Experiences of 10 years laser scanning

CHRISTIAN WEVER and JOACHIM LINDENBERGER, Steinfurt

ABSTRACT

Airborne Laser Terrain Mapping is a proven technology for topographical surveys with accuracies equivalent to traditional land surveys. It is characterized by an automatic data capture and direct digital data processing. Since about 10 years Airborne Laser Terrain Mapping is an economical alternative to survey large and unaccessible areas, whit a short survey to product realisation time and with a high degree of accuracy.
Primary results are 3-D coordinates of all points. Digital Terrain Models or Digital Surface Models are standard products.

1. INTRODUCTION

Laser scanning has been developed in response to the need of a wide range of users for up-to-date digital elevation models even in cases where traditional methods (tachymetric mapping, stereoscopic photogrammetry, digital image correlation) are not sufficient.
Following initial experiences with airborne laser profiling [*Lindenberger 1993*] performed by the special research group 228 "High-precision navigation - Integration of navigational and geodesic methods" of the Deutsche Forschungsgemeinschaft led to the creation of the TopScan GmbH. In collaboration with the Canadian Optech Inc., TopScan has developed a laser scanning method, which has, since its first international pilot and demo projects in 1993, become a state-of-the-art-technique. Laser scanning is characterized by largely automated measuring, fully digital data recording and computer-based evaluation; this allows to supply the required measurement data for up-to-date digital elevation models even of large areas with a high degree of accuracy and in fairly short time. In the past few years laser scanning with the TopScan method gained ground on an increasing number of applications. Actually 15 ALTM-systems are operated all around the world.

2. LASER SCANNING

2.1. Principle

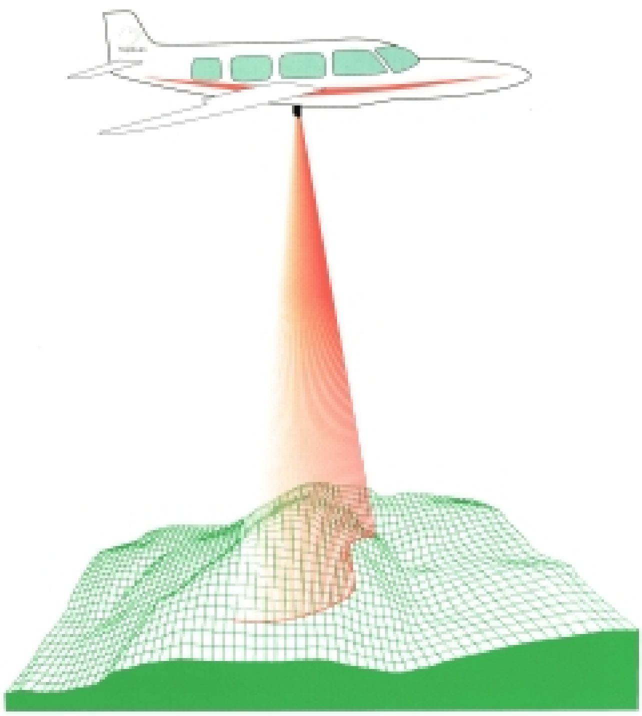

Figure 1: Principle of laser scanning.

Laser scanning is an airborne elevation profile mapping method (Fig. 1). The scanner deflects the laser beam at right angles to the flight line; as a result, a swath of ground along the flight line is sampled.
The distance from the earth's surface is determined by measuring the pulse return time. The physical attitude, i.e. the position and location of the sensor, is calculated from GPS and INS data. In combination with scan angle measuring, the 3D position of each laser beam spot on the earth's surface can be determined.

Laser scanning is performed with a multisensor system with the following main components: ranging laser with scanner for distance measuring, GPS receiver and Inertial Navigation System (INS). The system also comprises a computer for control of the components and time-synchronized data storage, as well as an integrated video camera for imaging of the scanned terrain.
One such system is the Airborne Laser Terrain Mapper (ALTM), which is offered in different versions by the Canadian company Optech Inc. and has been developed together in collaboration with TopScan. The principal parameters of the ALTM 1020 used by TopScan are summarized in Table 1.

