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Mapping of understory lichens with airborne discrete-return LiDAR data

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ABSTRACT

High backscatter reflectance at NIR wavelengths has been observed for reindeer lichens (*Cladina* sp.) in the laboratory. The results suggested that lichens could be separated from soil and other parts of forest understory using this property. An experiment was carried out to test this hypothesis *in situ*. The lichen vegetation of a 960-m^2 plot in a barren pine stand in Juupajoki, Finland was mapped in 3D, using methods of close-range photogrammetry. The data of two airborne discrete-return sensors were compared for their ability to classify understory lichen vegetation. Normalization of the LiDAR intensities was carried out, using natural targets. The results showed that lichen surfaces had a higher intensity than on average. Normalization of the intensities improved separability of lichens from other surfaces, and the best-case classification accuracy was 75%. Detailed analysis of geometric errors revealed small, decimeter-level planimetric offsets in the LiDAR datasets that affected the results notably.

1. Introduction

Airborne ranging LiDAR systems are operated in a monostatic configuration; the target is illuminated and the reflected echo is registered from the same direction at the 0° phase angle (Wehr & Lohr, 1999). In LiDAR, the maximum amplitude of the echo is referred to as the intensity and is a quantity analogous to backscatter. A strong peak in target reflectance occurs typically near the 0° phase angle, which is known as the hot spot in remote sensing. The backscattering surge is observed for most surface types, including vegetation canopy structures (e.g. Russell et al., 1997).

Commercial, discrete-return, ranging LiDAR systems use pulsed lasers. A short, narrow cone of pulsed energy is transmitted and received. A discrete-return LiDAR extracts 1–4 echoes from the received waveform by logging the times when the return intensity exceeds a threshold. The time information transforms into a range and, using instrumentation for accurate positioning and attitude observations of the sensor, the 3D vector lidar target can be computed, giving the 3D coordinates of the scatterer. For each point, an intensity measurement is usually registered.

The factors that affect the observed intensity are many. They include the intentional and random output power variation of the transmitted pulse, fading (the speckle effect), electronic noise in the receiver and the background noise, changes in the receiver sensitivity, the wavelength used, surface geometry and reflectance (Morsdorf et al., 2007), pulse width, scanning distance and angle, as well as the two-way transmission losses in the path of the signal (Ahokas et al., 2006; Kaasalainen et al., 2007a; Wehr & Lohr, 1999). In one LiDAR campaign, the variation due to the deviating lidar target distance (the range) is the most important factor to be accounted for on rough vegetation surfaces (Hopkinsson, 2007; Kaasalainen et al., 2007a). Work on developing methods for absolute calibration and retrieval of surface albedo from calibrated intensity observations is also ongoing (Ahokas et al., 2006; Kaasalainen et al., 2005, 2007a). Future laser scanning runs may be carried out using hyperspectral systems (Kaasalainen et al., 2007b).

The use of LiDAR intensity for surface classification is based on the differences in backscatter properties of the objects. Intensity has not been used extensively in the context of mapping forest vegetation. One reason may be that the intensity measurements have been noisy until recently. Intensity metrics were used for the classification of tree species (Brandtberg, 2007; Donoghue et al., 2007; Holmgren & Persson, 2004; Ørka et al., 2007), for modeling of canopy gap fraction (Hopkinson & Chasmer, 2007), and for land cover classification (Brennan & Webster, 2006). LiDAR is particularly effective in the mapping of topographic relief under forested conditions, because it offers means of finding gaps in the canopy, where the geometry of terrain and the understory flora can be sampled without interaction by the upper canopy. It is an active instrument and thus largely unaffected by shading. In terms of monitoring applications, the high geometric accuracy of airborne LiDAR aids in improved change detection accuracy. Spectral mixing in 3D is present inside the footprint of the energy cone and, in contrast to images, LiDAR

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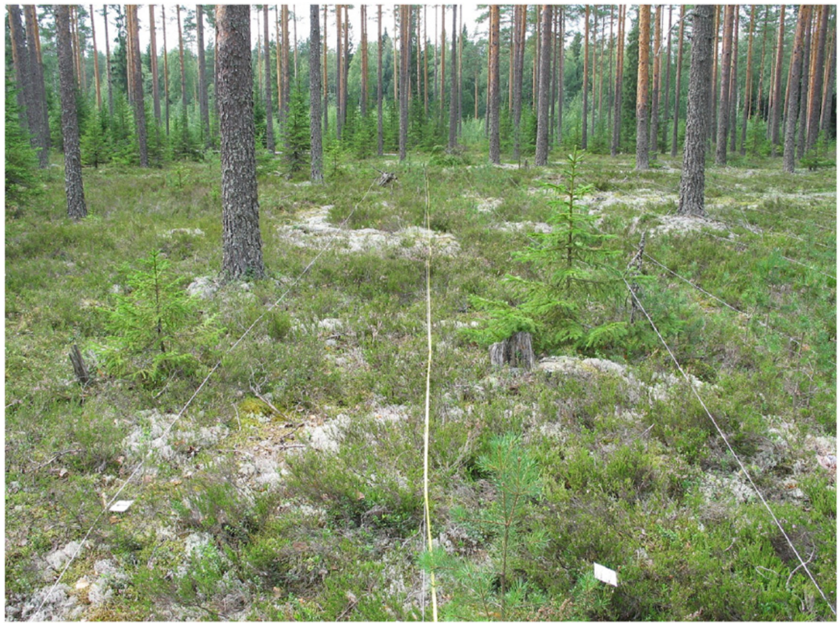

