The First Spectral Map of a Forest Understory from Multispectral LiDAR

Google Earth Image of the location for data collection at Corbin, Virginia, USA

Multi-Spectral LiDAR

Airborne LiDARs are recognised for their strength in mapping and surveying the structural properties of almost everything from forests to buildings. They offer flexibility over the scale and coverage that is not available from other surveying techniques; such as deploying a ground team, or utilising data from remote sensing satellites.

There is a growing recognition of a number of applications that if you were able to combine the structural mapping abilities of LiDAR with instruments able to measure spectral properties, then the potential uses expand exponentially. This has been explored previously through the combined use of LiDAR and hyperspectral imagery, to give both structural and spectral information about the top surface. However, merging a point cloud with a pixel-based imager is complex, and the spectral information is limited by the same factors as other passive remote sensing instrument, such as solar illumination and reflectance.

It was from these limitations that the idea of a multispectral LiDAR system was borne, with a number of options explored. One such solution has been to fly multiple LiDAR systems simultaneously; another is to build an integrated system with multiple lasers of different wavelength for operation. It is on this premise that the first operational multispectral LiDARs were built, with bathymetric LiDAR traditionally deploying two wavelengths, however until recently these systems weren't used as 'multispectral data'.

The principle for using dual wavelengths for this purpose was originally posed in 1965 for tracking submarines,

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with one in the Near Infra-Red (NIR) at 1064nm and one in the green at 532nm. However it was soon realised that this approach could be used to map the sea depth. The infrared beam is reflected by the sea surface for topographic mapping, whilst the green goes through the water surface and is used to determine the water column thickness, from which you can derive a depth, when you account for the tide and waves. However it has only been recently, in instruments such as Optech's CZMIL and SHOALS systems, that the use of radiometrically corrected data has been produced to determine further properties of the surface material from the spectral information.

Multi-Spectral LiDAR and Forests

Of particular interest to us is the development of multispectral LiDAR for forest mapping, with many exciting new developments. The mapping of forest under canopies has been a key research interest in institutions across the planet for a while. A number of specific instruments have been proposed for use on terrestrial, airborne, and even spacebourne systems. Recently, we have seen this academic interest in multispectral LiDARs for forest applications filter through to commercial and operational spheres. Carbomap, based in Edinburgh, are the only commercial purveyors for the processing of this type of data, and have developed a suite of software tools specifically for extracting key metrics from multispectral LiDAR used for forestry applications.

The interest in this technology demonstrates a growing recognition of the potential of multispectral LiDAR, its potential for superseding the current standard model for generating datasets which contain both forest structure and the spectral signature of the forest canopy. Presently, this can be achieved by creating a synergy between standard single-wavelength LiDAR and passive optical remote sensing, such as hyperspectral imagery or Landsat-type satellite imaging. Whilst by using a full-waveform system, it presents the opportunity to combine the structural and spectral information throughout the full vertical profile of the forest canopy.

> "Multispectral Lidar really is the 'MRI scanner for forests'."
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> —Prof. Iain H. Woodhouse

The operational interest has come from a wide variety of industries within the forestry sector, including conservation efforts such as REDD+ (Reducing Emissions from Deforestation and Degradation), and timber production. Both of these focus on the estimation of tree biomass, carbon, or volume; which can be improved through the use of Multispectral LiDAR. These systems can be used to increase the information within a Monitoring, Reporting, and Verification (MRV) framework. It also improves the ability to monitor forest degradation, map fire risk or burnt area, which are used in the prevention and mitigation of forest fires which can threaten conservation projects or areas of timber. However, future developments also include estimation and mapping of biodiversity, species identification, or tree health. Particularly in the lower canopy where there may be issues for forest managers with invasive species or diseases which threaten large areas of forest.

