# *RIEGL* Ultimate LiDAR in Forestry

*RIEGL* scanners capture and provide highly accurate, extremely effective, and good-quality 3D LiDAR data.



*RIEGL* Ultimate LiDAR[TM] provides an extremely accurate, efficient, and reliable data capture process for forest monitoring and management.

*RIEGL* VZ-400i Terrestrial Laser Scanner and *RIEGL* VUX-120 UAV LiDAR Sensor during a joint field campaign in the forestry sector.

Forests are critical to the environment's health. Their ability to regulate climate and water resources, carry out ecological functions and provide habitat for plants, animals, and human beings makes them the backbone of biodiversity. But unfortunately, these ecological primers are rapidly disappearing due to the challenges of the 21st century climate change and global warming. Deforestation is not only considered as one of the leading causes of global threats, but these pressures in return also impact the existing conditions of forested areas.

For tracking the changes in climate and better accessing of forest structure, disturbance, management, and resources, LiDAR (Light Detection and Ranging) is identified as an indispensable tool[5]. The laser scan data does not only save time but also aids in post-processing. LiDAR is a breakthrough remote sensing technique that gains appreciation from scientists around the globe due to its unprecedented accuracy. It has immensely modified digitization in multiple fields of applications due to high accuracy and meaningful data acquisition of large areas.

LiDAR technology has revolutionized forest structural characterization in recent times[1]. It has emerged as a vital tool for assessing Vegetation

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Canopy Structure (VCS). This is especially true for dense and complex forest canopies that prohibit manual and destructive sampling.

It doesn't matter how advanced the technology is, what counts are the instruments that gauge the ability of any technology. *RIEGL* is a leading developer and provider of laser scanners and laser scanning systems, and has been for more than 40 years. It has a proven record in research and development by producing world-class laser sensors with cutting-edge technology that fulfill the measurement tasks with absolute accuracy.

## LiDAR in Forestry

Background knowledge regarding LiDAR would be helpful before bringing the subject to the most recent advancements in this field. Airborne laser profile systems were first introduced in the late 1970's and early 80's, but were commercialized only in the mid 90's. Every literature that talks about LiDAR agrees on the fact that Europeans have taken the lead when it comes to this technology.

Professor Friedrich Ackermann is referred to as the 'pope' of LiDAR technology in the European world. His motivation to study LiDAR was based on the requirement of Digital Elevation Models (DEMs) in forests[2]. Furthermore, in the early 2000's LiDAR developments in forestry progressed as it was used to perform three-dimensional (3D) analysis of forest structure and terrain. Since then, there is no looking back as many foresters and researchers consider LiDAR as the break-through Remote Sensing (RS) technique for forestry applications.

Furthermore, its ability to map topography and forest canopy with an ultra-high level of accuracy is unparalleled to any other remotely sensed data. Researchers have evaluated individual leaf-off deciduous trees, specified forest inventory parameter including timber volume and stem density, predicted single stem volumes, etc. by utilizing LiDAR.

## Kinds of LiDAR

Classification of LiDAR sensors can be performed based on their platforms, underlying technologies, and mode of operations. If the sensor is attached to a fixed-wing aircraft, helicopters, or unmanned platforms the LiDAR scanning will be termed as airborne laser scanning (ALS). Whereas, if the technology utilizes static laser scanners, then it is coined as terrestrial laser scanning (TLS).

However, both ALS and TLS are well-established and renowned capturing technologies for forest applications. If on one hand, ALS data allows for forest mapping at a large scale, TLS data on the other hand delivers point clouds at a high level of detail for relatively smaller regions. Hence, TLS data, covering small parts of the area acquired by an airborne campaign, may be useful to "calibrate" the airborne-based estimation of forest inventory parameters. This is how the two data acquisition procedures complement each other optimally.

In recent times however, due to the advancements in technology, the usage of small unmanned aerial vehicles (UAV) has dramatically increased. UAVs have been recognized as important remote sensing tools, thanks to novel algorithms such as Scale Invariant Feature Transform (SIFT), that can directly geo-reference and rectify imageries using low-accuracy camera positions. These platforms can be altered and fitted with various sensors such as laser scanning sensors or digital cameras.

There are multiple companies that manufacture scanners and scanning systems for users but one that is known for its outstanding technology, assembling, and potency is the famous *RIEGL* Laser Measurement Systems.

## *RIEGL*'s Ultimate Waveform LiDAR™ Technology

*RIEGL* delivers guaranteed innovations in 3D. Its scanners capture and provide highly accurate, extremely effective, and good-quality 3D data. The brand gained the trust of its customers by committing to supplying quality, reliability, durability, and highest performance products and services. Its priority is to serve the users with cutting-edge hardware for all kinds of LiDAR technologies i.e., terrestrial, industrial, mobile, airborne, bathymetric, and UAV-based laser scanning coupled with equally state-of-the-art software packages. This combination results in outstanding data acquisition and processing that in return yields potent solutions for a wide range of surveying applications.

