The suitability of airborne laser scanner data for automatic 3D object reconstruction

H.-G. Maas
Institute of Photogrammetry and Remote Sensing, Dresden Technical University, Dresden, Germany

ABSTRACT: Beyond its original application field of digital terrain model and digital surface model generation, airborne laserscanning has proven to have a high potential as a general tool for 3D object model generation. The paper discusses the performance and suitability of data acquired by modern laserscanner systems for 3D object modelling tasks and shows application examples from the fields of forestry, building reconstruction and powerline monitoring.

1 INTRODUCTION

Airborne laserscanning is an active technique to acquire point clouds describing the earth surface. While early systems generated datasets with an average point spacing of a few meters, modern systems are capable of acquiring several points per square meter. In addition, they offer the capability to record multiple echoes per laser pulse as well as pulse intensities. Originally being used as a powerful technique for the acquisition of data for digital terrain models, airborne laserscanning is meanwhile often referred to as a tool for adding the third dimension to GIS data, and to acquire data for a wide range of 3-D object modelling tasks.

In the following, the capabilities and performance parameters of modern airborne laserscanner systems will be described, and their suitability for 3-D object reconstruction tasks will be discussed, showing examples from the fields of forestry, building modelling and corridor mapping.

2 PRECISION AND RELIABILITY

Several authors have examined the precision potential of airborne laserscanner data. Early investigations based on low density datasets acquired for digital terrain model generation (Huising & Gomes Pereira 1998) address only the height component and report a precision in the order of 15 cm. This figure is almost independent from the range of the recorded area and contains a number of systematic errors, mainly introduced by the integrated GPS/INS pose determination system. The local precision of neighbouring data points in one laserscanner data strip can reach a level of 4 cm (Maas 2001).

The reliability of individual data points of a laserscanner dataset is rather high. Blunders are sometimes generated by a laser pulse hitting temporary objects such as birds, by double reflections or by carelessness in data handling, but are generally rare. Digital terrain models generated from airborne laserscanner data will usually require much less interactive post-processing than terrain models generated by means of stereo matching techniques.

With the increasing use of high resolution laserscanner data for general 3-D modelling tasks such as building model generation, the planimetric accuracy of laserscanner data becomes relevant as well. (Huising et al. 1999) detected planimetric errors of up to 1.5 meter by the

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comparison of building locations with photogrammetricly measured roof edges. Errors of that magnitude should be avoidable by proper calibration of a system and correct data processing. (Maas 2000) shows a least squares matching technique to determine discrepancies between neighbouring laserscanner data strips and reports discrepancies of up to 70 cm in two sample datasets. These figures are in accordance with the specifications for the scanning mirror and the INS unit of most systems.

3 DIGITAL TERRAIN MODELS

Within rather short time after the appearance of the first commercial airborne laserscanner systems, the technique has become the most important tool for the generation of dense accurate digital terrain models. The Netherlands were the first country to have a complete country-wide digital terrain model acquired by laserscanning (Wouters & Bollweg 1998, Huising et al. 1999). The model was sampled with an average point spacing in the order of 3 meter and is specified with a precision of 15 cm. It is planned to be used as a multi-purpose dataset, with applications including flood risk analysis, ground water level planning, drainage, infrastructure planning, submergence analysis, ventilation simulation and noise propagation.

As an active technique, laserscanning is independent on the presence of surface texture, and may also be used over regions, where conventional image matching based techniques will often fail, such as beaches, meadows, snow and ice. The high degree of automation in data processing and the high precision and reliability of the results has accelerated the acceptance of the technique.

4 FORESTRY APPLICATIONS

The characteristics of penetration and reflection of laser pulses through and from vegetation have made airborne laserscanning an important technique for height data acquisition in forest areas. Laser pulses penetrate vegetation to a certain depth. In forests with moderate density, a large percentage of the laser pulses will penetrate to the ground. Thus, a laserscanner system operated in last pulse mode (i.e. the time of flight is determined by the last part of the reflected echo) may be used to generate a digital terrain model of forest areas. This is hardly possible by conventional interactive or automatic stereo-photogrammetric approaches; therefore airborne laserscanning can be used to fill large gaps in existing digital terrain models. In addition, a laserscanner system operated in first pulse mode can be used to determine a digital surface model over forests, which is built up by points in the crowns of trees.

