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Demonstration of a virtual active hyperspectral LiDAR in automated point cloud classification

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ABSTRACT

In this paper, a measurement system for the acquisition of a virtual hyperspectral LiDAR dataset is presented. As commercial hyperspectral LiDARs are not yet available, the system provides a novel type of data for the testing and developing of future hyperspectral LiDAR algorithms. The measurement system consists of two parts: first, backscattered reflectance spectra are collected using a spectrometer and a cutting-edge technology, white-light supercontinuum laser source; second, a commercial monochromatic LiDAR system is used for ranging. A virtual hyperspectral LiDAR dataset is produced by data fusion. Such a dataset was collected on a Norway spruce (*Picea abies*) sample. The performance of classification was tested using an experimental hyperspectral algorithm based on a novel combination of the Spectral Correlation Mapper and a region growing algorithm. The classifier was able to automatically distinguish between needles, branches and background, in other words, perform a difficult task using only traditional TLS data.

1. Introduction

By the year 2011, LiDAR laser scanners have become an essential technology in remote sensing. They are commonly used on terrestrial (Lichti et al., 2008), airborne (Hyyppä et al., 2009), and satellite missions in 3D mapping of anything from centimetre scale to global scale. As more and more 3D data are collected, there is an increasing need for automation in the classification and interpretation of LiDAR data.

In addition to the 3D spatial data, laser scanners also record the intensity of reflected light. Although, commercial laser scanners are commonly not designed for radiometry, it has been shown that the intensities can be calibrated (Ahokas et al., 2006; Coren and Sterzai, 2006; Höfle and Pfeifer, 2007; Kaasalainen et al., 2009; Wagner et al., 2006), and used in automatic object classification from point clouds (Kim et al., 2009; Korpela, 2008; Ørka et al., 2009). Höfle and Pfeifer (2007) and Wagner et al. (2008) have reviewed the physical concepts of the radiometric calibration of LiDAR intensity.

Most typically, calibrated LiDAR intensities are used in classification to enhance the results. Monochromatic intensities help in classification, but in many cases even more accurate results could be acquired if multispectral data were available. As multispectral laser scanners are still rare, an effort has been taken to fuse monochromatic LiDAR data with other datasets. For example, photographs (Secord and Zakhor, 2007) and hyperspectral images (Mundt et al., 2006; Rottensteiner et al., 2005) have successfully been fused with LiDAR data. While data fusion is a working technique, it requires additional measurements, calibrations, and labour. A passive hyperspectral measurement also issues additional weather and illumination requirements to an otherwise rather environment-insensitive LiDAR operation. In an ideal case, a LiDAR system itself would also produce the multispectral information.

Dual-wavelength LiDARs are already in use in specific applications; for example, coastal water depths are routinely mapped using green-NIR bathymetric LiDARs (Irish and Lillycrop, 1999), and atmospheric gasses are monitored using Differential Absorption LiDARs (Browell et al., 1998). A bathymetric LiDAR, with an additional 645 nm Raman energy sensor, has been successfully used to map vegetation in salt-marshes (Collin et al., 2010). Also, specific vegetation index dual-wavelength LIDARs have been presented and evaluated in vegetation mapping (Chen et al., 2010; Rall and Knox, 2004).

Traditional laser sources have limited the LiDAR systems to using only a single or a few precise transmitted wavelengths. However, a recent development in supercontinuum laser technology has made it possible to manufacture powerful fibre light sources with a continuous spectrum, that is to say, 'white lasers' (Dudley et al., 2006; Genty et al., 2007). In supercontinuum lasers, a high-peak-power laser pulse is passed through a non-linear optical fibre where the combined interaction of various non-linear optical processes transforms it into a broadband pulse. For example, a modern

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micro-structured non-linear fibre allows a 1064-nm pulse to be broadened into a spectrum ranging from 480 to 2500 nm.

If such a 'white laser' is combined with a hyperspectral time-of-flight sensor, it is possible to construct an active hyperspectral LiDAR (Johnson, 1999). As technology matures, such devices are expected to be commonly available. Similar sensors without a hyperspectral light source have already been exploited in the collection of LiDAR induced fluorescence spectra (Gleckler, 2001; Samberg, 2005).

An active hyperspectral LiDAR system will allow for a higher level of automation in data processing (Puttonen et al., 2010), as hyperspectral algorithms could be used to classify the point clouds. Hyperspectral algorithms could also allow a new approach for retrieval and analysis of chlorophyll and nutrient concentrations and forest vegetation indices in 3D geometry. While waiting for hyperspectral LiDARs to develop, there is a need for virtual data to test future algorithms. Such test data can be produced using either pure modelling (Morsdorf et al., 2009) or data fusion.

In this paper, we present an experimental measurement setup for producing 3D-referenced hyperspectral data and demonstrate its performance in point cloud classification. Chapter 2 presents the system and algorithms used in data collection. In Chapter 3, the performance of a hyperspectral classification algorithm is tested on a point cloud collected from a Norway spruce (*Picea abies*) sample.

2. Instrumentation

The system consists of two components: (1) an active hyperspectral scanner (HSS) for retrieval of backscattered reflectance spectrum and (2) a commercial terrestrial laser scanner (TLS) for range finding. To retrieve a 3D-referenced hyperspectral dataset, the sample is measured in succession with both scanners from the same observation point and the data are fused afterwards.