The digitization of waveform signals is the fundamental technology of the *RIEGL* laser measurement systems. It offers distinctive methodologies for resolving range uncertainties, multiple targets per laser shots, optimal measurement distribution, calibrated amplitudes, and reflectance estimates along with continuous integration and system components correction. Additionally, the Ultimate LiDAR™ 3D scanners from *RIEGL* have a wide range of performance characteristics and assist in continuously serving as a foundation for constant 3D innovation in this industry.

*RIEGL*'s Ultimate Waveform LiDAR™ technology emphasizes pulsed time-of-flight laser radar technique in numerous wavelengths. The comprehensive range of *RIEGL* LiDAR sensors and systems delivers an extraordinary high-density point cloud ideally appropriate for further post-processing in forestry. Advanced processing methods ensure that all the information in the scan data is exploited rightfully in every possible way. Excellent vegetation penetration and the computation of comprehensive terrain models are made possible by the multi-target capabilities. Point classification is the foundation for tree detection, tracking growth, height modeling, and detection of Coarse Woody Debris (CWD).

A few examples of the airborne (ALS), terrestrial (TLS), and UAV-based (ULS) scanners manufactured by *RIEGL* are discussed in the next section.

## Airborne Laser Scanning

Airborne LiDAR or laser altimetry technically referred to as airborne laser scanning is an active remote sensing technique that determines the topography of the Earth's surface by measuring the round-trip duration of an emitted laser pulse. The principle involves a photodiode that records the backscattered echo from a laser that discharges brief infrared pulses towards the Earth's surface. It aids in capturing 3D data of large areas, for instance, agricultural and forestry sites with extreme accuracy, effectiveness, and promptness. Besides, airborne laser scanning is one of the best and most important methods for gathering data for forest resource management.

*RIEGL* airborne laser scanners and scanning systems are quite reliable as they utilize up-to-date state-of-the-art laser processing technology. They are aimed to meet the most demanding requirements in airborne surveying and are exceedingly compact, easy to handle, and cost-effective.

*RIEGL* produces a wide range of airborne scanners and scanning systems. *RIEGL*'s VQ-1560 Series is specially designed for covering large areas. These Dual Channel LiDAR scanning systems offer additional bays for two cameras and a high-performance inertial measurement unit (IMU) / global navigation satellite system (GNSS) unit complements the system. The two cameras used are a 150 megapixels RGB camera and a thermal or near-infrared (NIR) camera. The former is used as the primary camera while the latter is secondary. The design features a mounting flange for interacting with typical hatches or gyro-stabilized leveling mounts, making the system ready for straightforward integration to helicopters and fixed-wing planes.

One of the scanning systems of the *RIEGL*'s VQ-1560 Series named as VQ-1560i-DW Dual Wavelength LiDAR system is especially suited for applications in forestry. It combines two laser beams at two different wavelengths, i.e., green at 532 nm and infrared at 1064 nm, each operating at a laser pulse repetition rate of up to 1MHz, resulting in a total of more than 1.3 million measurements on the ground per second. Also, it formulates two separate point clouds with intensity registering in green and infrared wavelengths. The VQ-1560i-DW allows the derivation of 3D spectral indexes like the Green Normalized Difference Vegetation Index (GNDVI) throughout the canopy.

So, the condition of forests can be monitored by detecting spectral changes in the lower parts of the tree crowns, where the first indicators for tree diseases unfold. Additionally, the forest understory can be mapped, which is prone to spark wildfires. This 3D vertical spectral mapping capability is unique and provides excellent data to validate the conditions of forested areas concerning tree species, tree health, and underwood structures.

For instance, in Figure 1, ALS point cloud is processed for a huge, forested area. The maps reveal information regarding the forest canopy height, crown coverage, and vegetation mask for the particular area.

