CHARACTERIZATION OF FULL SURFACE ROUGHNESS IN AGRICULTURAL SOILS USING GROUNDBASED LIDAR

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1. INTRODUCTION

Surface roughness characterization is an important step in the mapping of soil moisture using microwave remote sensing techniques. A recent literature review by Verhoest et al. [1] concluded that "the way [soil] roughness needs to be described and measured for the modeling of backscattering is not fully understood…". According to Ulaby et al. soil roughness can be considered as a stochastically varying height of the soil surface relative to a reference surface [2]. Roughness is generally described as a single-scale process and characterized by three metrics: the root mean square (RMS) of it height, the correlation length and the shape of its autocorrelation function (ACF). To obtain these metrics researchers have used several different instruments and practices. The general practice is to record the terrain height variation along transects using either contact (pin profilometer and meshboard) or non-contact instruments (LASER profilers, stereo cameras, acoustic, infrared and ultrasonic devices). [1] The obtained profile then needs to be detrended in order to separate the random component from the reference surface. The roughness metrics are then obtained from the random component data.

The non contact instruments are preferred for roughness characterization, as they do not disturb the surface, and they can obtain terrain profiles more efficiently in a remote fashion. Among the non-contact instruments, the LASER based are the most popular. Examples of LASER profilers include the ESA CESBIO LASER profiler described in [3] and the Wageningen University Micro-LASER relief meter described in [4]. Commercially available LiDAR sensors have the potential to revolutionize the way surface roughness is characterized. Some examples of the use of LIDAR include work by Davenport et al [5, 6] in which roughness metrics and corresponding errors were characterized from airborne LiDAR measurements near Coventry, England. Perez-Gutierrez et al. used a Trimble ground based terrestrial LiDAR to obtain four 20m x 20 m field surface samples in the Duero Basin, north central region of Spain [7]. Bryant et al. employed an Optech Ilris-3D in Arizona, USA to obtain profiles that then were compared against pin profiler measurements [8]. Despite these early efforts, the potential of full surface digitization with high accuracy, fine sample spacing and large area coverage, attainable from LiDAR has not yet been fully exploited.

The values of these roughness metrics can vary over a relatively large range even for the same field using the same technique. This is because current roughness metrics are defined under assumptions of isotropy and single scale. However, agricultural fields are anisotropic especially for plowed fields which exhibit very different roughnesses in the parallel and perpendicular directions with respect to the rows. Many studies recognize the multiscale nature of soil surface, however, its has never been shown at what scale or dimension surface roughness needs to be characterized to yield an accurate description of the electromagnetic scattering or emission [1]. Also the way three-dimensional roughness characteristics of a surface are deducted from two-dimensional profiles may cause underestimation of the metrics as the profiles might not record the extremes of the surface. Bryant et al. showed that in order to obtain consistent RMS values from short profiles (~ 3m in length) an average of RMS values from at least 20 independent profiles must be obtained from the study area [8]. Extensive studies have shown that RMS for agricultural soils typically lie in the range from 2.5 mm for sown fields to 4 cm for plowed fields. With respect to the correlation length, it has been extremely difficult to obtain consistent ranges of correlations lengths; obtained values typically lie between 2 and 20 cm. Consistent estimation of correlation lengths is problematic because it is sensitive to digitization parameters such as length of the profile and the sampling distance. Some studies recommend that to fully characterize the autocorrelation function of a surface the profile sampling distance should be at least as small as one tenth of the expected correlation length with long profiles. Finally, the shape of the ACF, which is typically assumed to be either exponential or Gaussian, has a significant effect on the output of random surface microwave scattering models, such as the IEM, and, these theoretical descriptions do not always describe well the roughness of natural surfaces [1].

With this work it will be demonstrated that by digitizing the full soil surface using high resolution LiDAR, rather than undersampling it by profiles, several of the documented limitations of the current roughness metrics can be resolved. This approach has several advantages. First, the roughness will be derived from a remote measurement of the physical surface structure and not through inference or modeling. Second, the complete surface model allows for an accurate characterization of the surface that produces the scattering or emission of microwave energy. It also enables its analysis in a space-frequency domain through wavelets; the wavelet analysis will provide an accurate characterization of the surface properties and allows for the proper separation of the reference and random components. Finally, a wavelet-based approach makes it possible to obtain the traditional soil roughness metrics used in the models at any given scale, which should be related to the sensor wavelength.

2. INSTRUMENTATION, METHODS AND RESULTS

Data were collected employing the University of Florida Mobile Terrestrial LASER Scanning system (M-TLS). The M-TLS acquires high density LiDAR point clouds from an advantageous terrestrial geometry. The core of the M-TLS is the Optech's ILRIS 3D, a commercial 2-axis time-of-flight ground based laser scanner. The ILRIS is integrated with a mobile telescoping, rotating, and tilting platform which provides up to 6 degrees of freedom for performing scanning operations. The platform is mounted on the bed of a heavy duty 4x4 truck that enables the system to operate in off-road environments. The ILRIS-3D is capable of generating XYZ and intensity values for each laser returnalong with RGB textured point clouds in a range from 3m to 1500m for targets with an 80% reflectivity or 3m to 350m for targets with a 4% reflectivity. The laser operates at a wavelength of 1535 nm, with a pulse width less than 10 ns and energy of less than 10μjoules. The sample separation can be adjusted down to 0.00115°, and the laser pulse rate is 2,000 shots per second [9]. The M-TLS was used to obtain three-dimensional point clouds of the soil surface from a height of 5 to 7 meters, with a sample spacing that ranged from 5 mm to 3 cm and covering areas of several hundred square meters per scan. An extensive dataset of agricultural fields at different preparation stages has been collected over several years at the University of Florida Plant Science Research and Education Unit (PSREU), which is located near Citra, Fl.

