HIGH-RESOLUTION ENVIRONMENTAL MONITORING OF WOODED MOUNTAINOUS REGIONS SUPPORTED BY AIRBORNE LASER SCANNING

Elmar Csaplovics, Stefan Wagenknecht
University of Dresden
Institute of Photogrammetry and Remote Sensing
D-01062 Dresden, Germany
csaplovi@rcs.urz.tu-dresden.de

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ABSTRACT

Since a few years the technology of airborne laser scanning has been operationalized to a great extent. High-precision calculation of position and attitude of the sensor system along the flight path is provided by an on-board GPS-receiver and an Inertial Navigation System (INS). The running time of the pulses to and from the points of reflection is measured. Distances from the specific sensor positions to the laser points within the related scans can be calculated. After the mission, the elements of the outer orientation of each laser pulse and subsequently the polar coordinates of the laser points are determined and transformed to a global coordinate system. Raw data of wooded terrains have to be filtered by means of automatic classification algorithms for separating data representing the ground surface and the treetop surface respectively. The presented paper describes an approach to digital topographic modelling of rugged wooded landscapes characterized by solitary rock formations. The approach bases on advanced methods of filtering and object-orientated treatment as well as representation of the rocks. The object-based analysis of airborne laser scanner data of rugged wooded regions represents a first step towards high-resolution digital modelling of discontinuous topographic surfaces covered by dense ligneous vegetation strata. Recent laser scanners retrieve first pulse and last pulse data simultaneously. This will lead to increasing accuracies in rock extraction. The question has then to be answered, to what extent high-resolution extraction of vegetation surfaces and rock surfaces can be supported by appropriate medium-to-low cost hard- and software equipments.

RÉSUMÉ

Depuis quelques années les systèmes laser à balayage sur avion fonctionnent dans un mode plus ou moins opérationel. Par support du GPS et INS, les coordonées des positions du système sont calculées en haute précision. Il est possible d'évaluer les distances entre les positions d'avion et les points de réflexion sur terrain correspondants. Les coordonées des points sur terrain sont calculées et transformées dans un système de coordonées praticable. Les données des terrains boisés sont filtrées en utilisants des algorithms de la classification automatisée pour sélectionner des points du terrain et des points des cimes des arbres. L'article présent traite une méthode de la modèlisation numérique du terrain boisé et rugueux, characterisé par des aiguilles ainsi que des bancs des rochers isolés. Une méthode spécifique du filtrage en combinaison avec un traitment des données originales au niveau des formations des rochers est présentée. Cette méthode d'éxtraction des données laser en fonction de la rugosité du terrain, de la modèlisation numerique des rochers isolés et de la synthèse des objets modèlés avec le modèle numerique du terrain continu représente une possibilité de la creation d'un MNT des terrains rugueux et boisées en haute résolution. Des nouveaux systèmes laser à balayage sont capable d'enregistrer la première réflexion ainsi que la dernière réflexion du chaque rayon laser dans un mode simultané. L'utilisation des ces données va améliorer la précision de l'extraction des surfaces rocheuses dans une certaine mesure. En tout cas il est très nécessaire d'explorer l'efficacité de l'applicabilité des données laser au niveau de lignes de la technologie appropriée.

KURZFASSUNG

Seit einigen Jahren werden flugzeuggestützte Laserscanner-Systeme zur operationellen Gewinnung von hochgenauen digitalen Geländemodellen eingesetzt. Mit Unterstützung von flugzeugintegriertem GPS und INS können die Koordinaten der Flugbahn mit großer Genauigkeit bestimmt werden. Aus der Messung der Laufzeiten der Laserpulse werden die Distanzen zu den reflektierenden Geländepunkten und in weiterer Folge die Koordinaten dieser Bodenpunkte berechnet. Reflektierende Punkte sind jedoch nicht nur Bodenpunkte, sondern – in Abhängigkeit der Struktur der Geländeoberfläche – auch Vegetationspunkte und Punkte auf künstlichen Oberflächen, wie zum Beispiel Gebäudepunkte. Daten von bewaldeten Gebieten können durch diverse Filteransätze auf mehr oder weniger präzise Weise in Bodenpunkte und/oder

Vegetationspunkte klassifiziert werden. Der vorliegende Beitrag beschreibt einen Ansatz zur digitalen Modellierung von bewaldeten Gebieten mit hoher Reliefenergie, die durch eine Vielzahl von Unstetigkeitsstellen in Form von solitären Felstürmen und anderen Felsformationen geprägt sind. Ein spezieller Filter auf Basis einer linearen Prädiktion mit schiefer Fehlerverteilung wird mit objektbasierter Extraktion und Rekonstruktion der Felsstrukturen aus Rohdaten kombiniert. Diese semi-automatische Methode der Felsmodellierung stellt einen ersten Schritt hin zur Operationalisierung der Berechnung von digitalen Geländemodellen heterogener, durch isolierte Felsformationen geprägter Waldgebiete dar. Seit kurzem werden Lasersysteme lanciert, die pro Laserpuls die Laufzeit in bezug auf die jeweils nächstgelegene und entfernteste Reflexion simultan aufzeichnen und damit die gleichzeitige Berechnung von Vegetationspunkten (Kronendach) und Bodenpunkten möglich machen. Damit werden auch der automatischen Extraktion von Felsoberflächen neue Möglichkeiten eröffnet. Die Effizienz der lasergestützten Berechnung von digitalen Geländemodellen heterogenen Terrains wird insbesondere in bezug auf die den Grundlagen angepaßter Technologien entsprechenden projektspezifischen Anforderungen an low-cost-Hard- und Softwarekonfigurationen zu prüfen sein.

