

# STATUS AND DEVELOPMENTS

## Airborne Lidar Scanners

The first commercial airborne Lidar systems appeared on the market in the mid-1990s. This active remote-sensing technology rapidly evolved to become the laser scanners which can today emit 400,000 pulses per second and record the full waveform of the backscattered signal. Soon they will be even able to record half a billion full waveforms per second. In tandem with the new product survey on airborne Lidar sensors (see our website), the author here gives an overview of status and developments, particularly focusing on beam divergence, multiple pulses in air and full waveform recording, and associated opportunities for existing and new applications.

Airborne Lidar enables accurate and detailed capturing of the 3D geometry of ground surface and objects on it. Developments mainly focus on increasing the level of detail in terms of point density and object characteristics, enabled by small beam width, multiple pulses in air and full waveform digitisation.

### Footprint

The beam divergence of the various systems varies from 0.2mrad (Riegl VQ-580) to 11mrad (Hawk Eye II). Beam divergence is an angular measure which determines the size of the footprint: the cross-sectional diameter at reflecting surface when the pulse hits an object or the ground (Figure 1, left).

Beam divergence is an important parameter because it determines the penetration level of the pulse in forests and other vegetated areas, the level of detectable detail, the sharpness with which outlines of buildings and other objects can be recorded, and the level of eye safety. For creating bare ground digital elevation models (DEM) or determining tree height it is desirable that the pulse hits not only the trees but also the ground surface. The higher its energy, the greater the chance that the pulse passes through spaces between leaves to reach the ground. Small beam divergence warrants a high energy level present in the footprint and is thus beneficial for forestry applications; however, there is also a raised probability of causing damage to sensitive tissues, such as the eye, if a person is hit by the pulse (see GIM International, August 2010). When surveying urban areas for 3D modelling of buildings, bridges, channels and so on, the outlines of objects should be reconstructed as sharply as possible, requiring small footprint in tandem with high point density. In contrast, when small or thin objects such as electric power lines are being surveyed, the footprint should be large to increase the probability of hitting the object.

Most commercial systems produce a small footprint, typically 20cm to 110cm at 1km flying height, but they also allow divergence tuning by the operator, introducing the advantage of adjusting footprint size to specific application, some mentioned above. Discrete switching is possible from one beam width to another, for example from 0.3mrad to 0.8mrad, or tuning may be effected on a continuous scale. Tuning requires placement of moving mechanical parts in the optical system, which may introduce a shift in optical axis and thus degradation of laser pointing accuracy. Planimetric error may be a few decimetres at an altitude of 1km, and changes linearly with flying height. The relationship between beam divergence expressed in milliradians (mrad) and footprint size is quite simple. At a flying height of one kilometre, beam divergence of 0.2mrad equals a footprint size of 0.2m; footprint size of 0.8mrad equals 0.8m (Table 1). At 2km the size of the footprint doubles as it varies linearly with flying height.

### Multiple Pulses

Multiple-pulses-in-air (MPiA) is a technology that allows firing of the next laser pulse before reflection has been received from the previous pulse. The pulse rate of single-pulse in-air systems is determined by the ratio of the speed of light to two times the flying height; for example, at 1km, the maximum pulse rate is 300,000km/s divided by 2km: 150,000 pulses per second; at 2km this number diminishes to 75,000.

The basic advantage of MPiA becomes clear when surveying at higher altitudes. It reduces acquisition time (and hence costs) and also reduces occlusion by variations in relief; the latter makes possible a reduction in width of across overlap. Further, air turbulence at higher altitudes is less severe than closer to the ground, so the flight is more comfortable and crew can stay airborne longer. MPiA technology is beneficial for capturing data on large areas, such as for creating high-accuracy nationwide DEMs, flood-risk mapping in delta areas, and coastal mapping.

### Full Waveform

Airborne Lidar systems conventionally measure one or more ranges to objects present in the trajectory of the laser pulse, as well as strength of backscattered signal. Typically one (first or last), two (first and last) or a few (up to four) return signals are recorded for each pulse. The strength of the return signal gives a clue concerning type of object. Most Lidar systems developed for land applications use near infrared laser, so high-energy returns indicate that the pulse has been reflected from trees, meadows or other vegetation. Recording of the first and last pulse makes it possible to distinguish between canopy and ground surface. However, in forestry and other applications the interest is in structure of objects above ground surface.

The signature of the return signal is determined by interaction between laser beam and object(s) present in the footprint, and can be inferred from capturing the full waveform. In the full waveform approach the entire backscattered signal is sampled at equal intervals over a hundred nanoseconds depending on object height (1ns = 1-9s). If maximum object height is 15m, sample time should be 50ns (15m / 3 108 m/s). Usually a few hundred samples are recorded, yielding a high level of detail of structures present in the footprint. The method

thus considerably improves distinguishing between diverse objects. For example, in forestry the waveform provides an indication of the top of the canopy, underlying layers and ground surface, allowing more accurate determination of ground surface DEM and canopy height (Figure 2). In urban areas roofs can be distinguished from trees, cars from cuboid garage, and so on. Systems using this technology became operational in 1999, primarily for forest applications, and by 2004 they were implemented in commercial systems.

The commercial potential of full waveform Lidar data is high and coming years will bring development of methodologies, applications and software for extracting useful information. One main challenge is the storage and management of the huge volumes of data created by collecting billions and billions of full-waveform returns over a few hours. Manual processing will be impracticable or impossible, making vital the development of software to further automate processing and classification.

### Concluding Remarks

Manufacturers of airborne Lidar systems find it virtually impossible to provide reliable statistics about the precision of the coordinates of point-clouds generated using their systems; precision largely depends on external factors, in particular the GNSS infrastructure used to achieve differential GNSS precision. Precision issues are, therefore, ultimately more a topic for airborne-Lidar service providers than manufacturers.

## Product Survey

In many ways the internet provides a more efficient means of communication than printed media. This is certainly true for rapidly developing technology that leaves specifications quickly outdated. We therefore felt it appropriate as from 2011 to online publish our regular product surveys. These surveys cover a wide range of geo-data acquisition and processing systems, varying from [total-station](#) s, GNSS receivers and airborne laser scanners to remote-sensing image processing software. Online publication also allows updating of specifications as and when appropriate; we are no longer limited to one yearly or biannual updating, as was the case with static paper representation. The new product survey on airborne Lidar, the fourth in a row, [is now available](#). The last was published in February 2009. Contributing manufacturers are Airborne Hydrography AB, with Dragon Eye - Topographic Lidar Sensor and Hawk Eye II - Bathymetric and Topographic Lidar system; IGI with LiteMapper 5600 and 6800-400; Optech with ALTM Orion M/C, ALTM Gemini and ALTM Pegasus; and Riegl with LMS-Q680i and VQ580. Missing is Leica Geosystems, who postponed submitting their contribution until tests were successfully completed on an innovation called 'point density multiplier', to be incorporated into the ALS 70 series; it will allow emitting half a billion points per second, equivalent to a pulse frequency of 500kHz. The pulse frequency of the present ALS60, introduced in 2008, is 200kHz.