Raw LiDAR data consist of irregularly spaced point clouds with an arbitrary reference frame determined by the orientation of the ILRIS instrument at the moment of data collection. The initial processing step is the transformation of the point cloud such that a best-fit plane through the scanned points is leveled and the orientation of the reference frame aligns in some way with the agricultural field. From the leveled point cloud, horizontal rectangular regions of interest are cropped. The resultant irregular point clouds are then interpolated to create regular grids with cell spacings that range between 5 mm and 2 cm. From these grids the roughness analyses were performed. The analyses performed included: comparison of roughness metrics obtained from an averaging of metrics obtained from a sample of 12 individual profiles as concluded by Bryant et al. [8] against the metrics obtained from the full surface model; the characterization of the reference surface plane vs. a parabolic reference; the effects of detrending, and multiscale reference surface generation.

Preliminary results indicate that the surface RMS obtained from a sample of profiles is generally smaller than the RMS obtained for the full surface by up to 1 cm, where as the correlation length is also smaller, up to 1/3 smaller than the average correlation length obtained from the entire surface. It was also observed that soil surfaces with linear extent exceeding 5m on a side tend to follow second order trends rather than simple planes; this can be expected as a result of natural erosion processes. Detrending by first vs. second order has considerable effect on the RMS and correlation length values. With a sample of 12 profiles extracted from the grid it was found that if coefficients of determination R^2 for the second order trend increased between 40 to 50% with respect to the first order trend, RMS values decreased by roughly 25% and correlation lengths decreased by roughly 50%. For those whose R^2 increased close to 70%, RMS values reduced by roughly 50% and correlation lengths decreased by roughly 65%. Finally, it was possible to generate reference surface models at different scales using wavelet decomposition. However, the analysis of the roughness metrics derived from these models and the appropriate scales needs further development.

3. CONCLUSIONS

Full surface, high resolution 3D models of agricultural soils obtained from LIDAR can allow us to better understand the way we characterize surface roughness and in turn can improve the way we model microwave scattering and emission and thus improve soil moisture mapping.

4. REFERENCES

[1] N.E. Verhoest, H., Lievens, ; W. Wagner, J. Álvarez-Mozos, M..S. Moran, F. Mattia. “On the Soil Roughness Parameterization Problem in Soil Moisture Retrieval of Bare Surfaces from Synthetic Aperture Radar”. Sensors 2008, 8, pp. 4213-4248.

[2] F. T. Ulaby, R. K. Moore, A. K. Fung, “Microwave Remote Sensing: Active and Passive”; Artech House: Boston, MA, 1982; Vol. II.

[3] M. Callens, N.E.C. Verhoest, M.W.J. Davidson “Parameterization of Tillage-Induced Single-Scale Soil Roughness From 4-m Profiles,” Geoscience and Remote Sensing, IEEE Transactions on , vol.44, no.4, pp. 878-888, April 2006.

[4] Zhixiong, L.; Nan, C.; Perdok, U.D.; Hoogmoed, W.B. Characterisation of Soil Profile Roughness. Biosystems Engineering 2005, 91, 369-377.

[5] Davenport, I. J., Holden, J., Pentreath, R. J. Derivation of soil surface properties from airborne laser altimetry. In Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS '03), Toulouse, France, 2003; pp. 4389 – 4391.

[6] I.J. Davenport, N. Holden, R.J., Gurney, "Characterizing errors in airborne laser altimetry data to extract soil roughness," IEEE Trans. Geosc. Remote Sensing, 42, pp. 2130-2141, 2004.

[7] Perez-Gutierrez, C.; Martinez-Fernandez, J.; Sanchez, N.; Álvarez-Mozos, J. Modeling of soil roughness using terrestrial laser scanner for soil moisture retrieval, In Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS 2007), Barcelona, Spain, 2007; pp. 1877-1880.

[8] R. Bryant, M.S. Moran, D.P. Thoma, C.D. Holifield Collins, S. Skirvin, M. Rahman, K. Slocum, P. Starks, D. Bosch, M.P. González Dugo, “Measuring surface roughness height to parameterize radar backscatter models for retrieval of surface soil moisture,” IEEE Geosc Remote Sens. Letters 2007, 4.

[9] J. Fernandez-Diaz, “Scientific applications of the Mobile Terrestrial Laser Scanner (M-TLS) system,” unpublished master’s thesis, University of Florida, Gainesville, Florida, 2007. available at: http://purl.fcla.edu/fcla/etd/UFE0021101