The possibility to acquire measurement data of ultra-wide areas and to provide profound data of large, forested areas makes airborne laser scanning especially interesting for scientific and research projects. For example, Prof. Jorg M. Hacker, Chief Scientist at Airborne Research Australia, and Flinders University, has been using *RIEGL* airborne laser scanners for numerous projects. In 2020, Prof. Hacker along with his team documented the horrifying bush fires and helped restore burn areas.
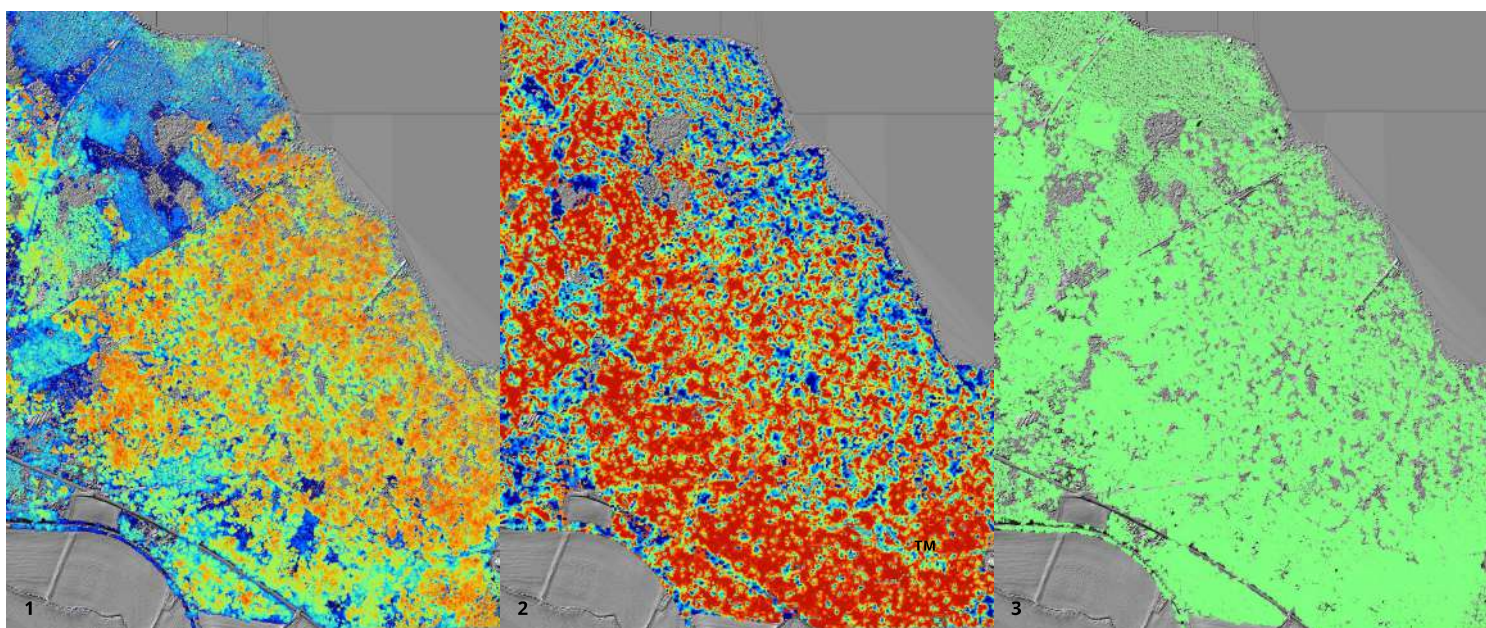


**Figure 1: 1) Forest canopy height: Tree heights are color-coded (blue to red) according to the height above ground. 2) Crown coverage map: The terrain is colored by the percentage of vegetation coverage. 3) Vegetation mask: Areas of vegetation 3m and above, exceeding 10 sq m.**

### Terrestrial Laser Scanning

Ground-based light detection and ranging commonly referred to as terrestrial laser scanning is an active imaging method that utilizes millions to billions of 3D points to automatically measure the surrounding 3D space[4]. It derives the 3D position of items within the scanner field of view using range-finding measuring technology. This technology finds its applications in a wide variety of fields including surveying, engineering, environmental sciences, and forestry.

In the field of forest inventory and monitoring, TLS has proved great potential. It focuses on the rapid semi-automated determination of stand parameters such as tree density, height, diameter at breast height (DBH), whole-tree volumetric assessment, individual modeling of branch architecture, and characterization of vegetation types. In addition, it presents precise measurements of trees in the forest, which are planned and evaluated using statistical models. They are intended to answer the question of how much timber is in the forest, how much is growing each year, and what type of damage is increasing or decreasing.

The process of terrestrial laser scanners is expressed in the given figures. In this example the entire data has been processed using the tool 3D Forest.

**3D Forest**

It is an open-source software application recognized by world researchers for segmentation, visualization, measurement, and export of various tree parameters of TLS data. The X-ray view of the cross-section of forest captured by TLS is shown in Figure 2 whereas Figure 3 highlights how segmentation, calculation of tree heights, crown coverage, and convex hull of individual trees can be calculated. Moreover, the question of how much carbon is sequestrated in the forest and whether biodiversity is flourishing or not has been
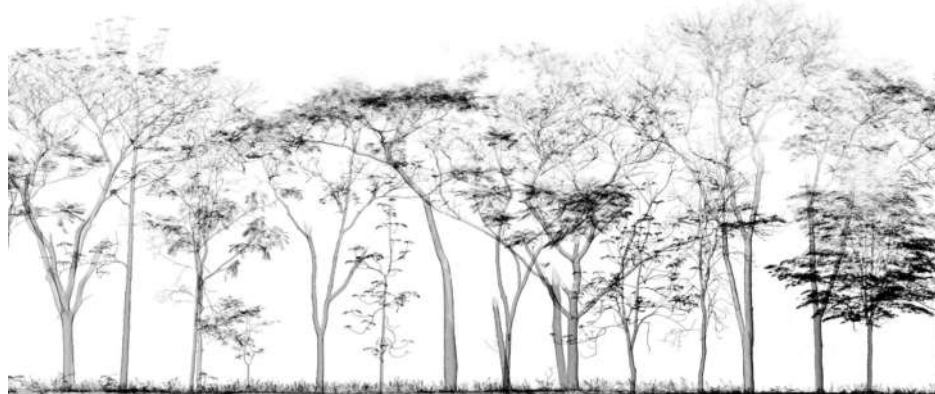


