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Snow surface roughness from mobile laser scanning data

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ABSTRACT

Mobile laser scanning is a rapid and flexible method for acquisition of high resolution three-dimensional topographic data. Lidar based mobile mapping system produces three-dimensional point cloud from the surrounding objects. Typically, a two-dimensional profiling scanner is mounted on the system and the third dimension is achieved by the movement of the vehicle. The characteristics of the obtained point cloud depend largely on the sensor arrangement and the sensor properties.

In this paper we discuss an application of mobile laser scanning for producing snow surface roughness information for climate data validation. The ROAMER, a single-scanner mobile laser scanning system, was deployed for the survey of three dimensional snow surface data.

Relatively large areas could be reached with mobile laser scanning, which improves the output of surface roughness measurements and increases the statistical validity.

The accuracy and precision of the mobile scanning system used in the study are almost at the same level as those of terrestrial laser scanners. The relative point precision for the system is estimated to be a few millimetres with centimetre level absolute positioning. The results show that the roughness produced from the data is in agreement with the validation data obtained from the plate photography process. This means that mobile laser scanning can be successfully used in snow surface roughness determination from large areas. The major challenge is related to direct georeferencing of mapping sensor data with global satellite navigation and inertial positioning. However, computation of surface roughness is a local operation, where the absolute accuracy is of little significance, but good relative precision is essential. The dense sampling of the surface enabled us to study multi-scale approach for surface roughness modelling, which is discussed more in this paper.

We believe that even in the near future, mobile laser scanning will be considerably exploited in many applications in the environmental modelling and monitoring e.g. in forestry, hydrology, glaciology and climate sciences.

1. Introduction

Laser scanning is a technology that has revolutionized the surveying industry in producing topographic information in the past two decades (Bufton, 1989; Flood and Gutelius, 1997; Lohr and Eibert, 1995). Its use has contributed in microscale and fine toposcale mapping of the Earth from satellite and airborne platforms (Garvin et al., 1996; Haala et al., 1998; Hyyppä et al., 2001; Kraus and Pfeifer, 1998; Maas and Vosselman, 1999; Naesset, 1997). Since the advent of this technology, laser scanning has been used to produce in ever more detailed mapping and modelling of terrestrial systems (Alho et al., 2011; Connor et al., 2009; Heritage and Milan, 2009; Hyyppä et al., 2012; Jaakkola et al., 2008; Kaartinen and Hyyppä, 2006; Lehtomäki et al., 2011; Rutzinger et al., 2011; Zhu et al., 2011). This means a vast diversity in sensor systems applied on to static or mobile platforms. Static laser scanning provides details and accuracy, but is limited with coverage. Kinematic applications of laser scanning are becoming more into use as they provide effective data collection over larger spaces.

Mobile laser scanning (MLS) is a method for acquiring three-dimensional topographic data. The survey is conducted as the ground vehicle moves around while the navigation system, typically based on a global navigation satellite system (GNSS) and inertial measurement unit (IMU), tracks the vehicle's trajectory and attitude for producing a 3D point cloud from the range data collected by the onboard scanners.

The characteristics of the obtained point cloud depend largely on the sensor arrangement and the sensor properties. The use of MLS for snow surface measurement and monitoring was studied in our previous paper (Kaasalainen et al., 2010). The first results demonstrated the potential of MLS for fast and accurate snow profiling of large areas, which is further investigated in this study.

Surface albedo is one of the essential climate variables (ECV) defined in the Implementation Plan for the Global Observing System for Climate in Support of the United Nations Framework Convention on Climate Change (UNFCCC) (http://unfccc.int/2860.php). The reflectance of new pure snow can be 98% (Warren and Wiscombe, 1980). The

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seasonal snow cover can occupy 50% of the land area of the Northern Hemisphere (Mialon et al., 2005) thus having a considerable effect on the earth's energy budget. Therefore it is essential to understand the behaviour of seasonal snow cover and in particular its optical properties.

The importance of the snow and ice albedo for climate and the earth's energy budget has been widely recognized (e.g., Hudson, 2011). Surface roughness is one of the main features affecting the optical properties of snow cover (Warren, 1982) including the bidirectional reflectance distribution function (BRDF) (Warren et al., 1998) and surface albedo (Shuravleva and Kokhanovsky, 2011). Therefore it is an important variable in remote sensing. According to Williams and Gallagher (1987) the microwave backscatter end emission from snow cover depends mostly on wet snow surface roughness. Despite the importance very little research has been done on the subject.

Surface roughness in general has been widely studied and described with a number of parameters (Church, 1988; Fassnacht et al., 2009a, 2010; Hollaus et al., 2011; Lacroix et al., 2008; Manes et al., 2008; Manninen, 2003; Rees and Arnold, 2006), and a good overview can be found in Dong et al. (1992, 1993, 1994a, 1994b). The choice of parameters depends on the application. In remote sensing the most commonly used parameters are the root-mean-square (rms) height and the correlation length. However, snow surface roughness is a multi-scale and multi-directional phenomenon affected by several factors, some of which are global (sun elevation, maritime/continental, tundra/taiga) and some local (prevailing wind direction, distance to the canopy, undergrowth, moisture and temperature of the soil, rain and other climate conditions). All these factors affect the snow metamorphism and through that the surface roughness (Fassnacht, 2010, 2004). Therefore the rms height and the correlation length are not fully able to describe the nature of surface roughness (Church, 1988; Keller et al., 1987; Manninen, 1997a). Some multi-scale parameters have been developed (Davidson et al., 2000; Manninen, 1997b, 2003) but attempts to capture the directionality of the surface roughness are considerably fewer. Herzfeld (2002) used higher order vario functions in snow surface roughness descriptions and Trujillo et al. (2007) presented a directional spectral analysis on the spatial distribution of snow. Lacroix et al. (2008) present a recent review of snow surface roughness measurements.

