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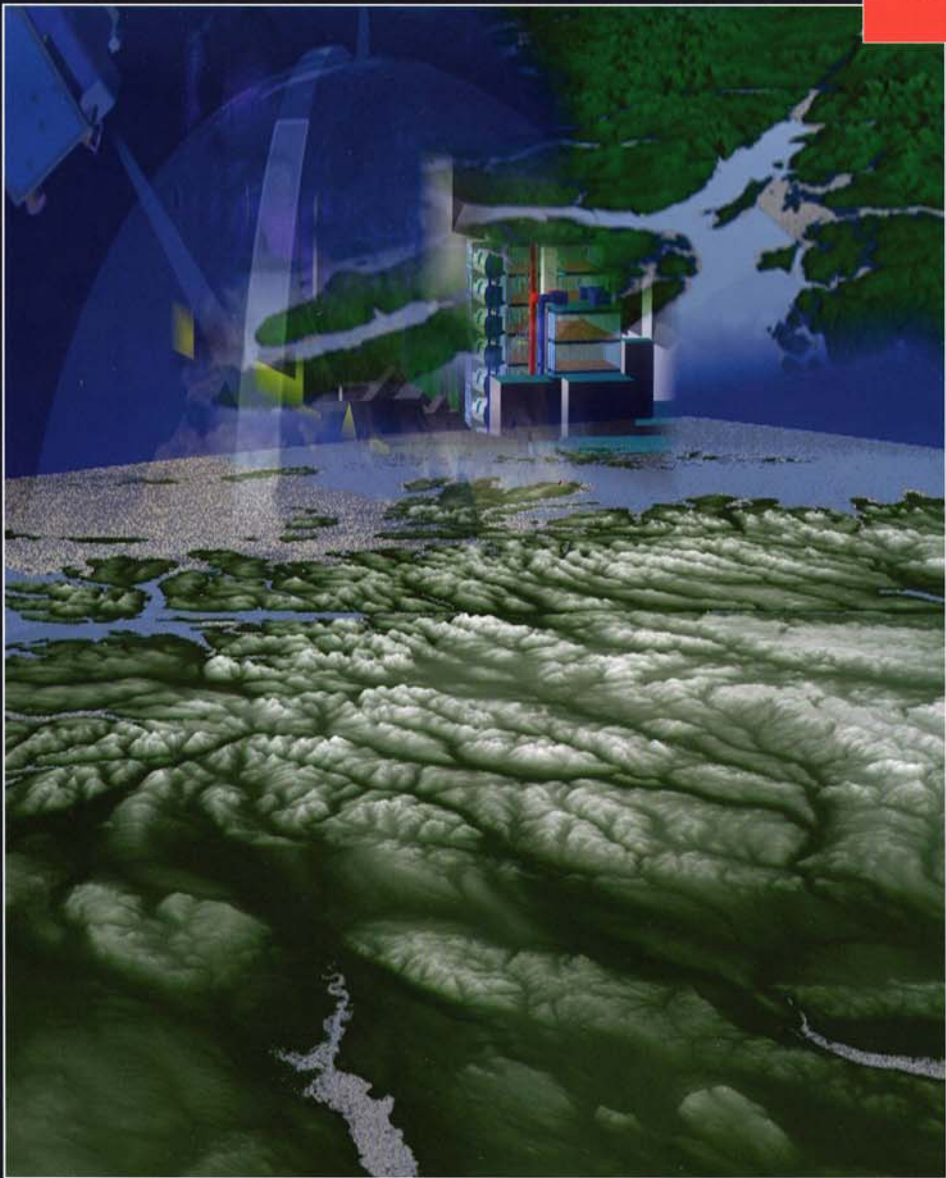

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Linking Laser Scanning to Sur

Integrating Geo-technologies with a New Beaming Method

The use and application of laser scanning technologies requires that a linkage be established with survey and visualisation technologies. This coupling and integration of geo-technologies provides maximum flexibility for capturing, analysing and presenting laser acquired spatial information through the application of light detection and ranging (LIDAR). This article discusses basic principles of airborne laser scanning (ALS), which have great impact on the usability of ALS for certain applications. The underlying measurement principles for different sensor systems are shown and scan pattern and other technical parameters are examined and discussed.

By Alexander Wiechert

Figure 1: Lidar sensor system Falcon II installed in a Piper Seneca.