Figure 2 : Cross-section of forest captured by TLS, visualized in X-ray view.
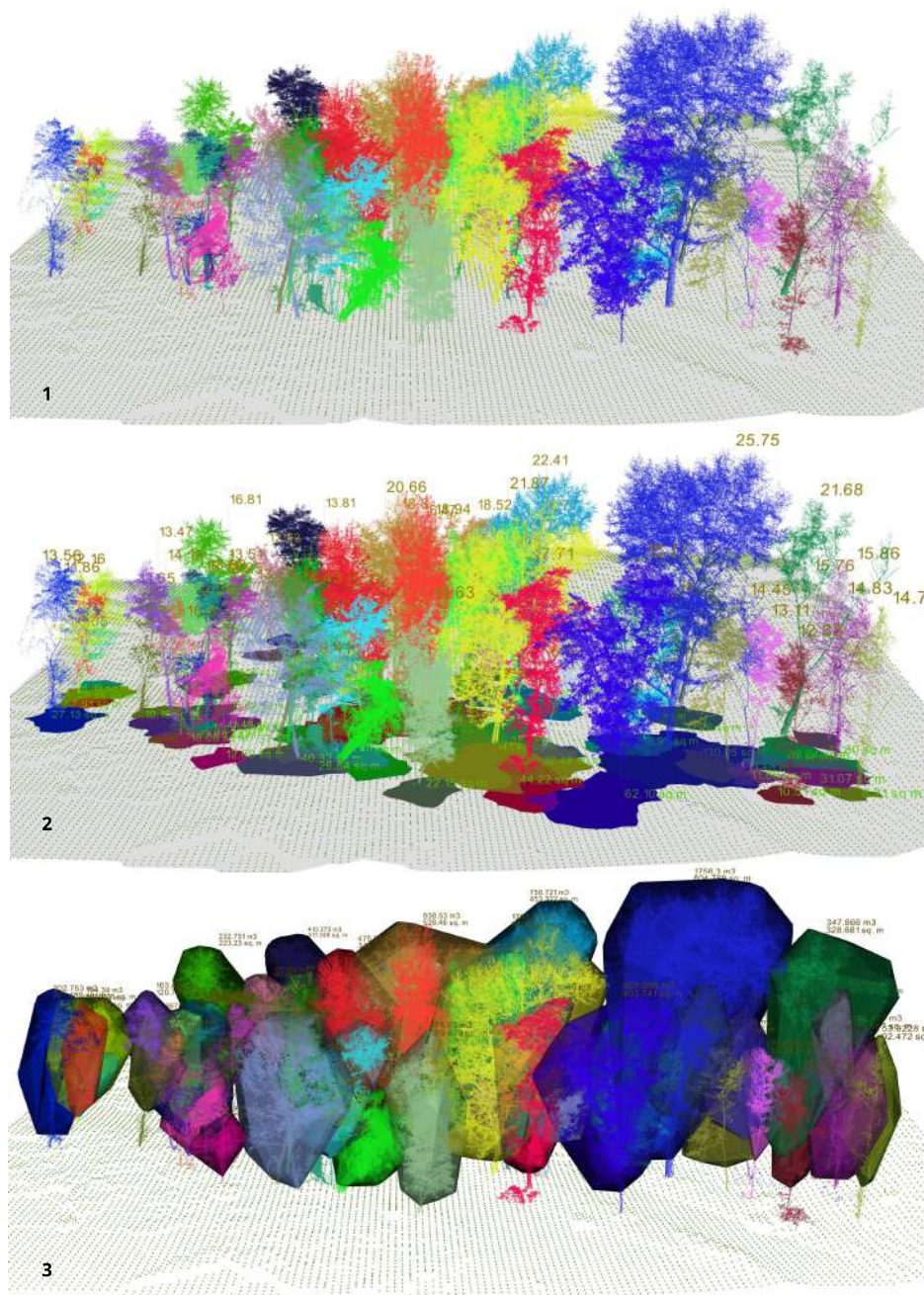


**Figure 3: 1) Single tree segmentation of the terrestrial point cloud. 2) The point cloud is segmented to individual trees. From the segmented point clouds, tree heights and the crown coverage area are derived. 3) The convex hulls of the single trees are calculated from the segmented point cloud.**

investigated by the researchers. In most cases, several hundred sample plots are distributed over the forest area to be investigated, and very precise measurements are then taken. In general, a distinction is made between national forest inventories, which are usually carried out by state institutions, and operational forest inventories, which support the sustainable forest management of a forest enterprise.

*RIEGL*'s TLS quickly and accurately produces detailed and extremely accurate 3D data. All the *RIEGL* TLS scanners are tough and portable instruments that have been rigorously tested to ensure reliable performance even in the most unpredictable and extreme environments.