2.1. Hyperspectral scanner

The HSS is a system that measures the backscattered reflectance spectrum of the target using supercontinuum laser illumination. The HSS consists of a supercontinuum laser (SuperK, Koheras A/S, Denmark), a spectrometer (AvaSpec 3648, Avantes, The Netherlands), collimation optics, and a two-axis scanner (URS75BCC and URS100BCC rotators, Newport, USA) (Fig. 1).

The optical system is designed so that the light is transmitted and received on the same optical axis. First, the laser light passes through an adjustable collimator (f = 4.6 mm), producing a beam with 0.3° opening angle. The collimated beam is transmitted through a 4-mm hole in the centre of an off-axis paraboloid mirror. The paraboloid mirror (f = 150 mm, d = 50 mm, off-axis-angle = 90°) is used to collect light to the spectrometer optical fibre. The laser and spectrometer optics are collimated so that both have the same opening angle of 0.3°. Thus, the laser and the spectrometer footprints coincide better the further away the target is from the instrument, maximising the return intensity on the long distances.

The SuperK outputs 150 mW of power at a 20 kHz pulse frequency with 1–2-ns pulse width on a continuous spectrum over a band ranging from 480 to 2200 nm (Fig. 2). The AvaSpec spectrometer is a silicon-based instrument with a nominal spectral range from 280 to 1100 nm. As a combination of the transmitted spectrum and the sensor sensitivity, the effective spectral range of the HSS measurement is limited to between 480 and 900 nm (Fig. 3). In a typical white target measurement, noise is lower than 2% at a 1-nm resolution. In addition to the noise, another 2% error in intensity levels is produced by the short-term instability of the light source.

To obtain a measurement, the HSS has been installed on a tripod. The spectrometer exposure time, vertical scan speed, and horizontal sweep density are selected freely, balancing between the scan time and data quality. A good compromise for targets closer than 10 m was found to be using 50 ms spectrometer exposures, 4°/s scan speed, and a 0.5° horizontal step between the sweeps, producing a fairly even data point grid with 0.5° resolution. After the scan

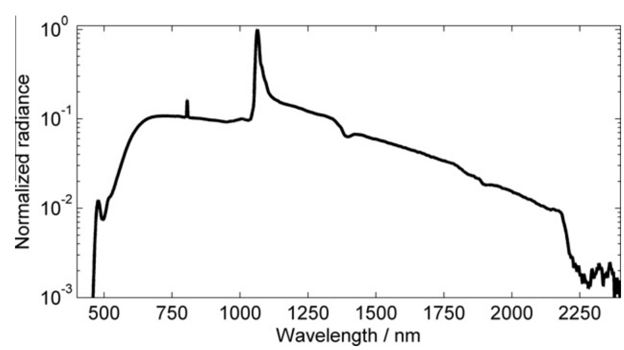

Fig. 2. Normalised laser transmitted radiance spectrum. Total average transmitted power is approximately 150 mW at a 20 kHz pulse frequency.

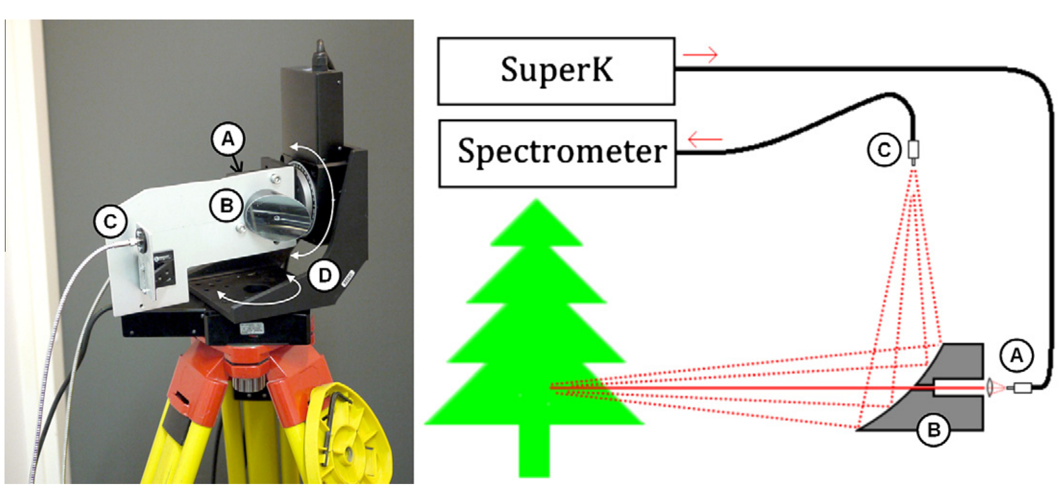

Fig. 1. (Left) Hyperspectral scanner (HSS) on a tripod. (Right) Operation principle of HSS measurement (not in scale). Light from SuperK fibre (A) is collimated and the beam is guided through a hole in the centre of the receiving mirror (B). The reflected light is collected, using an off-axis paraboloid mirror, to the spectrometer optical fibre (C). The whole optical system is rotated using a turret-style two-axis scanner (D).