Operating altitude	up to 1000 m
Laser repetition rate	variable up to 5000 Hz
Scan angle	variable form 0° to ± 20°
Scan rate	variable up to 35 Hz
Scanning mode	first and last pulse
Range accuracy	< 10 cm

Table 1: System parameters of ALTM 1020.

2.2. Features

Typical features of a laser scanner are reflectorless distance measuring of nearly all natural surfaces, detection of multiple reflections and higher resistance to adverse meteorological conditions as compared to aerial photography.
The reflection of the laser beam is usually diffuse, i.e. not oriented but scattered. The reflection depends on the properties of the scanned surface and is expressed in terms of reflectivity: the brighter the surface, the higher the reflectivity. The reflectivity of natural surfaces is between 10 % and 20 % in case of sand, between 30 % and 50 % in case of vegetation and between 50 % and 80 % in case of ice and snow. Over water, a sufficient reflectivity can be obtained with a scan angle of not more than ± 10°.
The reflectivity of the target surface has an influence on the range of the laser distance measuring. The range of the ALTM 1020 is 1000 m with a reflectivity of 20 %. The range is less over surfaces with a lower reflectivity and more over surfaces with a higher reflectivity. A detailed description of the properties of ranging lasers can be found in *Lindenberger 1993*.
With a beam divergence of 0.25 mrad and a flight altitude of 1000 m, the laser beam has a diameter of approx. 25 cm when it reaches the ground. It can therefore produce multiple reflections when passing through vegetation (Fig. 2a) since some particles of the light pulse are reflected by the vegetation (e.g. by individual leaves or branches) whereas others may be reflected by the earth's surface. ALTM 1020 is able to distinguish between such multiple reflections and to record either the first or the last pulse return. This capability to accommodate multiple reflections makes it possible to map the ground of forested terrain, since the last pulse return is the most likely to be a reflection from the ground, although it can also come from the vegetation if the latter is very dense. Figure 2b shows a profile of the last pulse returns taken over forested terrain. Some spots were reflected by the vegetation, but there is a sufficient number of spots describing the ground, although the measurements were taken in October, i.e. when the foliage was still dense.
The ratio between the number of spots reflected by the ground and the total of measured spots is called the penetration rate. Empiric research by *Hoss 1997, Kraus 1997 et al., Reiche et al. 1997 and Washausen 1996* have shown that the penetration rate is between 31 % (for coniferous forest) and 64 % (for mixed forest). The distribution of spots is described in these publications as

adequately dense and homogenous, with problems arising only in case of young plantation areas of coniferous forest.

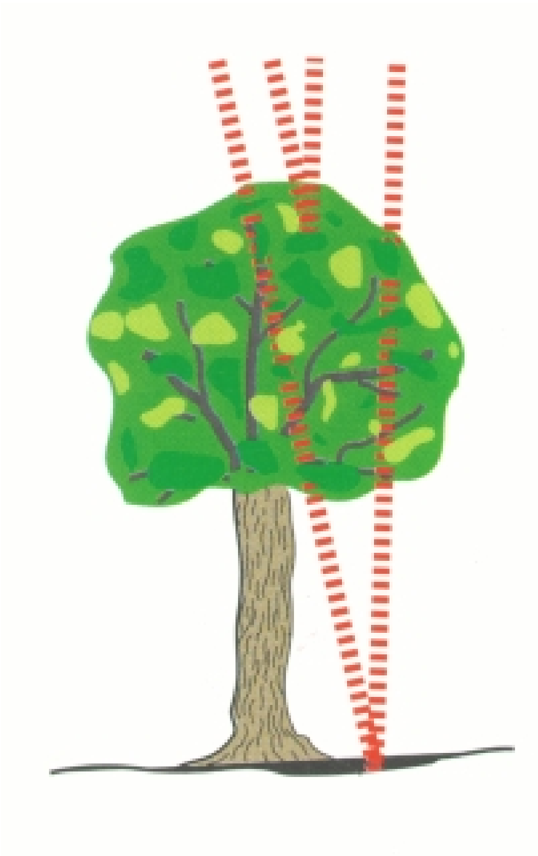

Figure 2 a: Schematic drawing of multiple reflections.

Figure 2b: Last pulse over forested terrain; flight performed in October.

Laser scanning can be performed in all seasons and at any time during the day or at night. The only prerequisite is that there are no obstacles such as clouds, rain or ground mist between the aircraft and the mapped surface. For topographic mapping of forested terrain, the best period is between late autumn and spring since the penetration rate is highest in this period.