One of *RIEGL*'s terrestrial laser scanners is the *RIEGL* VZ-400i. It can be used on a tripod or mounted on a mobile platform in a Stop-and-Go-Mode which makes it capable of recording a scan area of 360 degrees in a horizontal direction and 100 degrees in the vertical direction. The standard point spacing of 7mm at 10m is recorded in just 45 seconds – resulting in 20 million 3D measuring points, which can also be colored with simultaneously acquired photos. Each measuring point is assigned a 3D coordinate, first calculated in a scanner's coordinate system, and subsequently geo-referenced by means of GNSS automatically.

On the one hand, this provides the exact geo-location of each individual tree on the globe. But much more - namely the entire environment - is measured with millimetre precision from such a single scan. A multi-target capability allows obtaining several echoes for each single measurement pulse. Even the densest vegetation can be penetrated to show exact data of every layer from the tree crown to the forest ground. To get a gapless digital twin of a piece of forest, the scanner must be set up at several different locations. The *RIEGL* technology allows you to do up to 50 scan positions within an hour.

Applying so many scan positions, scan shadows are eliminated. The scan

positions are co-registered automatically and simultaneously during the scanning in the scanner. Additional built-in sensors, e.g., inclination sensors, acceleration sensors, GNSS receiver, etc., supplement this registration method.

This type of registration turned out to be extremely robust without the need for external reference targets. This proved to be a great advantage over other registration methods, especially in a densely overgrown forest. In post-processing, a so-called "multi-station adjustment" is registering the scan positions with each other and - if necessary - includes external control points measured by total stations, to ensure a higher-level control.



**Figure 4 : A *RIEGL* terrestrial laser scanner at work.**

Günther Bronner, CEO from Umweltdata, an Austrian service provider of laser measurements for forest inventory, has been working with a *RIEGL* VZ-400i for more than 2 years. For him, it was a very appealing idea to leave the tedious and error-prone measuring of trees to a scanner. But only the *RIEGL* VZ-400i could convince him with its performance. "External targets? - You don't need them! Precise planning of the set-up points? Levelling of the scanner? Forget it! 15 minutes per scan? With the VZ-400i, a scan takes half a minute! We tried it and the result convinced us.", Bronner reports excitedly. In the *RIEGL* Podcast "Forest Inventory by Means of Laser Scanning Technology" available in the *RIEGL* Newsroom he gives an insight into his work and experiences with the VZ-400i.

**UAV-based Laser Scanning**
Unmanned aerial vehicles (UAVs) have gained importance in recent times

since they provide a cost-effective solution for investigations that demand high temporal frequency for small areas using aerial remote sensing.

They offer improved spatial resolution and accuracy as their use provides for high-quality temporal images captured at lower altitudes and speeds.

Recent research has utilized UAV-mounted laser scanning systems (ULS systems) to characterize the 3D structure of ecosystems, including forestry volume, estimation of biomass, carbon storage, and mapping biodiversity. In addition, to complement terrestrial laser scan data, airborne data acquired by UAV-based laser scanning offers new perspectives in commercial forest inventory. Scan data acquisition by drone enables a different look from above and a different angle of incidence to penetrate through the forest to get even better ground penetration data.
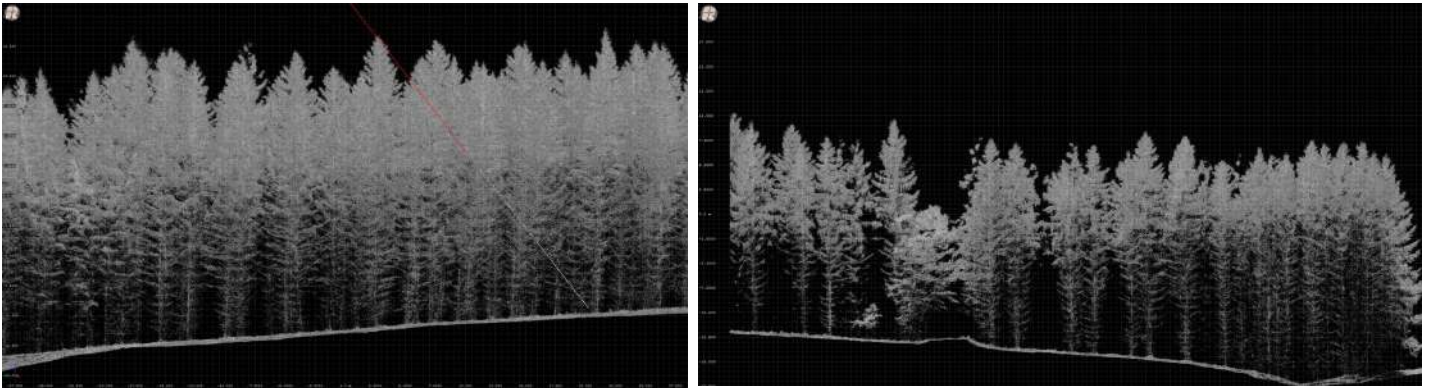
**Figure 5 : Cross section of a typical UAV-born laser scan in forestry, reflectance scaled view.**

Figures 5 and 6 explain the process of how ULS point cloud is processed. In Figure 6, single trees in a raw ULS point cloud are delineated and then a volumetric stem model is derived from it.

