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Improvements in farmland surface roughness measurement by employing a new laser scanner

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ABSTRACT

Farmland surface roughness is related to the surface root mean square height (rmsh) and surface correlation length (cl), and it is not only an important factor influencing wind and water erosion but also an input parameter for modeling radar backscattering coefficients and the passive microwave brightness temperature. Although these surface roughness parameters are important for soil erosion estimation and land surface parameter retrieval from microwave remote sensing data, their measurement accuracy is limited by the measurement method, instruments used and data preprocessing. To obtain high-precision surface roughness measurements, a laser scanner with spatial measuring range of 400 mm × 600 mm is used to measure the surface height of four test sites with different surface roughness. Based on the surface height data measured using the laser scanner, the effect of segment number on the surface roughness accuracy is analyzed using the random sampling method. The results show that the measurement uncertainties $rmsh_m$ and cl_m decrease with increasing segment number. Among all four test sites, 80% and 90% accuracies can be achieved for $rmsh_m$ and cl_m, respectively. In addition, the required segment number for the same cl_m accuracy is found to be related to the degree of surface roughness, but this conclusion does not hold for $rmsh_m$. In summary, the accuracy of the surface roughness measured by the laser scanner is greater than 80%, and this scanner is very suitable for field measurements due to its ease of operability and mobility.

1. Introduction

As an important factor to control wind erosion, water erosion and surface scattering, the surface roughness can be measured in many ways. However, the required measurement accuracy is difficult to attain due to the limitations of the different methods (such as large spatial sampling interval, short sampling segment, the shortage of measuring segments and inconvenient operation).

Surface roughness is defined as the topographic expression of surfaces on horizontal and vertical scales of millimeters to a few hundred meters. These are the scales with which the field geologist is most familiar and are therefore of value to those studying the geology of the earth or terrestrial planets. These same scales also have the largest effects on the behavior of scattered and radiated microwaves (radar and radiometer) and are therefore of interest to any geologist interpreting radar and radiometer data (Shepard et al., 2001).

For agriculturalists, surface roughness describes the micro-variation in the surface elevation across a field resulting mainly from tillage practices and soil texture; additionally, surface roughness is a major factor influencing wind and water erosion (Vidal Vázquez et al., 2005; Moreno et al., 2008). Soil surface roughness can also predict wind erosion by defining the potential for soil particle retention, emission and saltation (Zhang et al., 2002; Moreno et al., 2008). The soils of semi-arid regions such as Northwest China suffer mainly from wind erosion, where the loss of both organic matter and nutrient-rich topsoil affects soil productivity and air and water quality (Dong and Kang, 1994; Chen and Ma, 2006).

Accurately measuring surface roughness parameters is important for agricultural scientists as well as for remote sensing scientists because these parameters (such as rmsh, cl and rmsh/cl) used to describe the farmland surface roughness help to explain and quantify the surface-scattered components of incident microwave radiation. More specifically, these parameters are the inputs of microwave physical surface scattering/radiation models (AIEM and IEM) and semi-empirical surface scattering/radiation

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models (QP, QH and HP models) (Fung et al., 1992; Chen et al., 2003; Wang and Choudhury, 1981; Wigneron et al., 2001; Shi et al., 2005). In the process of developing and validating microwave remote sensing surface parameter inversion algorithms, high-precision surface roughness parameters are very important.

The methods of measuring surface roughness can be classified into two categories: contact methods and non-contact methods. The former includes the grid plate method and the profiler method, and the latter includes the laser profiler, stereophotography and pencil-beam radiometer sampling methods (Verhoest et al., 2008; Davidson et al., 2000; Zribi et al., 2000a,b; Zheng and Zhao, 2010). Although all these methods can measure surface roughness, they have different measurement accuracies for surface roughness. Regardless of the measurement method, measurement accuracy is controlled by the spatial sampling interval (Δx, such as the grid size of the grid plate, spatial interval of two neighboring pins for the profiler or spatial resolution for a laser scanner) and segment sampling length (L).

To obtain approximately 90% accuracy for the surface roughness measurement, the length of the measured segment should be at least 40cl long and 200cl long and the segment should be sampled at a spacing no longer than 0.2cl, where cl is the mean (or true) surface correlation length value (Oh and Kay, 1998). In practice, the spatial sampling interval requirement is easy to implement, but the segment length requirement is difficult to attain. We assume that the correlation length of the farmland surface is 7 cm and that the required segment lengths are 2.8 m and 14 m for 40cl and 200cl, respectively, to meet the requirements for 90% measurement accuracy. The instrument used to measure such long segments would be very large and inconvenient to operate. Fortunately, averaging several surface roughness of shorter segments can compensate for a deficiency in the long segment requirement (Oh and Kay, 1998).