2.3. Point Distribution and Point Density

The system parameters of the ALTM laser repetition rate, scan angle and scan frequency can be set variably; in combination with the flight altitude above ground level, the aircraft speed and the distance between flight lines, they determine the density and distribution of laser beam spots on the earth's surface.

The width of the scanned swath is a function of the scan angle and the flight altitude. With the maximum range of 1000 m and the maximum scan angle of ± 20°, a maximum swath width of 730 m is obtained. On the other hand, setting the scan angle to 0° produces an extremely dense longitudinal profile (70 laserpoints per meter) along the flight line. Such longitudinal profiles may be desired e.g. in corridor planning.

Very dense "transverse" profiles are obtained with a repetition rate of 1 Hz (Fig. 3). In this case, two scan lines per second are produced that have 2500 spots each (with a sampling rate of 5000 Hz). In a 500 m wide swath, the distance between the laserpoints in the scan line is 20 cm; with a maximum swath width of 730 m, it is < 30 cm. Assuming an aircraft speed of

140 kn (70 m/s), the distance between these "transverse profiles", i.e. between the scan lines, is 35 m along the flight line and 70 m at the swath edges. Transverse profiles are useful for mapping very long objects such as dykes, railway corridors, power transmission lines etc.

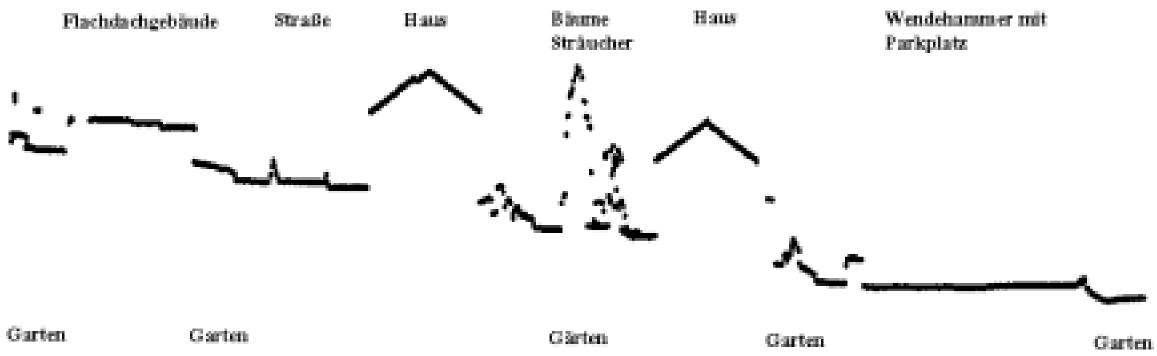

Figure 3: Laser points of one scan line.

With a higher repetition rate, the distance between scan lines on the flight axis is reduced while the distance between spots within the scan line is increased. A fairly even distribution of spots is obtained with a repetition rate of 12 Hz combined with an aircraft speed of 70 m/s and a swath width of approx. 600 m (Fig. 4a). The resulting maximum mean distance between spots is 3 m. If the distance between flight lines is reduced, the mean distance between spots decreases accordingly. Distances of < 1.5 m are possible at reasonable cost.
Thanks to its variable system parameters, ALTM 1020 offers a wide range of mapping options, from longitudinal profiles to transverse profiles to even point distribution, and thus a high degree of flexibility with respect to different requirements.

2.4. Evaluation

The data obtained during the flight mission is processed in several steps that are mostly computer-based. These steps comprise preparation, GPS evaluation, system calibration, coordinate calculation of all laser points in the country-specific system and automatic laser points classification.
The GPS records are first individually decoded and checked for completeness (continuous data recording). Next, the flight track is calculated on the basis of a model of relative kinematic positioning using double phase differences.
Next, system calibration is performed on the basis of the swath overlap and given control surfaces. Control surfaces may be e.g. sports fields, large parking lots or other types of terrain with an even profile. The elevation properties of these control surfaces are measured by a separate method such as tachymetry or GPS. In the system calibration, various parameters determined during lab calibration are checked and corrected, if required.
Next, the coordinates of each reflected laser spot are calculated for the whole area covered by the project. The primary result produced by laser scanning is a number of spots describing the elevation profile of the scanned area, including vegetation, manmade features and temporary surface features (Fig. 4a). At this point in time, the spots supply only elevation information. Depending on the specified requirements, there may also be spots that do not belong to the desired and/or defined model surface.