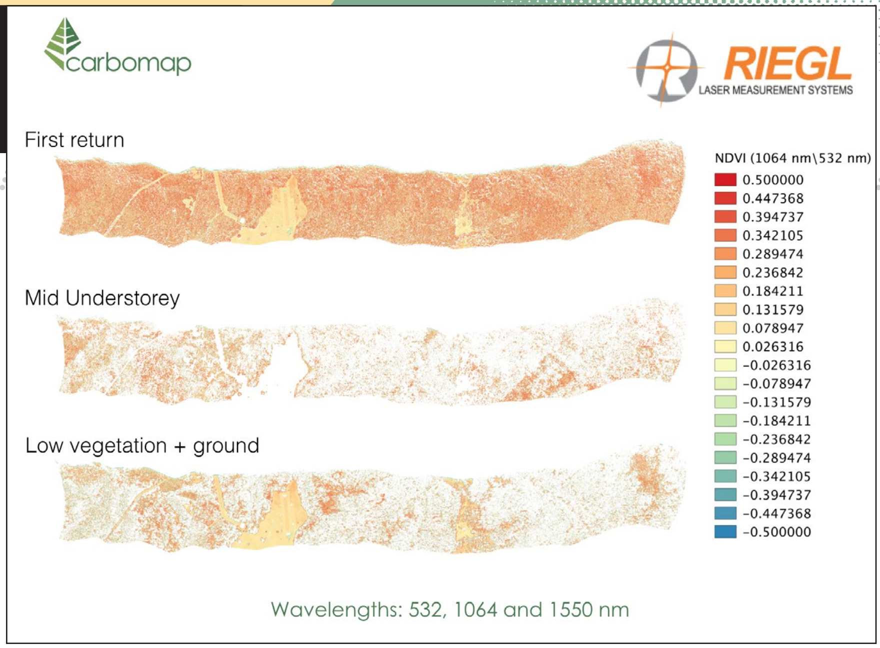
Data Collection

In June 2013 Riegl and Riegl USA flew a combination of three LiDAR systems on the one airborne platform, over the course of two flights, over Corbin in Virginia, USA. Each laser was a different wavelength, at 532nm, 1064nm, and 1550nm. The goal for these flights was to simulate an integrated multispectral LiDAR system. This provided an opportunity to explore the potential uses and applications for such data. Carbomap were provided the data by Riegl USA to demonstrate the operational capabilities of multispectral LiDAR for forestry applications, specifically with regards to the lower canopy layers, extracted through the full-waveform element of the LiDAR.

Vertical Spectral Variation

The result of this investigation was the very first understory canopy map from a multispectral LiDAR. Pseudo-NDVI (Normalised Difference Vegetation Index) was produced to demonstrate that differences in the spectral response could be detected within the vertical profile. This approach was taken as NDVI is a standard tree-health metric used by optical remote sensing. The pseudo-NVDI was generated between the point clouds of the 1064nm and the 532nm wavelength systems, as the two colour channels for the NDVI equation. The traditional equation uses the following form NDVI = (NIR – VIS) / (NIR + VIS), and in this circumstance the 1064nm was used as the NIR, and the 532nm was used as the VIS.

The first step was to select one of the point clouds as a reference layer. Each point from the reference layer was then



Pseudo-NDVI of three layers within the vertical structure of the forest. (Top) First return from the LiDAR instrument, including the ground layer; (Middle) The mid-section of the forest canopy; (Bottom) Low section of the forest canopy and the ground layer. This demonstrates the differences in NDVI throughout the vertical canopy.

considered and the closest point in the other point cloud was identified and the point couples were tied together, allowing the NDVI ratio to be calculated using Carbomap's purpose built LiDAR processing software.

In order to demonstrate the results two approaches were used, the first was to segment the pseudo-NDVI into three vertical layers, the first return; mid canopy; and low vegetation and ground. These layers not only demonstrate a difference between the different land cover types, but also highlight the spectral differences between the different layers of vegetation.

The second was to create a three-channel false colour composite, which highlights the difference in spectral response throughout the vertical forest canopy profile. The same process for tying together two points clouds for the pseudo-NDVI was used to create triplets, from which this dataset was generated. This image shows a ratio of the energy returned from the different wavelength LiDARs. Until now this has only previously been demonstrated under laboratory conditions; however the ability to extract meaningful spectral information from a real-life dataset signifies progress within the operational use of such systems.

Spectral Calibration

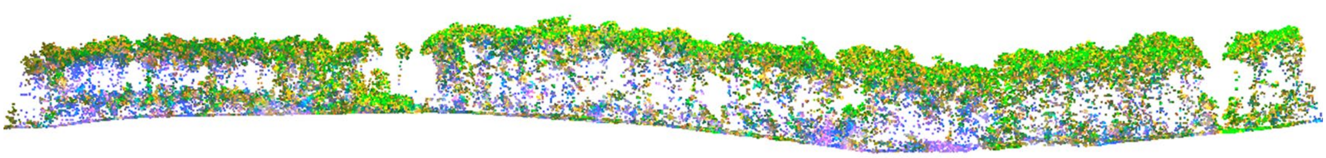
Reflectance is a function of the incidence angle between the incident laser beam and the surface normal of the target material. Therefore all the intensity values recorded by the LiDAR systems were corrected to ensure the returned data has the same incident angle to nadir. However, there was no target surface used during the original data collection, which would have provided a true spectral correction to apply to the point clouds. Therefore there was a need to empirically calibrate the datasets relative to each other.