EDM and Lidar Philosophy

Distance measurements by an Electronic Distance Measurement device (EDM) might be considered as comparable to those measurements made by airborne laser scanning. But there are a few essential differences. An experienced surveyor will set the measurement duration of his EDM depending on distance and target (reflector, man-made, natural) and thus will increase the duration as the stability of the target decreases. In other words, he will take a few measurements against a stable target (reflector) but also a large number of measurements against a natural object. Increasing the number of measurements (duration) will make the final result more precise and more reliable, as the EDM averages over the total number of individual measurements. Airborne laser scanning does not allow that an individual measurement can be repeated, as sensor position and beam direction are changing continuously. So each distance measurement has to be considered as an erroneous random measurement depending strongly on the shape and topology of the area illuminated by the laser beam. A deep understanding of the Technology of course is very important to user Lidar scanning in the appropriate way. A lot had been promised in the early days of airborne lidar scanning and less has been delivered. For some applications, airborne Lidar scanning has been established as the means of survey, for some others not. What seems to be forgotten completely is the fact that airborne lidar scanning is just another form of EDM and that a large amount of knowledge and experience exists and guidelines about how to utilise such equipment for precise measurement are well known. Firstly, no one would accept singular measurements for a reliable distance and secondly, multiple measurements depend on the of reflecting surface and the calculated distance is a weighted average of all measurements

With reflectors the required measurement duration is about 1 second and the required number of measurements is between 100 and 1000. Without reflectors, the required measurement duration is more than 1 second and the required number of measurements is greater than 1000. We need to ask ourselves: why are these common rules not applied to airborne laser scanning? Why does anyone rely on singular distance measurements?

Scan Pattern

Having gone back to the roots of EDM measurement philosophy and guidelines, let us now turn our attention to how lidar scanner systems deal with these principles and compare the scan pattern of existing lidar sensor systems and examine how well these patterns follow the requirements of EDM. In the next figure (see Figure 2 - left), we show the typical scan pattern of a mirror based ALS system. Clearly the scan pattern does not follow the expertise of EDM. Characteristics of these types of systems are:

- Narrow beam
- High lateral accuracy of individual measurement
- Wide measurement spacing
- No direct neighbors, so no context analysis possible
- Sensitive against random erroneous mea-

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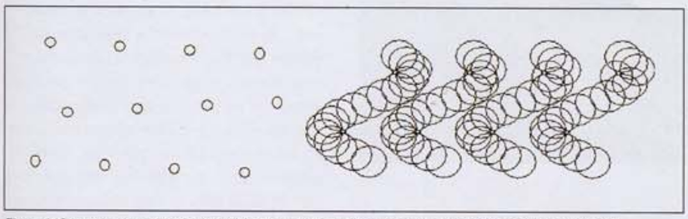
Figure 2: Scan pattern mirror based ALS systems (left) and Scan pattern fiber based ALS systems (right).

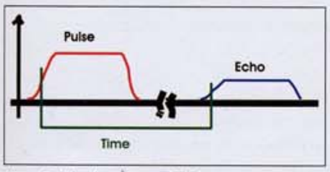

Figure 3: Echo detection - principle.

surements
Adjacent to this figure (see Figure 2 – right) is the typical scan pattern of a fiber based ALS system. Obviously the scan pattern is fully in line with the requirements of EDM. Characteristics are:
- Wide beam
- Medium lateral accuracy of individual measurement
- Narrow measurement spacing
- Large overlap, so precise context analysis possible
- Insensitive against random erroneous measurements

Obviously, depending of the scan pattern and other underlying measurement principles like beam divergence, an ALS may be suitable for particular applications but not others. Choosing the correct ALS will prevent the user from being disappointed with the result.

