources. However, obtaining precise SM data across large agricultural areas remains a significant challenge. In-situ invasive SM probes can deliver highly accurate data but are limited to localized, point-based measurements that do not provide complete field coverage. Conversely, satellite-based SM measurements, such as those from the Cyclone Global Navigation Satellite System (CYGNSS), Soil Moisture Active Passive (SMAP), etc., offer extensive coverage but at resolutions (in kilometer range) that are insufficient for the high spatio-temporal accuracy required in precision agriculture.

To address these limitations of coverage and resolution, we propose an Uncrewed Aircraft Systems (UAS) based Global Navigation Satellite System (GNSS) Reflectometry (GNSS-R) approach for SM measurement at a sub-field level. This study explores several SM resolutions with different accuracies that can be achieved using a UAS approach. We utilized a dataset collected from an agricultural field in Mississippi, USA, containing data products from GNSS-R, multispectral imaging (MSI), and Light Detection and Ranging (LiDAR), along with in-situ SM measurements. The dataset spans 3 years and includes 337 GNSS-R flights at an altitude of 15 m above ground level. If we can determine a resolution for the GNSS-R surface reflectivity estimates, we can extract appropriate vegetation and roughness information using the MSI and LiDAR data. For instance, at 5 m/s drone speed, using 1s data integration specular points (SPs) at each 5 m for every visible satellite can be obtained. Thus, 5 m $\times$ 5 m resolution can be assumed but the resolution also depends on the size and orientation of the Fresnel Zone (FZ). The dimension of the FZ for a receiver at 15 m height, for satellites at elevation angles between 30° to 65° (empirical angle range for reliable received signal strength), varies between 5 m to 10 m in minor and major axes.

This study employs grid sizes ranging from 5 m to 30 m. For each grid, the reflectivity within neighboring grids was averaged to calculate the aggregated grid cell's overall reflectivity. Our analysis indicated that the correlation between reflectivity and in-situ SM measurements improved as the grids were aggregated. This improvement is likely due to a larger number of SPs within the grid, providing more data points to average. To examine the impact of the FZ size on grid reflectivity, we considered only those SPs where the FZ overlapped with more than a certain threshold of the grid area (e.g., 50%, 75%). The correlation between the estimated reflectivity and in-situ SM measurements was then evaluated to determine the most optimum grid size and SP selection criteria for each grid. In this study, we analyze the trade-offs involved with integration time, grid size, crop growth stage, and optimal feature extraction strategies for SM estimation, and the comprehensive result will be presented at the conference.