In order to achieve this Carbomap were able to use a dry concrete surface, found in a parking lot in front of a building found within the dataset. An average hyperspectral reflectance profile was used to establish the average ratio offset to apply for each of the three wavelengths. This ensured that for the target surface each dataset was able to match the average ratio for this type of material. The distribution of reflectance is specific for each wavelength and, as you can see from the figure below, they are relatively narrow and similar for each channel. It is also possible to see that each wavelength shows a distinct pattern in the reflectance.

Although successful in this case, there are limitations to such an approach. Concrete can be of multiple composition and age, which will impact the reference reflectance curve used. However, in the absence of a true target material with which to correct for, this is an acceptable alternative.

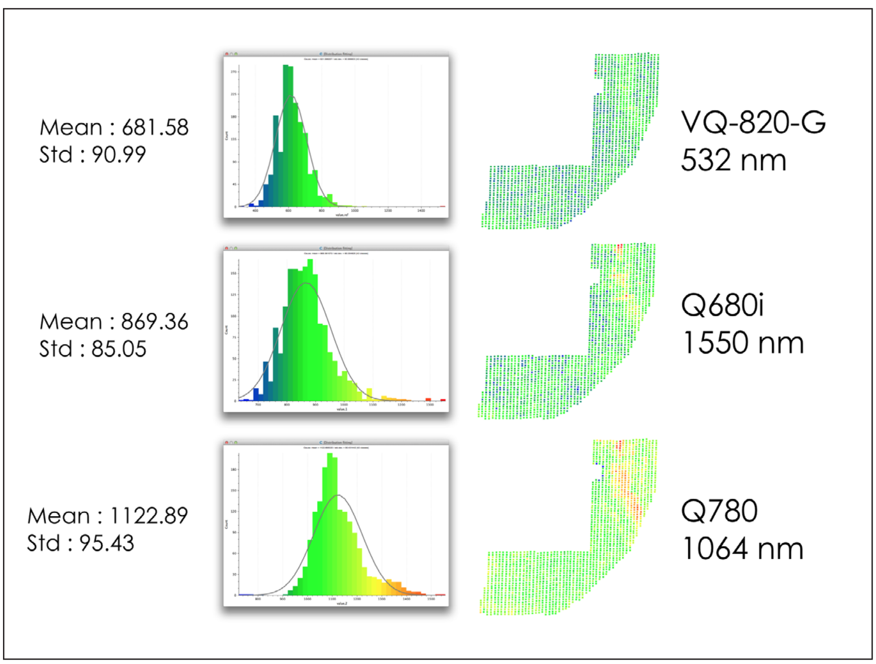
The future of multispectral LiDAR

In December 2014 Optech announced the very first commercially available integrated Multispectral LiDAR



Vertical Cross-Section for an area of forest, where the LiDAR point cloud has been assigned a false-colour composite of the three LiDAR wavelengths. This image highlights the ability of full-waveform multispectral LiDAR to identify spectral variations in the vertical profile.

Location of the parking lot used for the spectral calibration



Reflectance distribution over the concrete area for each of the three wavelengths. The shape of the calibration area has been shaped to exclude parked cars and surrounding grassy areas or buildings.

instrument, the Optech Titan. It builds upon their expertise for building multi-wavelength systems and the legacy of dual-wavelength bathymetric LiDAR; using three wavelengths of 532m, 1064nm, and 1550nm, which travel along a single optical path. However the beams are not triggered simultaneously, and this results in each beam being shifted by 5 degrees from the previous.

The specification of this instrument has been selected to fit a range of applications such as high-density topographic surveying, shallow water bathymetry, environmental modelling, urban surface mapping, land cover classification. However, the data output from this system is in three separate point clouds, each pertaining to a specific wavelength, rather than having one single point cloud where each point has three spectral data points. This comes from the fact that the beams are not collinear, but they can be combined through a gridding process. It is more of a challenge to produce one single wavelength, requiring a full overlap of the beams and for the returns to be measured simultaneously. However, once these technical challenges have been overcome, the benefits are enormous, particularly for forest mapping. Currently no other airborne sensor can provide spectral information about the ground or understorey in the presence of trees. With these exciting advances in the use of multispectral LiDAR for mapping forest undercanopies, the future is bright for this technology.

Carbomap applies state-of-the-art science to the problem of measuring and mapping the world's forests. We have over five years of world-class research in the development of new forest mapping technologies, our scientific founders have international reputations in remote sensing methodologies, forest structure mapping, and airborne survey.