Echo Detection

One of the essential features of laser scanning is its capability to penetrate vegetated areas and to measure the ground elevation. This feature is often associated with the term 'last echo mode' and refers to the recording of the last echo if several echoes are resulting from a single laser pulse. Last echo mode is taken frequently as a synonym for ground measurement. A laser pulse is very short but not infinitely small. Its intensity rises within a short time up to a certain level, remains there for some time and then decreases. Let's now assume that a laser pulse is a 'Packet of Light' (PoL) travelling from the sensor down to the earth.
The laser pulse is emitted from the sensor, reflected and received by the sensor's detector. The time difference between the leading edge of the pulse at emission and the leading edge of the echo at reception corresponds to twice the distance to the object (see Figure 4 - left). There are several methods to detect the edge of a sharply raising signal. A frequently used method is to apply a threshold (see Figure 4 - middle). If this threshold is exceeded by the echo a signal is derived which stops the counter. If the echo has a very short and steep edge as shown in the graph to the left, the amplitude of the echo has a negligible effect on the time the counter is stopped. Practical echoes are not such steep but take some time to reach the maximum level (or amplitude). If one does not apply reasonable corrections it means that the low reflective asphalt of a runway and the white painting on the runway will cause different distances and thus different elevations. The white lines will always be above the runway. TopoSys implies a more sophisticated method, which applies a dynamic threshold (Figure 4- right). The threshold is calculated from the amplitude of the echo and thus ensures that the trigger signal for stopping the counter will be always in the middle of the raising edge.

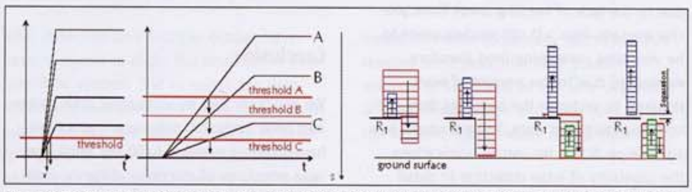

Figure 4: Treshold echo detection (left), dnamic treshold echo detection (middle) and multiple echo detection (right).

Multiple Echo Detection

One laser pulse can produce multiple reflections if the light travelling to ground illuminates several objects at different distances. Multiple reflections can occur when:
- objects are at different elevations (trivial)
- the laser beam has a chance to partly illuminate other objects
- objects are large enough and have a sufficient reflectivity to generate echoes

TopoSys GmbH was founded in spring 1995 as a spin-off of Dornier GmbH, an international air- and spacecraft manufacturer. In 1996 the "Falcon I", the first known fiber based airborne laser scanner system was developed. Since 1996 the company has operated its own laser scanning system and has covered thousands of square kilometers of digital terrain models. Building on the expertise gained in operating "Falcon I" and the customer-oriented evaluation of the laser data, a new enhanced lidar system - "Falcon II" – was presented at the beginning of 2000. "Falcon II" provides additional multi-spectral RGB/NIR scanner and enables taking digital true-ortho images of high resolution. Building on earlier knowledge, we decided at the end of 2003 to embark on the worldwide marketing of scanner hardware to provide high precision and highly reliable lidar data and RGB/CIR true-ortho images and a high-end fiber based lidar sensor system. This system uses a different methodology of beam deflection and a different underlying measurement philosophy than all other manufacturers do, making it well suited for high density elevation models in applications like urban mapping, corridor mapping, coastal survey or forest inventory and allows an easy transition from lidar scanning to survey and visualization (see Figure 1).

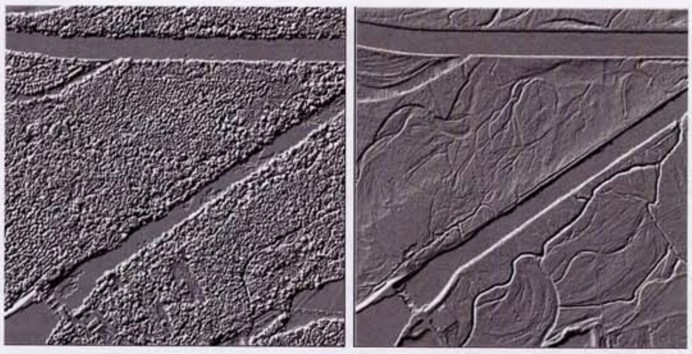

Figure 5: DSM (left) and DTM (right) of Danube river area.

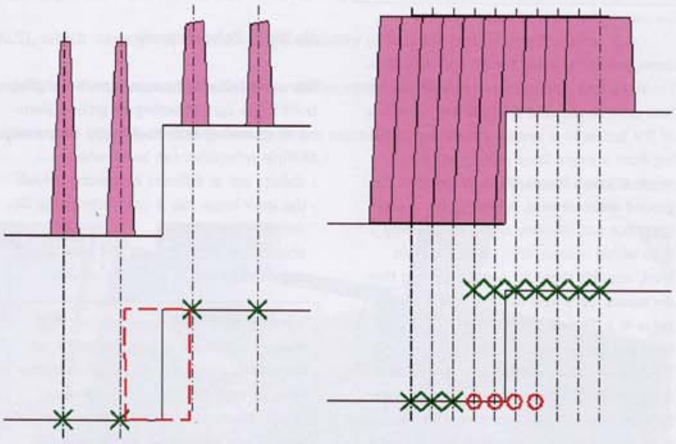

Figure 6: Edge detection mirror based ALS systems – (left) and edge detection fiber based ALS systems (right).