One reason for the lack of research on surface roughness can be the difficulty of measuring it. In remote sensing all surface roughness scales above the wavelength used are important (Rees and Arnold, 2006). Many studies have been made to measure roughness by airborne laser scanning systems and satellite based radars (Höfle et al., 2007; Hollaus et al., 2011; Van der Veen et al., 2009). These methods are able to measure the meso- and topography scale roughness. Manes et al. (2008) presented the roughness effects in terms of two categories: type I for grain size scale and type II for structures up to 16 times the average crystal size. The small scale roughness is typically measured with photography-based methods. Elder et al. (2009), Fassnacht et al. (2009a, 2009b), Manes et al. (2008), Manninen et al. (2012) and Rees (1998) have measured the small scale surface roughness by partially inserting a plate in the snow, photographing the plate with the snow–plate interface and later analysing the profile. This method gives a detailed profile for the width of the plate (typically app. 1 m). The downside of these methods is that the length of the profile is limited. Also, if you want to cover larger areas it is labour intensive and time consuming. In addition to this, the profile measurements produce 2D-data, while snow surface roughness is a 3D phenomenon with considerable directionality.

The use of airborne and terrestrial laser scanning on snow covered areas has previously been focused on forming surface models and monitoring changes in snow depth (Arnold et al., 2006; Hood and Hayashi, 2010; Kaasalainen et al., 2008; Prokop, 2008; Prokop et al., 2008). Snow properties that have been studied with lidar are, for example, snow thickness, water contents (Schaffhauser et al., 2008; Schirmer et al., 2011; Várnai and Cahalan, 2007) and depth distribution of snow (Schirmer and Lehning, 2011). Lehning et al. (2011) used terrestrial laser scanning data to model snow distribution. Also the use of laser intensity data has been studied for snow characterization (Anttila et al., 2011).

Compared to airborne laser scanning (ALS), MLS suits better for areas that are limited in size, and where precision and level of details are of any concern. It also provides considerable advantage over traditional manual data acquisition processes in terms of data coverage and effort. In addition, MLS can be used for acquiring precise multi-temporal data for change detection, and for studying processes causing them, like wind erosion.

Different laser scanning-based surface roughness measurement systems have been developed (Lacroix et al., 2008). TLS data have been used and found useful for surface modelling for, e.g., river-bed roughness in fluvial geomorphology (Heritage and Milan, 2009) and for soil erosion models (Eitel et al., 2011). ALS has proven efficient for the characterization of roughness over large areas, such as ice sheets (van der Veen et al., 2009) or forest canopy (Weligepolage et al., 2012), or to be used as input in the modelling of natural hazards (Hollaus et al., 2011).

In this paper we study the applicability and accuracy of mobile laser scanning data in characterizing snow surface roughness. The mobile laser scanning data were acquired with the FGI ROAMER (see Kukko et al., 2007, 2012 for system details and performance) in Sodankylä, Finnish Lapland during the melting period in spring 2010. We compare the results with surface roughness plate measurements made at the same location shortly after the scanning. The measurements were made as a part of Snow Reflectance Transition Experiment (SNORTEX)-campaign (Roujean et al., 2010).

2. Surface data capture and mobile laser scanning system

2.1. Study site

The measurements were carried out in Sodankylä, Finnish Lapland (67.4°N, 26.6°E) during the series of SNORTEX-campaigns taking place during the melting seasons of 2008, 2009 and 2010. The MLS and validation measurements were made 18th of March 2010. The 2.5 km long mobile laser scanning route and corresponding scan data are shown in Fig. 1, and followed the marked snow mobile trail that passes through open marshland and sparse pine forests. The reference surface roughness plate measurements (described in Section 3) were made along the trajectory shortly after the scanning at 11 locations shown in Fig. 1 as well.

2.2. Mobile laser scanning system

The FGI ROAMER mobile laser scanning system was deployed for capturing the three-dimensional snow surface topography. It is a system primarily developed for urban mapping, but its use for environmental applications is increasing. The ROAMER system is equipped with a FARO Photon 120 laser scanner and NovAtel SPAN GPS–IMU system, altogether with data synchronizing and recording devices. Table 1 summarizes the equipment and main characteristics. The laser unit provides a scanning (cross-track swath) frequency range of 3–61 Hz and point measurement rate of 120–976 kHz with ranging ability up to 150 m. The point measurement accuracy of the scanner is 2 mm with 1 mm repeatability for 90% reflective target according to the scanner manufacturer, but depends in practice on the object surface type and reflectivity, as well as the object orientation relative to the scanning beam.

The integrated tactical grade GPS–IMU system observes the GPS satellites and platform movements in order to reproduce the system trajectory for laser scanner data georeferencing. When fused in post-processing, the GPS–IMU data provide the laser scanner position and attitude recordings as function of time at 100 Hz data rate. The laser point data are time synchronized to the trajectory data in order to produce a three-dimensional point cloud of the scanned area similar to airborne laser scanning.