The data has been processed with the software Lis Pro 3D by Laserdata. Laserdata is a technology-driven firm that specializes in administrating, processing, and analyzing geographic point cloud data.



*RIEGL* offers a broad range of UAV LiDAR sensors and systems that can be used with numerous renowned UAVs to acquire high-density airborne data; in case airborne surveys by helicopter or fixed-wing planes are not efficient due to the costs, the size of the area in question, or the time frame given for data acquisition. UAV-based data is used to provide segmented point clouds displaying single trees. 3D piped models of the tree stems can be extracted from volume models for biomass measurement.

Moreover, *RIEGL* is the first company to deliver a fully integrated system suited for demanding UAV-based surveying missions with their exclusive surveying platform named RiCOPTER. It is a remotely piloted X8 array foldable octocopter specifically designed for UAV-based laser scanning (ULS).

The combination of UAV-based and TLS LiDAR data results in a point cloud of increased, extended informative value. It is also of use to get more detailed data on specific spots of the whole scanned environment.
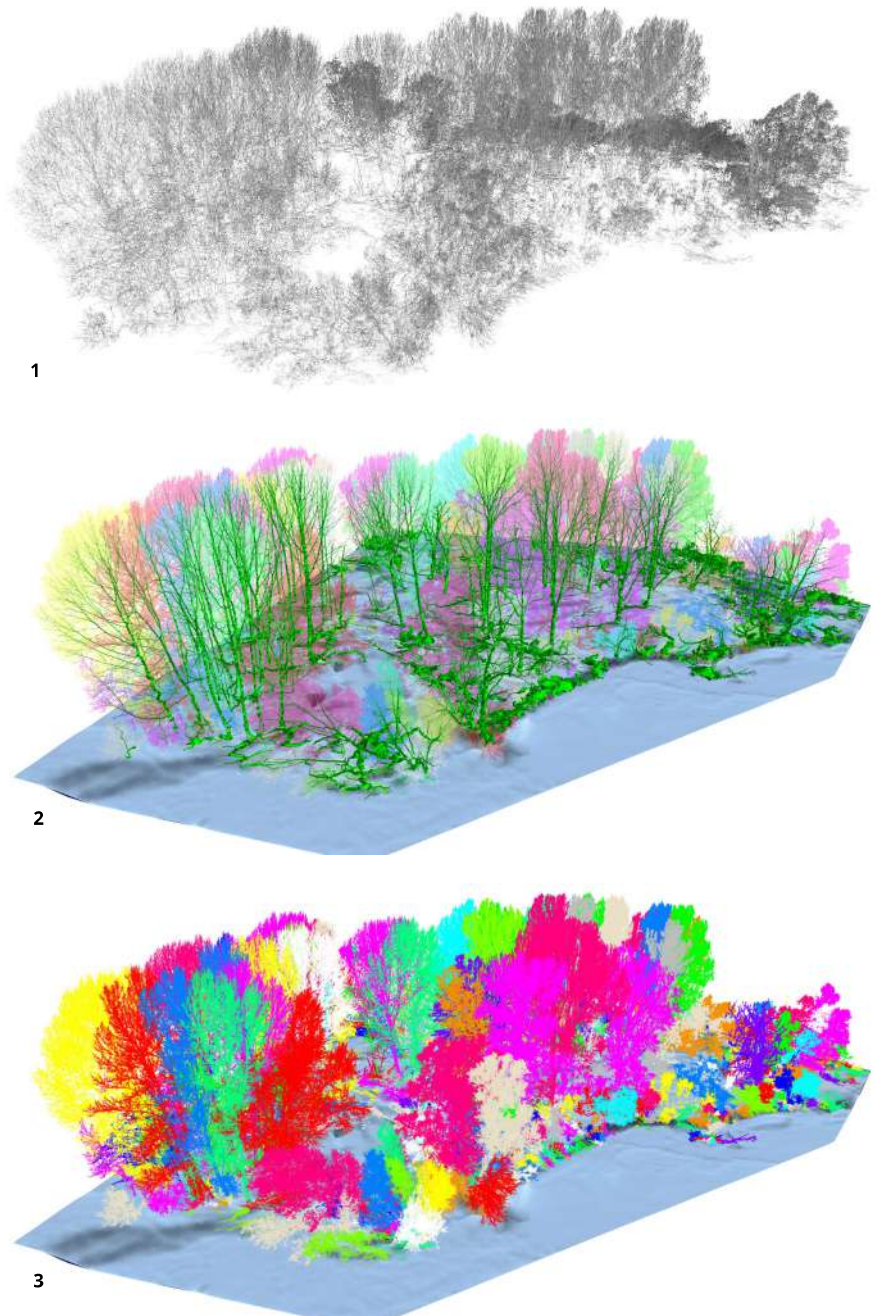