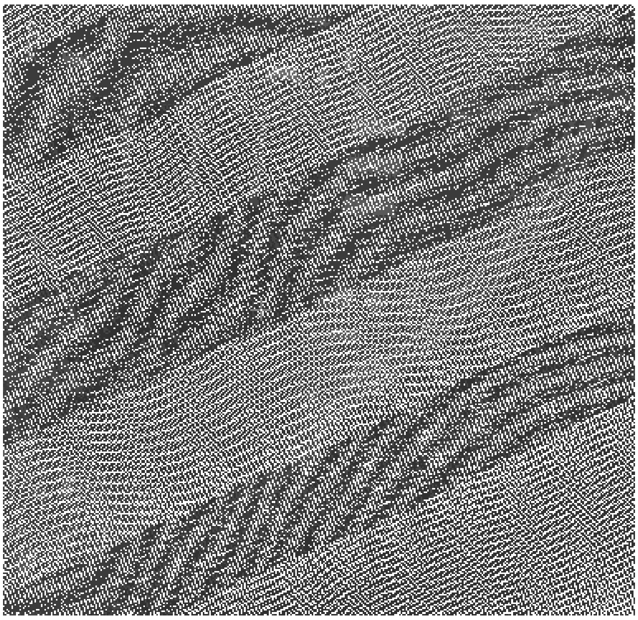

Figure 4a: Total number of laser points.

Figure 4b: Classified laser points.

The spots that will constitute the final DEM are selected automatically by means of a filter algorithm. At present, laser spots can be classified in two main groups: spots reflected by the terrain surface and other spots (Fig. 4b). The second group comprises mainly spots reflected by manmade objects and by vegetation. Depending on the desired quality, the automatic classification can be optimized using an interactive graphical editing function.
The classified laser spots constitute the final result of laser scanning. Standard products derived from this are digital elevation models (DEM) and digital terrain models (DTM). Existing elevation information such as mass points and/or isolines can be integrated in the calculation of DEM models, and breaklines be extracted automatically from the laser spots.

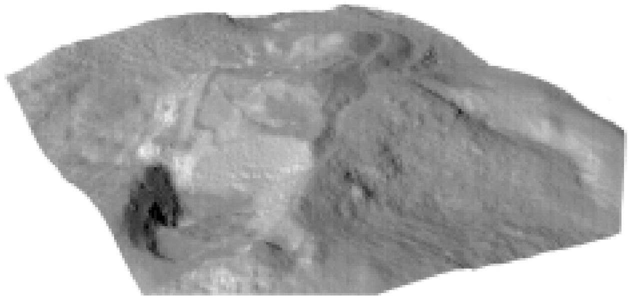

Figure 5a: Topographic mapping.

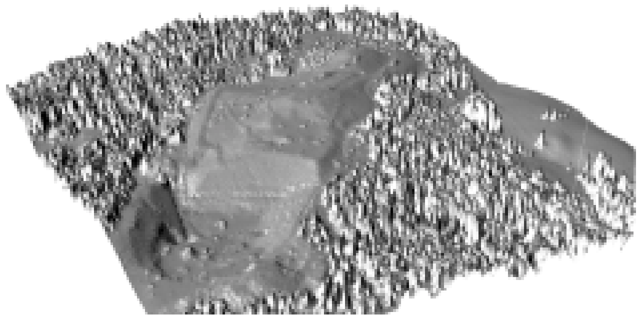

Figure 5b: Topographic mapping, including vegetation.

