8. Laser scanners

Laser scanners are categorised as active monitoring equipment, since they emit energy in the form of laser impulse and then measure the time of flight (TOF) and the intensity of the reflected light of the impulse. An acronym LiDAR (*Light Detection and Ranging*) is used to denote such remote sensing method. Laser scanners can be used on the ground with the help of UAVs, planes and satellites. An overview of the use of laser scanners on planes and UAVs can be found in Li *et al.* (2020).

Laser scanners have been used on manned planes by the Estonia's Land Board since 2008, and you can find general information on the operation principles of LiDAR devices in Estonian on their website.

As it is an active sensor, it can be used in poor lighting conditions or in total darkness. Laser scanners efficiently operate in conditions where photogrammetry based on images taken with a photo camera fails (low contrast, many similar elements, partially transparent objects such as power lines, tree crowns, etc.). One of the important features of LiDAR is the ability to record several partial reflections (E.g. top of the trees, tree crowns and ground surface) per sent impulse. Such an application allows to distinguish from the LiDAR data, that usually is distinguished as a 3D point cloud, the relief of the ground and its vegetation, height and structure. The main fields of use of LiDAR in geography are topography, bathymetry, (forest) vegetation and atmosphere research.

For the efficient georeferencing of objects, laser scanner has to be used together with synchronised precise satellite positioning system (GNSS), and with high precision IMU (*Inertial Measurment Unit*) that measures the orientation against all surfaces of the device on a very high frequency. Laser impulses are projected through space in a variety of ways, and they form a pattern on the surface of the observed object. This pattern is different in different systems and the interposition of points, usually not evenly placed on the surface of the object, is dependent on this pattern. Airborne laser scanning is done by *swaths* with the width dependant on the *field of view* (FOV) and the altitude of the flight. In such a case it must be considered that within a swath, even if the ground is level, the density of data, the size and shape of each footprint, and position accuracy, are not uniform – on the edges of the swath, precision is limited and the footprint of the impulse larger and more stretched out. In case of a more complicated relief the non-uniformity increases and 'shaded' non-reflective areas develop. In such cases, in order to acquire data from such areas, we need to plan overlapping swaths and in the overlap area, the point density becomes twice as high. Consequently, the results of two different surveys that report similar average point density (PD), but are conducted with different laser scanners and flight plans might not be comparable. This becomes especially important in 3D forest surveys.

The most important laser scanner parameters for drones:

- Sensor's weight that along with power consumption affects flight time;
- Power and length of the emitted impulse that along with the sensitivity of the sensor affects vertical separation and maximum altitude;
- The number of pulses emitted per second along with flight altitude, -velocity, and FOV affects point density;
- Maximum number of recorded partial reflections that affects the quantity and distribution of information coming from the semi-transparent section of the object;
- IMU accuracy and refresh rate determines directly the relative accuracy of referencing data points. IMU is the most expensive component in the entire system;
- GNSS accuracy and refresh rate on which depends the absolute accuracy of georeferencing points;
- Availability of an integrated photo camera that allows sending colour information to the first partial reflection, and that makes the classification of later points significantly easier.

The most well-known manufacturers of laser scanners are Riegl and Teledyne Optech, who have produced equipment for manned aerial vehicles for decades. Both companies offer best performing scanners for UAVs, however, these are the most expensive ones as well.

In addition, newer developers have emerged that, among other things, produce laser scanners specially for UAVs. Yellowscan, Routscene, GreenValley, Topodrone, etc., are among the most well-known companies on the European market. In comparison with Riegl's high-end models, the manufacturers use components wilt lower quality in cheaper laser scanners (E.g. Yellowscan Mapper+ and Routescene LidarPod) resulting in lesser accuracy and lower number of recorded partial reflections. The user will get the maximum number of partial reflections, the so called *full waveform*, in lidars that record (almost) the entire reflected radiation flux, and the user is able to configure the reflective threshold. However, such devices, E.g. Riegl Vux-1UAV, are much more expensive and the volume of data production is considerably higher.

DJI offers LiDAR L1 with gimbal for its M300 professional drone, one of the cheapest available, but with rather poor performance indicators. Generally LiDARs are not set up with gimbals, they are placed under the UAV because of their relatively heavy weight. Several UAV manufacturers (E.g. Microdrones, Topodrone) offer models specially integrated with LiDARs.

