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Enhanced discrete return technology for 3D vegetation mapping

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New airborne light detection and ranging sensors may bridge the niche applications of discrete return and full waveform technologies.

Airborne light detection and ranging (LIDAR) is an efficient way of generating accurate spatial data for a variety of applications, including forestry and vegetation mapping. Airborne LIDAR sensors currently used for 3D vegetation mapping can be categorized as either discrete return (DR) or full waveform (FW) systems.[1] An FW sensor measures the full profile of a return signal by sampling it at fixed time intervals, typically 1ns (i.e., 15cm sampling distance). The result is a quasi-continuous record of the reflected energy from the target per emitted pulse. In contrast, DR sensor measurements provide only up to four records—typically separated by a few meters—per emitted pulse (see Figure 1). For this reason, FW technology has often been considered a preferable choice for 3D vegetation mapping that requires detailed analysis of the vertical canopy structure. Here, we report the enhanced capabilities of our new DR sensor for 3D vegetation mapping, which is comparable to FW technology in certain aspects.

The quality of 3D vegetation mapping depends on the ability of the LIDAR sensor to resolve two separate targets along the sensor line of sight. For airborne sensors this ability is practically equivalent to the range measurement resolution. It is fully determined by the sensor hardware design and is independent of the properties of the illuminated targets.[2] For DR sensors, the range measurement resolution can be characterized empirically by the minimum pulse return separation distance, i.e., the minimum distance separating consecutive DR returns per emitted pulse.

For most commercial DR sensors the minimum pulse return separation distance is ∼2.0–3.5m, which results in gaps of a few meters between consecutive multiple returns. This is one of the factors limiting DR sensor use in vegetation research that relies on quasi-continuous vertical canopy profiles (i.e., FW data). However, our new airborne DR sensor—Airborne Laser Terrain Mapper (ALTM)-Orion—allows 3D mapping of vegetation at levels of detail comparable to FW technology. ALTM-Orion represents a radical departure from previous generations of airborne LIDAR sensors. First, its physical form factor (i.e., size and weight) has been reduced by an order of magnitude compared to other sensors.[2] Second, among its advanced performance features are sub-centimeter-range measurement precision, which has never been achieved before by any DR sensor. Additionally, the advanced design of the sensor transmitter and receiver hardware reduces the minimum vertical target discrimination distance to all new levels for DR sensors (i.e., sub-meter).

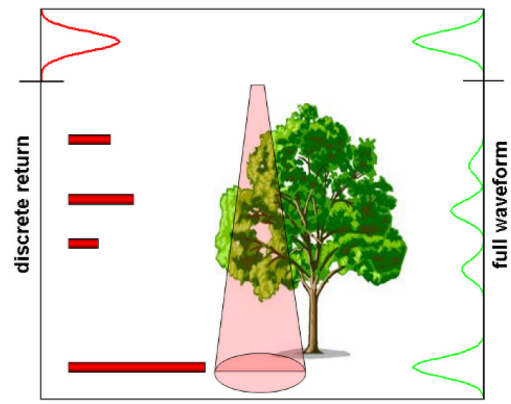

Figure 1. *Discrete return and full waveform data representing the same target may look dramatically different.*

We tested ALTM-Orion and showed that its minimum pulse return separation distance consistently fell within 60–70cm, independent of vegetation type and height.[2] We collected data using one sensor over vegetation targets of differing type and height, including cornfield and mixed forested areas of 2.2–2.8m

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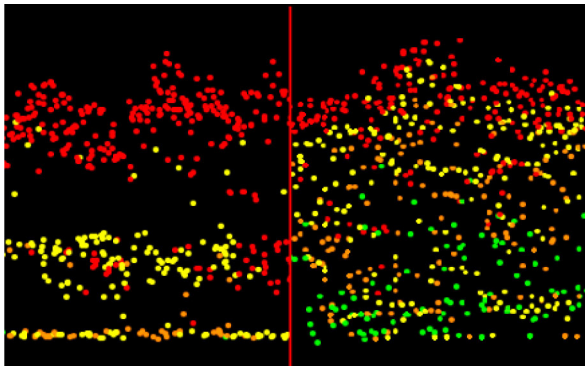

Figure 2. *Color-coded multiple returns of vegetation data collected over a mixed forested area (15–17m in height), where the ground point density is the same in both data sets. Data from (left) a previous-generation direct return (DR) sensor and (right) our new Airborne Laser Terrain Mapper (ALTM)-Orion DR sensor.*

and 6–7m average height, respectively. Our statistical analysis of the distribution of multiple returns in each data sample indicated a strong correlation between the number of multiple returns and the ratio of the vegetation height to sensor minimal pulse return separation distance.[2] In particular, ALTM-Orion consistently detected three multiple returns from corn stalks of 2.5m height and four returns from 6m mixed vegetation. This achievement would have been impossible for any previous-generation DR sensor (see Figure 2).

Furthermore, we showed that the enhanced 3D mapping capabilities of ALTM-Orion enabled representation of vegetation structure at the level of detail comparable to that of FW technology.[2] Since the scale of vertical 'sampling' of ALTM-Orion is significantly shorter than previous-generation DR sensors—60cm compared to ∼3m—this is a dramatic technological breakthrough, bringing DR capabilities to map complex 3D vegetation targets closer to those of FW sensors. Although the technology of range sampling differs between DR and FW sensors, this may indicate a trend toward the potential fusion of capabilities of both types of LIDAR technology in 3D mapping. We showed in our study that DR data of enhanced quality may provide sufficient information for waveform modeling.[2] However, this would work mainly in cases where a few discrete returns—separated by the sensor minimum pulse return separation distance—cover the full vertical extent of a 3D target (see Figure 3). In such cases, equivalent, or better, representations of the vertical vegetation structure could be obtained using DR data.

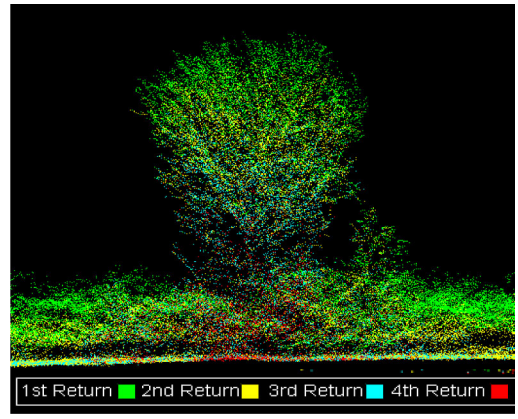

Figure 3. *Multiple discrete returns consistently detected over 6m tree and lower-canopy vegetation by ALTM-Orion.*

In summary, we have shown that vertical target discrimination distances unattainable by previous-generation DR sensors have been achieved by ALTM-Orion. This introduces the possibility of developing new, automated data analysis tools for 3D vegetation mapping, bridging the academic research on FW data analysis with the workflow practices for DR data established in the commercial sector of the LIDAR industry.[2] This constitutes our ongoing work.

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Valerie Ussyshkin is a technical manager whose current work is focused on performance analysis of airborne LIDAR systems. She leads a team of scientists and data analysts and has authored or co-authored over 50 publications.

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