Fig. 1. SE corner of the plot, view towards west. The shrub layer consists mostly of *Calluna vulgaris*.

provides discrete point sampling, whereas images have a continuous 2D coverage.

In boreal forests, lichens are present on almost all surfaces. There are epiphytic lichens high in the canopy that envelop bark, shoot and needles. They affect the spectral signal observed and can thus be considered a source of biological noise in tree species recognition by remote sensing, for example. In Finland, ground lichens that grow on mineral soil or on peat surfaces are common on the most barren, Scots pine pine-dominated sites, where their coverage can reach 100%. The LAI of trees is low at these sites and the coverage of soil lichens correlates negatively with site productivity, i.e. the lichen coverage indicates site productivity. Soil lichens are affected by forest succession, forestry operations (through light conditions affected by intermediate felling, use of fertilizers, soil preparation), air pollution, and reindeer grazing (e.g. Olsson & Kellner, 2006). Field monitoring and inventory of lichens is laborious. A large representative set of sample plots is required, and to improve the accuracy of monitoring, permanent plots are preferred. Remote sensing was used, implicitly, to detect ground lichens in the context of monitoring long-term changes in vegetation cover in the northern tundra and open woodland habitats (Tømmervik et al., 2003). Reflectance measurements carried out in northern, barren pine-dominated forests suggest that spectral signatures of the species in the understory vegetation overlap are strongly dependent on the imaging geometry (Peltoniemi et al., 2005). Under a canopy, the understory is in direct light, penumbra, or in shadow, and in optical remote sensing the reflected signal from the understory is mixed with that from the upper canopy, which complicates the interpretation of images (e.g. Eriksson et al., 2006). Using simulations with a forest reflectance model, Rautiainen et al. (2007) concluded that the contribution of the understory to total nadir reflectance ranged from 8% to 99%, depending on the canopy cover (LAI<2, sparse northern boreal stands). Their results suggest that separation of understory types of pine forests (dwarf shrub–lichen-dominated) in satellite images may be possible, using visible bands of satellite images, in thin canopies near the arctic region. In all, mapping of the understory vegetation in optical images is an ill-posed task.

In laboratory tests by Kaasalainen and Rautiainen (2005), common lichens that occur on barren soils in Finland showed high backscatter reflectance at 1064 nm. They suggested that lichens could be separated from soil and other forest understory, using this property and could thus be detected and monitored by means of remote sensing. Most ranging LiDAR systems use the Nd:YAG laser at 1064 nm. Based on the above, an experiment was carried out with the objective of testing whether mats of common *Cladina* (reindeer) lichens could be localized and separated from other understory vegetation using intensity data from an airborne LiDAR. Two LiDAR datasets; acquired using different sensors, were compared. The understory vegetation of a 960-m^2 area in a pine stand was mapped using terrestrial photography and photogrammetric methods, which allowed the 3D mapping of the lichen mats at absolute cm-level accuracy. Issues arising from the need to normalize the LiDAR intensities are also addressed.

Table 1
Characteristics of the LiDAR datasets

Instrument	ALTM3100, Optech	ALS50-II, Leica
Date	July 25, 2006	July 4, 2007
Time	15:41–16:57 UTC	15:40–17:20 UTC
Flying speed	~75 m/s	~66 m/s±4 m/s
Pulse frequency	100 kHz	115.8 kHz
Mirror/scan frequency	70 Hz	52 Hz
Beam divergence	0.3 mrad	0.22 mrad
Footprint	25–28 cm	7–18 cm
Strips covering plot	3	3
Scan angle	±14° (−11°, +2°, +8°)	±15° (−7°, −1°, −9°)
Flying heights, a.s.l.	986 m, 1005 m, 1063 m	911 m, 923 m, 939 m
Range, ground returns	846–935 m	776–813 m
Automatic gain control	No; Two levels of radiometric resolution	8 bits for each pulse
Returns	1–4	1–4
Intensity	12 bits, for each return	8 bits, for returns 1–3
Air humidity	48–52%	60–75%
Precipitation, 4 weeks prior to LiDAR	37.1 mm	73 mm
Last rain	13.3 mm, July 24	6.4 mm, July 2