While early systems could be operated either in first pulse or in last pulse mode (or in a toggle mode alternating between first and last pulse), several modern systems are capable of recording the first pulse and the last pulse simultaneously, thus allowing for the determination of tree heights (with the limitation that the distance between the pulses must be at least two meter). This gives foresters a unique tool to determine tree heights over large areas, and to monitor forest growth by regular scanning.

In automatic processing of laserscanner data, the differences between first and last pulse data may be used to facilitate the segmentation of data (Kraus & Rieger 1999): even though a first pulse is not always reflected from the upper branches of a tree and a last pulse may sometimes be generated by the trunk or large branches, forested areas will always be characterized by significant systematic differences between first and last pulse heights. Figure 1 shows height images generated from first pulse and last pulse data of an area with buildings and trees, and the difference image indicating trees in a park and along an alley. Filtering techniques which have been developed to extract digital terrain models from digital surface models (Pfeifer et al. 1998, Vosselman 2000) can be used to remove the non-terrain echoes in the last pulse data and to enable the determination of tree heights.

Figure 1. Village and park area, first pulse image, last pulse image.

The separation may be accentuated by multi-temporal data, combining first pulse data taken in summer with last pulse data taken in winter (Kraus & Rieger 1999). An additional option for the segmentation of laserscanner data is the use of intensity data, which are recorded by some laserscanner systems (Hug & Wehr 1997, Oude Elberink & Maas 2000). These intensity data represent an image, mostly in the near infrared, which is perfectly registered with the height data. Such an image may for example be used to separate green vegetation from fields, asphalt of building roofs (Fig. 2).

Figure 2. Laserscanner data: height and reflectance image.

Beyond recording first pulse and last pulse, there are two systems on the market which are capable of recording four or five returning echoes of a laser pulse (again with the prerequisite that the distance between the echoes must be at least two meter); this option may for example be relevant for powerline monitoring (see Section 6). NASA has extended this capability to a technique called ‘waveform analysis’ (Blair et al. 1999); this technique generates an intensity profile through the returned laser pulse echo with a spatial resolution of 11 cm, allowing for the determination of vertical density profiles in forests by using widened laser pulses. Beyond the monitoring of forest growth, such techniques may be used for the determination of tree species and for biomass estimation as a basis for the determination of the CO_2 storage capacity of forests.

Due to the complexity and unpredictability of the interaction of laser pulses with leaves and branches in the crowns of trees, the above mentioned precision potential of laserscanning can obviously not be reached in tree height determination. A bias towards lower tree heights can be expected as a consequence of the fact that a pulse is probably not reflected from the highest leaves of a tree, while the terrain model might be determined too high due to dense material on the ground. Tests performed by (Koch & Friedlaender 1999) indicate a precision potential in the order of one meter.

5 3D CITY MODELS

While early airborne laserscanner systems produced datasets with an average point spacing in the order of 3-4 meter, modern systems are capable of producing datasets with several points per square meter. Buildings are represented by hundreds of data points in such a dataset and can be well recognized in visualizations of laserscanner data, e.g. as a height image (Fig. 3). The structure of 2.5-D laserscanner data facilitates the detection of buildings in such data and the generation of 3-D building models based on segmented laserscanner point clouds.

The potential of airborne laserscanner data for automatic building model generation has been examined by several authors in the past few years: Brenner/Haala (1998) derive parameters for 3-D CAD models of basic building primitives by least-squares adjustment, minimizing the distance between a digital surface model generated by laserscanning and corresponding points on a building primitive. The boundaries of buildings are derived from available ground plans. Brunn/Weidner (1997) show the detection of buildings in digital surface model raster data by Bayesian networks applied to differential geometric quantities and attempts to data-driven extraction of building structures. While referring to digital surface model data in general, their approach shows good results when applied to laserscanner data with three points per square meter, but fails when applied to a surface model derived from stereo imagery. (Maas 1999) and (Oude Elberink & Maas 2000) use height texture measures combined with height and reflectance data for the segmentation of laserscanner data and the detection of buildings. (Maas 1999) presents closed solutions based on the analysis of invariant moments in a model-driven approach to generate parametric building models from dense airborne laserscanner data. The technique requires a point density of at least one point per square meter; from very high density datasets with 4-5 points per square meter, even roof details such as dorms can be derived (Fig. 3). Based on the same data, (Vosselman 1999) presents a data-driven approach which is also capable of handling buildings with rather complex ground plans.