2.5. Application

The primary aim in the development of laser scanning was topographic mapping of forested terrain [*Lindenberger 1989*]. Another intended field of application was the mapping of areas that are not suited for aerial photography because they do not offer contrast and texture (tidal flats, glaciers, beaches). In the meantime, laser scanning has conquered fields of application far beyond those that were originally intended. Laser scanning has been used, for instance, in:

- Topographic mapping (Fig. 5)
- Vegetation height measurement (Fig. 6 and 7)
- Tidal flat mapping and coastal zone management
- Mapping of flooded areas; flood protection, riverside construction and hydrological modelling
- Erosion surface detection; avalanche protection
- Glacier mapping
- Digital city models (Fig. 8)
- Corridor applications for roadway, railway, pipeline and power line construction
- Power line monitoring
- Volumetric control, e.g. in open-pit mining and waste dumps

In addition to these applications, which make direct use of laser scanning, laser scanning data might be integrated in geographical information systems. On one hand, a standard product of laser scanning, namely the digital elevation model, can be integrated into geographical information systems, and on the other hand, geographical information systems might be used for further evaluation of the laser spots.

2.6. Accuracy

The accuracy of laser scanning has been continuously examined since the first pilot projects. For such examinations, the laser spot information is compared to a control DEM obtained by independent measuring methods such as tachymetry, GPS or photogrammetry, or a DEM calculated from laser spot information is compared to control points obtained by independent methods. In both cases, an elevation value interpolated from a DEM is compared to a measured elevation value. Depending on the type and structure of the chosen control surface, the accuracy of the laser spots or of the DEM are analyzed on the basis of the difference between both values.
Different examination methods produce different results. The r.m.s. values and standard deviations of the differences between the laser spot and the reference elevation values vary between approx. 60 cm and 5 cm [*Brockmann 1997, Fluch and*

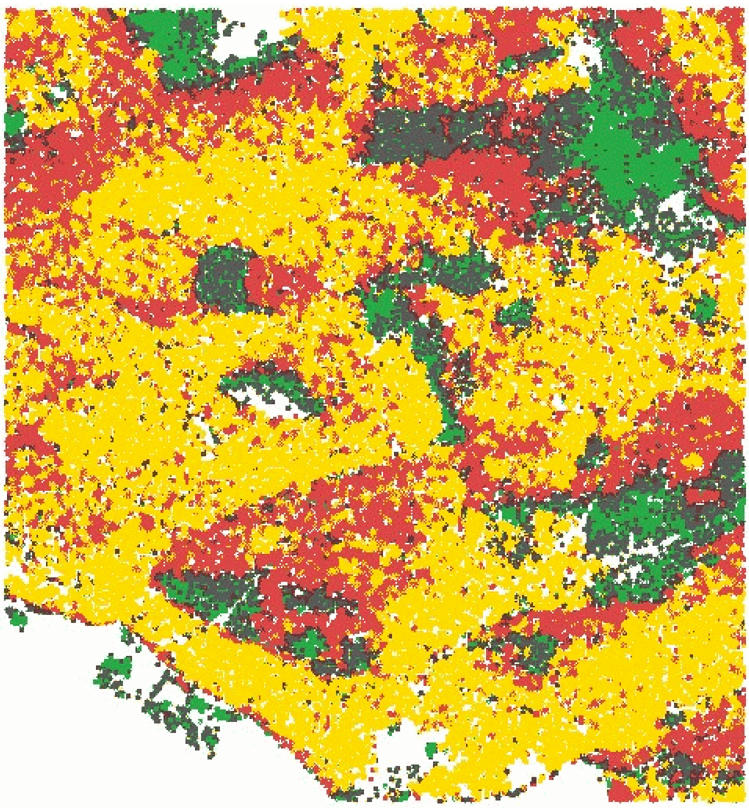

Figure 3: Vegetation height measurement
(brighter = higher)

Reil 1997, Hoss 1997, Kraus 1997 et al., Reiche et al. 1997, Washausen 1996].

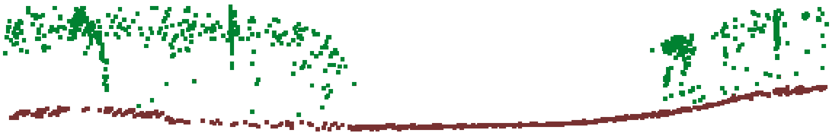

Figure 7: Vegetation height measurement – profile.

State-of-the-art evaluation methods produce an elevation accuracy of the laser spots that has a standard deviation of < 15 cm. This degree of accuracy is reflected in the acceptance criteria of government surveying departments, which accept the results of Laser scanning if the standard deviation of the elevation differences measured on several check surfaces is < 15 cm and if at least 95 % of al elevation differences are < 30 cm.