Based on this conclusion, a laser scanner with the ability to measure approximately 100 short segments in one scan is used in this paper to measure farmland surface roughness. The purpose of this paper is to analyze the uncertainty of the estimated surface roughness derived from the laser scanner data, evaluate its accuracy of estimated surface roughness and confirm its application in surface roughness measurement.

2. Data and methods

2.1. Laser scanner

A laser scanner, manufactured by the microwave remote sensing center of Northeast Institute of Geography and Agroecology (IGA) at the Chinese Academy of Sciences (CAS), is used to measure farmland surface roughness (Fig. 1). The semiconductor laser unit of this instrument emits laser light, and a red laser line is formed at soil surface. Two cameras are fixed on the sides of the semiconductor laser unit, and each camera can take a photograph of the observed surface. Then, the height of each point on the laser line can be computed from two photographs based on triangulation and coordinate transformation (Li et al., 2012). Controlled electronically, the semiconductor laser unit as well as the laser line moves from left to right, the entire measured surface is scanned and the height of this surface is obtained. The standard scanning area of this laser scanner is 400 mm × 600 mm, and it requires 20 s to scan the entire area. Table 1 lists the details for this instrument.

The laser scanner is characterized by high spatial resolutions of approximately 1 mm in the x, y and z directions and relatively short segment lengths – approximately 60 cm in the y direction. The spatial resolution of this instrument is 1 mm, which is far less than $\lambda/10$ in the L-band. Thus, the scanner is well suited for capturing the roughness information at those spatial scales important for modeling the backscattering coefficient from bare surfaces for current and future SMOS (soil moisture and ocean salinity) (Kerr et al., 2012) and SMAP (soil moisture active passive) (Entekhabi et al., 2010) missions.

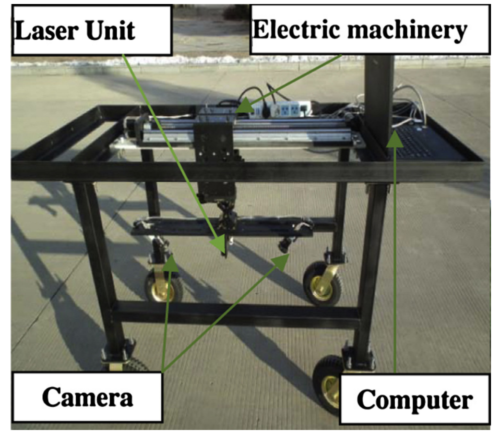

Fig. 1. Laser scanner built by IGA.

2.2. The experiment

To obtain a wide variety in roughness conditions and minimize the dependence of the results on a particular site, four separate sites were selected for the measurement campaigns. The four selected sites are located in the Daman irrigation district of the Heihe watershed. This watershed is located within 37.7–42.7°N, 97.1–102.0°E, covering an area of approximately 1,432,000 km^2. This basin is characterized by its distinct cold and arid landscapes: glaciers, frozen soil, alpine meadow, forest, irrigated crops, riparian ecosystem, and desert, which are distributed upstream to downstream.

In June 2012, an airborne experiment was carried out in the middle stream of Heihe watershed. During the time, soil surface height was measured by the laser scanner mentioned in Section 2.1. Four typical land covers in the middle stream of Heihe watershed are selected as the study site for estimating soil surface roughness. For simplicity, Test 1, Test 2, Test 3 and Test 4 are used to represent the Gobi desert, watermelon land, corn land and young plant nursery, respectively. Each test site was scanned once, and about 120 segments with a length of 600 mm were obtained for each test site except for Test 4. The scanned point of segment located inside of the observed test area is too small. Therefore, these segments were considered invalid and could not be used to estimate surface roughness. This is why the scanned segment number is less than 400 (the standard segment number). These four sites have different land cover (Fig. 2) and different surface roughness characteristics, which will enable evaluating the laser scanner roughness measurement accuracy in different surface roughness conditions.

Compared to Fig. 1, the black cover on the outside of the laser scanner (Fig. 2) is designed to prevent sunlight and parasitic light from entering the scanning area of the laser scanner. These other light sources could affect the identification of the red laser line

Table 1
Technical specifications of laser scanner (unit: mm).

Axis	x	y	z
Sampling range	400	600	400
Spatial resolution	0.78	1	0.83