**Figure 6: 1) Raw UAV point cloud colored by reflectance. 2) Single tree delineation of a UAV point cloud. 3) A volumetric stem model is derived from the segmented point cloud.**

## Difference between ALS, TLS, and ULS

All - ALS, TLS, and ULS - find their applications in forest management and monitoring. ALS is often acquired from manned aircraft that allows it to cover large ranges of areas, but it requires a significant amount of budget and infrastructure. TLS generates dense point clouds that allow single canopy elements such as stems and branches to be determined for decent project areas. So, ALS can cover large areas whereas TLS can provide data with extremely high resolutions[3]. In addition to ALS and TLS, ULS provides an alternative to the previous two by offering very reasonable mobilization costs and infrastructure requirements with rapid mapping speed – UAVs are very economical when compared to manned vehicles.

In figures 7, 8 and 9, top views of all scanning systems for a typical forested area reveal the suitability of each scanner according to their capability.

## Conclusion

*RIEGL* Ultimate LiDAR™ in forestry has gained appreciation and earned the trust of scientists and researchers over the years. It provides an extremely accurate, efficient, and reliable data capture process for forest monitoring and management. It's fast-scanning ability provides a boost to forest management and conservation activities. For commercial use in forestry or scientific projects, *RIEGL* Ultimate LiDAR™ provides profound data, to digitally preserve the current situation, and to simulate future scenarios to make the right decisions for today and tomorrow; for both the private forest owner and forest manager as well as for the global decision-makers.

Find more details on the broad *RIEGL* product range for laser scanning applications in forestry at *http://www.RIEGL.com/*.
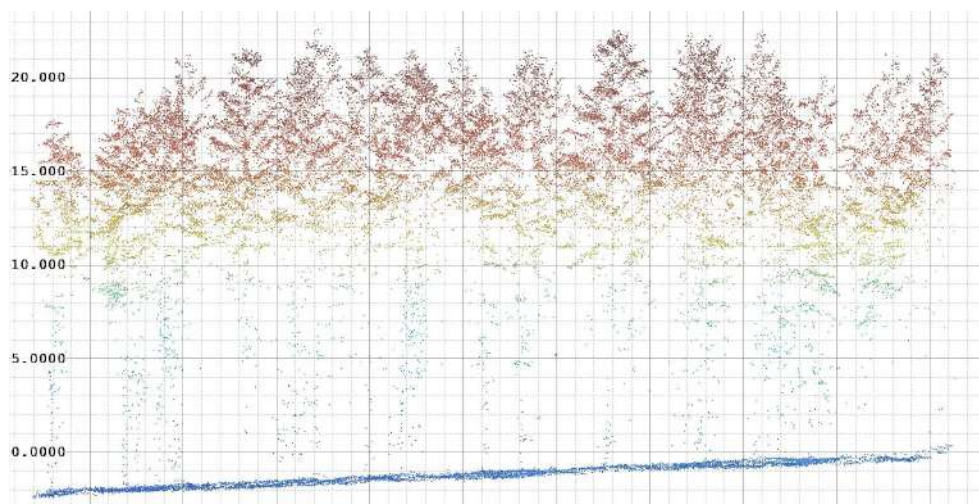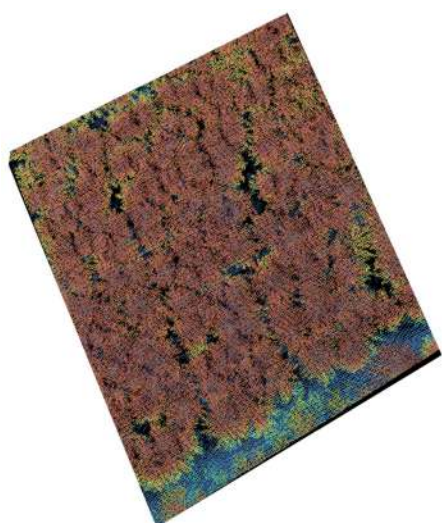