- the laser beam is large enough (in diameter) to illuminate several objects (if the beam diameter is only a few centimeters, then already one leaf may hide all lower objects) The (see Figure 5 – left) shows a laser pulse illuminating two reflecting surfaces on its way down. Part of the light is reflected on surface R1 and the remaining light is travelling further till it illuminates ground surface. Obviously the resulting two echoes are separated in time. If the separation of the two echoes is too short and they either fall together or the detector is not able to separate them, the distance to the reflectors cannot be detected separately.

This means for the ground surface that it can only be measured, if no reflector is present in a minimum distance from ground. Reflector in this context means any object capable of reflecting sufficient light to form a detectable signal. Tiny leafless branches of a scrub usually do not belong to that type of object.

The quality and usability of an elevation model derived by ALS highly depends on the capability of a very good echo separation of the sensor system. The TopoSys Lidar system "Falcon" measures up to nine echoes and is capable to separate objects of a distance of about 1.2 m. (see Figure 5 – right) shows a DSM derived from first echo and a DTM derived from last echo of an river area in Germany covered with dense vegetation without any manual post processing.

Edge Detection

Hydraulic simulations are an example where ALS is frequently considered not to be suitable and terrestrial methods are preferred due to the lack of keeping break lines precise enough. Also 3-D city models seem to be very time consuming (and therefore expensive) due to the amount of work required to vectorize the buildings from the corresponding lidar data. To understand how suitable an ALS is for certain applications, the capability of edge detection in detail must be considered. The next figure (see Figure 6 - left) shows the scan pattern of mirror based ALS systems at edges. The narrow beam and the wide spacing results in a precise position of each individual measurement but does not provide a precise location of the edge as the edge may be anywhere within the red area and no further information on the red area is provides, as compared to scan pattern of a fiber bases ALS system (see Figure 6 – right). Due to the wide beam, the high scan rate and the huge amount of overlapping measurements, first and last echo information is detected from all pulses which hit the edge. This allows to precisely detect the edge. The lack of precision of break lines or even the lack of capability of acquiring break lines is not common to laser scanning by itself but to certain types of laser scanner systems.

Applications

Laser scanning nowadays is used in a wide range of applications such as:
- 3-D city models and city planning
- Costal monitoring and erosion monitoring
- Flood protection and hydraulic simulations
- Monitoring of deposits and mines
- Power line mapping
- Corridor mapping
- Forest inventory and management
- Environmental protection
- Archeology

If and how suitable ALS is as the preferred mean of survey deeply depends on the selection of the right instrument. Especially with high density fiber based scanners like the Falcon II, the laser scanning has been successfully used for applications which are not possible to serve with other scanner systems.

A 3-D city model of Berlin, acquired by TopoSys with Falcon II is shown (see Figure 7). Laser scanner systems have been extended by optical means mostly by loosely coupled digital framing cameras. Falcon II embarks a tightly mounted four channel line scanner and provides a very cost effective acquisition of RGB and CIR true ortho images.. This expands the usage of ALS drastically. An example of the city of Colbe also acquired by Falcon II (see Figure 8).

Conclusion

We conclude that by evaluating scan pattern and other technical parameters only fiber based sensor systems fulfill the most common principles of electronic distance measurement. In addition to that, techniques of

Figure 7: Color codes DSM of city of Berlin, 1m grid.

Figure 8: RGB and CIR of Colbe, 0.5m grid.

echo detection and multiple echoes have been analyzed to allow the end-user to evaluate lidar systems and to select the right instrument for their project. The capability of edge detection has been discussed in detail to show that with the new measurement philosophy ALS is well suited to serve these needs, too. While lidar scanner systems based on mirror technology seems to have reached their peak, the fiber scanners seemed to be almost at the very beginning of their development and offer huge potential to serve future needs of the market.

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