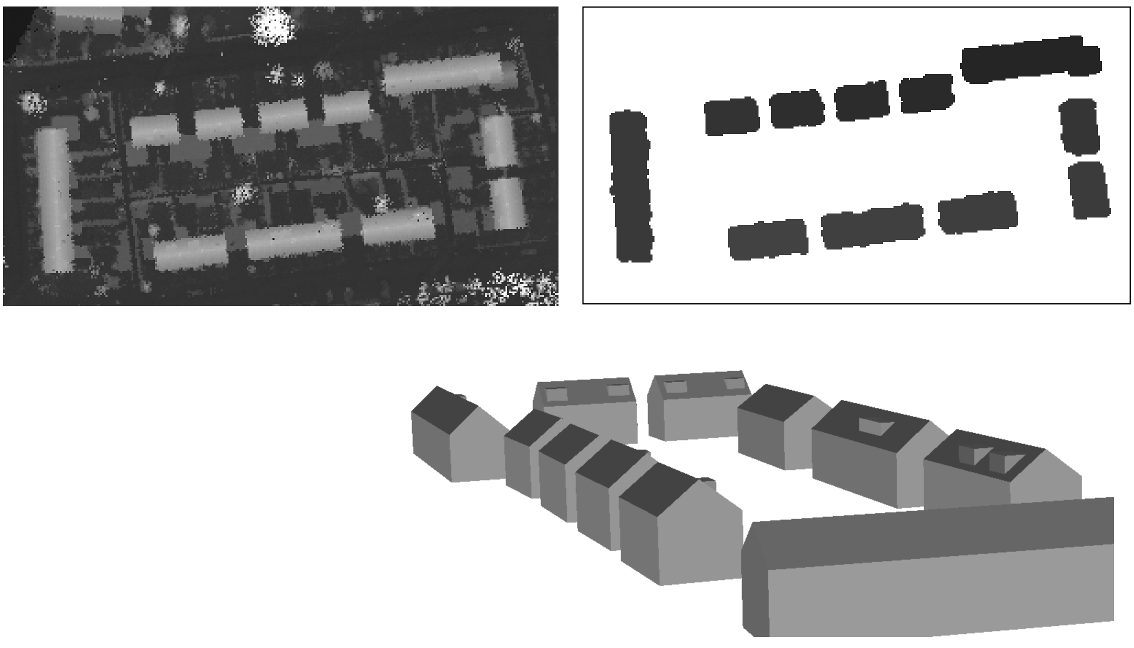

Figure 3. 0.5m resolution laserscanner height image, buildings after segmentation, building models (Maas 1999).

6 CORRIDOR MAPPING

A rather new application field of airborne laserscanning is corridor mapping, which can be described as the acquisition of GIS data along long linear objects such as dykes, railway lines or electrical powerlines. Laserscanning is for example being used for the acquisition of railway line inventory data, mapping the relative position of rails, cables, substructure ballast and potential obstacles. The 3-D geometry of electrical powerline cables, corrected for temperature effects, may be used to monitor powerlines and to determine the adherence of safety margins to close-by vegetation and to the ground.

Figure 4. Laserscanner data point cloud representing an electrical powerline (TopEye).

This task includes the segmentation of a laserscanner point cloud (see Fig. 4) into points on powerlines, vegetation and the ground. 3-D line tracking followed by catenary curve fitting yields parametric wire models, which are used to determine the distance of wires to vegetation and the minimum wire height above the ground under extreme temperature conditions.

7 CONCLUSION

Airborne laserscanning has found wide interest in the photogrammetric community within rather short time after its appearance as a commercial measurement technique. Beyond the original application field of airborne laserscanning in data acquisition for digital terrain models or digital surface models, recent high resolution systems have proven to be rather suitable for a number of 3-D object reconstruction tasks. Point densities in the order of one point per square meter, as they can be achieved by most modern systems, show a high potential in building reconstruction. High resolution systems are capable of achieving point densities of several points per square meter, which even allow for the reconstruction of roof details such as dorms. Multi-pulse systems show a high potential in forestry applications, as they allow for the simultaneous determination of a forest ground digital terrain model and of tree heights. The reflectance value provided by some systems may be useful as additional information in segmentation procedures. The proven precision and reliability potential of laserscanner data points forms a good basis for automatic reconstruction and can be propagated into results.

Laserscanning data can be considered to be complementary to conventional digital image data in many aspects. While laserscanner data is well structured and well suited for automated processing, the resolution and interpretability of panchromatic or multispectral image data is superior. Obviously, data fusion - preferably from a laserscanner and a digital camera integrated on a common platform - will merge the advantages of both types of sensors.

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