The **parallel use of LiDAR** is another interesting development for the UAV itself, both in surveying and spatial modelling. This enables the UAV to fly in places with unreliable or out of reach GNSS signal (E.g. mines, internal spaces, caves, in dense urban areas, etc.). For creating real time spatial models *Simultaneous Localization and Mapping* (SLAM) algorithms are used, that, in addition to laser scanners, can use the input of data by a regular camera, radar, or the like (Gupta and Fernando, 2022). For instance, drones such as Flyability Elios 3 or Exyn ExynAero are able to map caves by themselves. Furthermore, a manufacturer Leica Geosystems started selling BLK2FLY drones in 2022 that have a fully integrated laser scanner. However, creating such spatial models requires a lot of calculation power and therefore the flight velocity is lower. In addition, Leica warns that cables/branches finer than 5 mm cannot be identified by laser scanners (yet).

In the first phase of data processing, practically all laser scanners allow the use of only one specific manufacturer, a practice that can be quite expensive. Most of the contemporary manufacturers offer an integrated laser scanner and photo camera that allows adding RGB information to the data points, which makes the later classification of point cloud easier (Image 13).

8.1. Less common versions of laser scanners.

In NIR spectrum (*ca* 1550 nm) usually a laser is used that is invisible to the human eye. **Bathymetry**, on the other hand, uses lasers with a wavelength of 640 nm. For that purpose Riegl, for example, offers an integrated LiDAR-multirotor solution Ricopter that can be used for bathymetric mapping. A precondition for mapping underwater relief by an UAV is water transparency, because a laser scanner is able to record the bottom of a body of water only up to 1.5 Secchi disk depths (Secchi depth is a measure the transparency of the water).

Scanner systems have been developed for manned aerial vehicles with **several different lasers working on different wavelengths** that give spectral information on the object using respective wavelengths; however, such UAV accessories are not yet available for regular consumers.

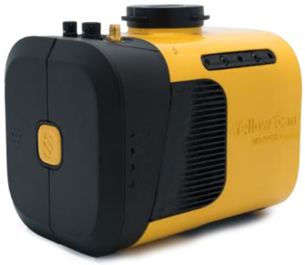
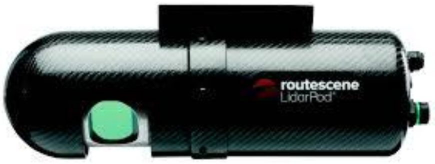
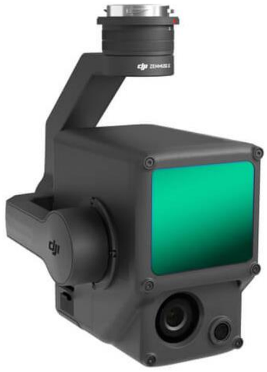
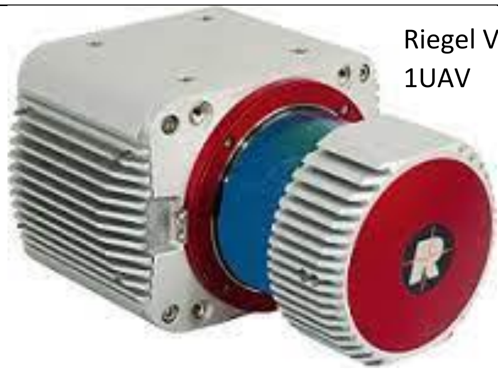
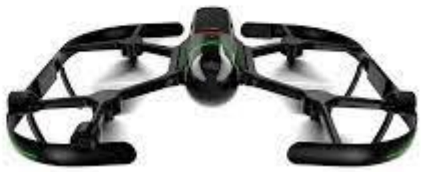
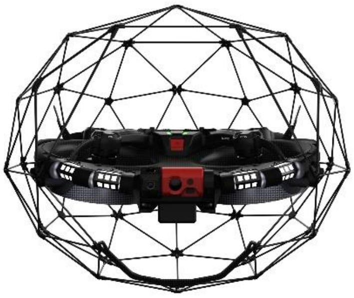
 Yellowscan Mapper+	Routescene LidarPod 
 DJI L1	 Riegel VUX – 1UAV
Leica Geosystems BLK2FLY 	Elios 3 

Image 1. Some images of laser scanners and drones mentioned in the chapter.

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