3. CONCLUSION

Ten years after the first experiments with laser profiling, laser scanning has reached, thanks to continuous improvement of the measuring system and the evaluation methods, a degree of performance that is on a par with that of classic methods of topographic mapping or even surpasses it by far in terms of efficiency, cost and accuracy. While first developed for topographic mapping of forested areas, laser scanning today with its high degree of accuracy and automation is used for the creation of country-wide digital elevation models and is continuing to conquer further areas of application.

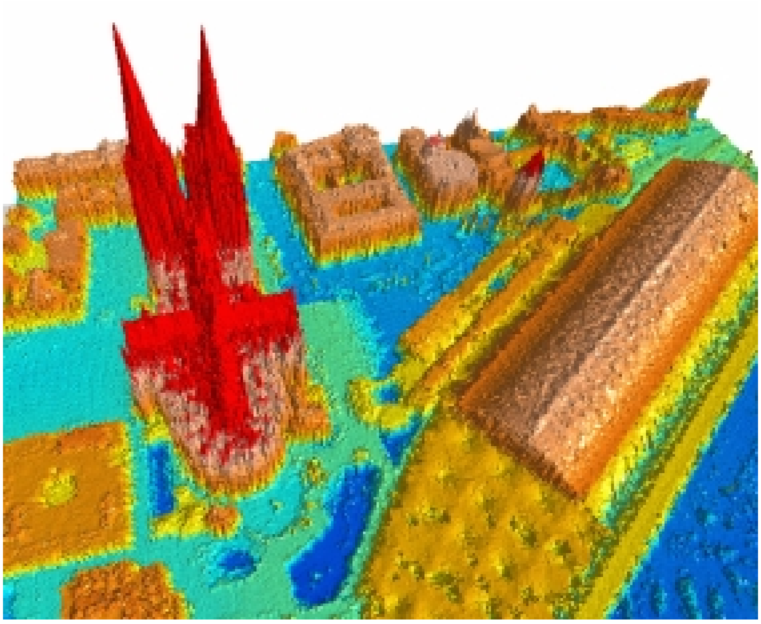

Figure 8: Digital city model.

4. REFERENCES

Brockmann, H.: Erfassung räumlich-hydrologischer Informationen - Bewertung derzeitiger Möglichkeiten unter Berücksichtigung der Erprobungsergebnisse zum Einsatz der flugzeuggestützten Laser-Scanner-Technik. Bericht BfG-1071 der Bundesanstalt f. Gewässerkunde, Koblenz 1997.

Fluch, M., W. Reil: Airborne Laser Scanning - Ein Anwendungsbeispiel zur Bestimmung der Geländehöhen bei seismischen Vermessungen. Der Vermessungsingenieur, Zeitschrift des VDO, 48. Jg., Heft 1, 1997, pp. 2-6.

Hoss, H.: Einsatz des Laserscanner-Verfahrens beim Aufbau des Digitalen Geländehöhenmodells (DGM) in Baden-Württemberg. Mitteilungen des Deutschen Vereins für Vermessungskunde, Landesverein Baden-Württemberg. 44. Jg. Heft 1, 1997, pp. 5-26.

Kraus, K., Hynst, E., Belada, P., T. Reiter: Topographische Daten in bewaldeten Gebieten - Ein Pilotprojekt mit Laser-Scanner-Daten. Österreichische Zeitschrift für Vermessung & Geoinformation, Heft 3, 1997, pp. 174-181.

Lindenberger, J.: Test Results of Laser Profiling for Topographic Terrain Survey. Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, Heft 13, 1989, pp. 25-39.

Lindenberger, J.: Laser-Profilmessungen zur topographischen Geländeaufnahme. Deutsche Geodätische Kommission, Reihe C, Heft 400, München 1993.

Reiche, A., P. Schönemeier, M. Washausen: Der Einsatz des Laserscannerverfahrens beim Aufbau des ATKIS-DGM 5. Nachrichten der Niedersächsischen Vermessungs- und Katasterverwaltung. 47. Jg., Heft 2, Hannover 1997, pp. 68-87.

Washausen, M.: Geplanter Einsatz des Laser-Scanning-Verfahrens beim Aufbau des niedersächsischen Digitalen Geländehöhen-Modells (DGM 5). Vortrag während des Hansa Luftbild Symposiums 1996.