**Figure 7: Top view and cross-section of a forestry airborne laser scan (~170 pts/m2): canopy and ground are very well covered. Suitable for large area acquisitions.**
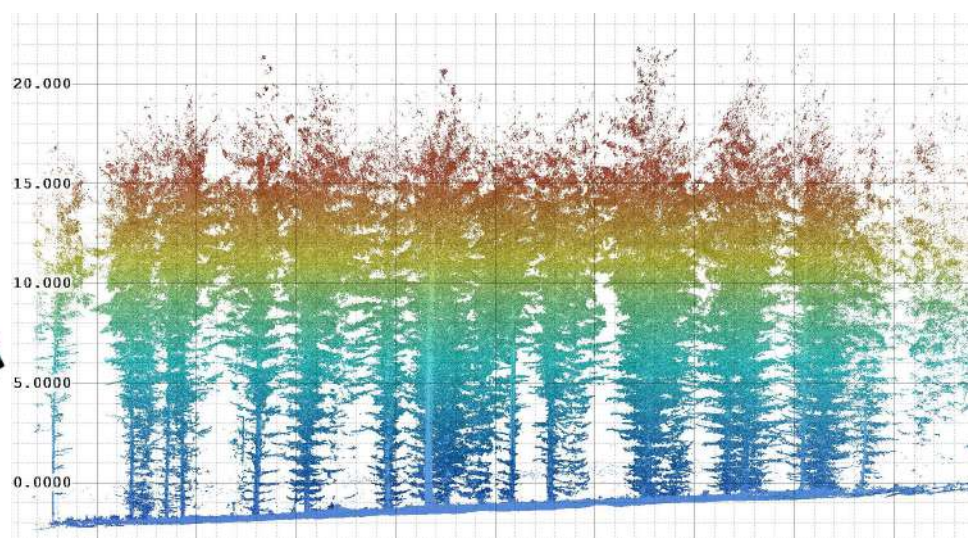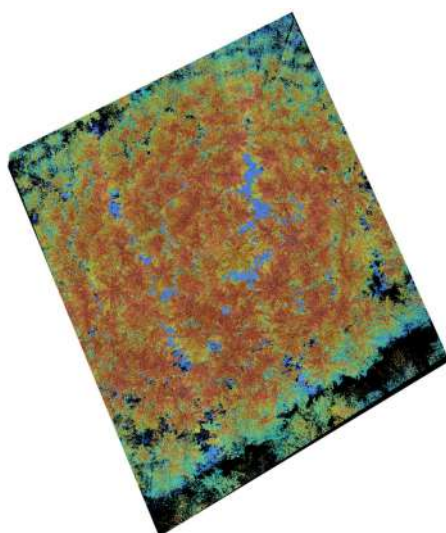


**Figure 8: Top view and cross-section of a typical terrestrial laser scan in forestry (~90k pts/m2). This method provides a very dense point cloud on the ground and stems. Detailed analysis can be derived for individual plots.**
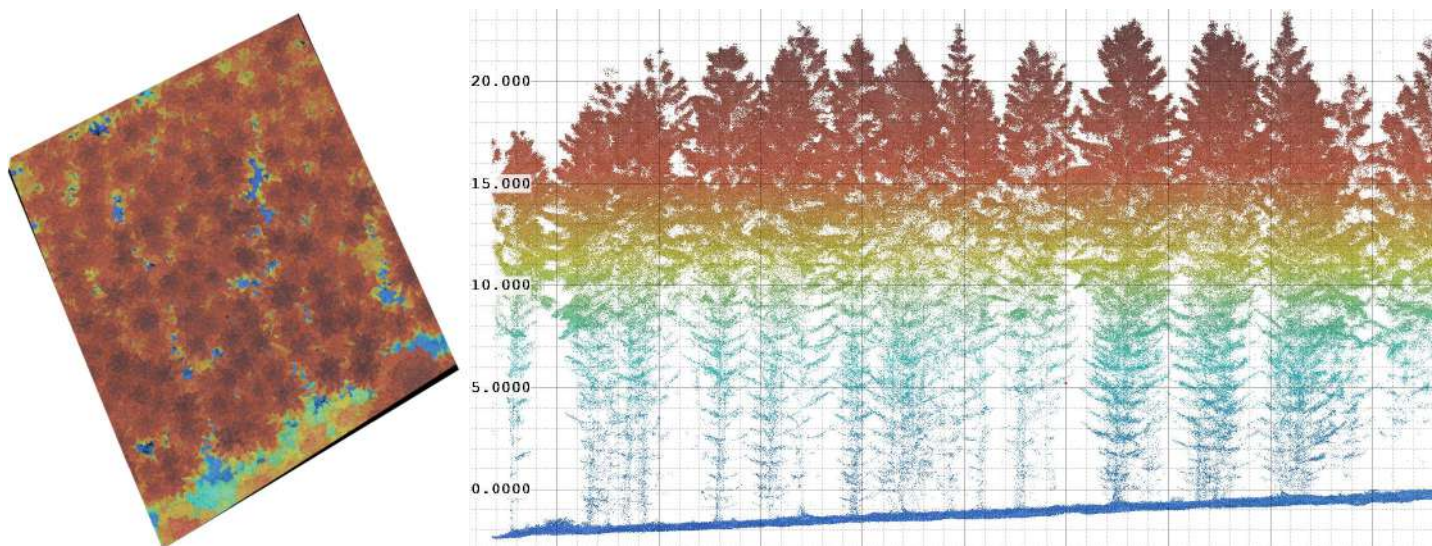
**Figure 9: Top and cross-section view of a UAV-based LiDAR collection (~9k pts/m2). Due to the oblique measurement directions, the canopy, stem, and ground is exceptionally well covered. Suitable for plot measurement or medium size project areas.**

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