1 INTRODUCTION

Airborne laser scanning is a powerful tool for high-resolution mapping of terrain as well as of treetop surfaces. Commercial airborne laser scanner systems are available and applicable for operational use. An airborne laser scanner system consists of the laser scanner including a deflection unit, the GPS-receiver and the Inertial Navigation System (INS). The laser scanner emits high-energy light pulses, which are deflected across-track by means of rotating or oscillating mirrors It is possible to record the first and/or the last return of every single laser pulse. Position and attitude measurements are provided by the GPS-receiver and the INS. After the flight the elements of the outer orientation of each laser pulse are determined and the polar coordinates of the laser points are calculated. In a final step the polar coordinates are transformed to a global coordinate system (Ackermann, 1999, Baltsavias, 1999, Wehr et Lohr, 1999).
Raw data have to be filtered by means of automatic classification algorithms for separating data representing the ground surface and the treetop surface respectively. Due to the high density of laser pulses penetration rates of less than 25% are sufficient for building high-resolution digital terrain models. Mapping of wooded terrain with accuracies far beyond the reach of traditional methods of topographic mapping is made possible (Kraus et Pfeifer, 1998).
The presented paper discusses an approach to digital topographic modelling of wooded landscapes characterized by patterns of solitary rock formations. The method bases on advanced filter algorithms and object-orientated treatment and representation of rock formations.
Laser scanner data of wooded terrains show asymmetrical error distribution. Robust estimation of weights for each measurement is possible by applying an asymmetrical weight function. The shift value, that quantifies the asymmetrical characteristics of the weight function, can be extracted by the analysis of the histogram of the residuals after computation of an average surface based on the assumption of equal weights (Kraus, 1997).
Based on the shift value and the weight function, individual weights can be calculated. Points with significantly negative residuals get maximum weights and thus strongly influence the following iteration of the most likely surface. Satisfactory results may be obtained after 4 to 5 iterations.

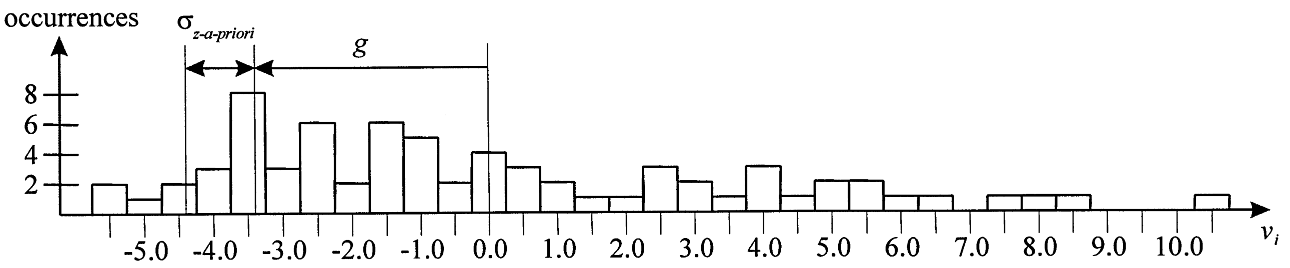

Fig.1. Histogram showing the asymmetrical distribution of residuals and the resulting shift value g after computation of an average surface based on the assumption of equal weights for all points (Kraus, 1997)

Besides the application of these advanced methods of filtering implemented in the SCOP-software for digital terrain modelling (Pfeifer et al., 1999), an object-orientated selection and representation of rock formations has been developed (Csaplovics et Wagenknecht, 1999a).

2 LASER DATA OF WOODED RUGGED TERRAINS

Case studies focussing on the digital representation of selected forest areas of the National Park Saechsische Schweiz, situated about 30km south-east of the city of Dresden (Germany) and extending over an area of about 370km², predominantly covered by dense forest and characterized by sparsely distributed cliffs and rock towers, prove the power of airborne laser scanning for digital topographic modelling of extremely rugged wooded terrains. 56 millions of laser points have been calculated based on last returns of the pulses. The regions of interest are covered with a density of about one point per 9m².

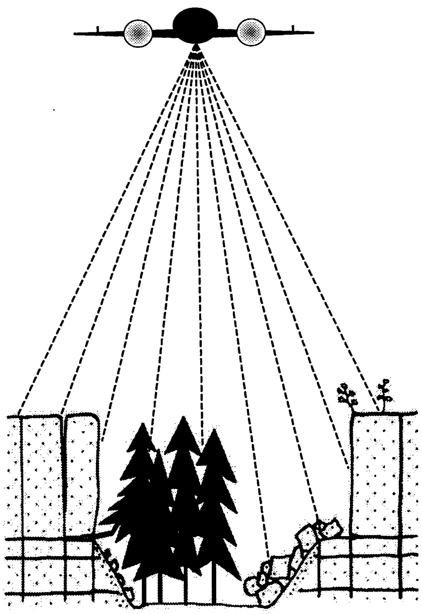

Fig.2. Rock cliffs versus tree stands

The distribution of laser points representing reflection by cliffs, rock towers and small rock plateaus is often similar to the distribution of laser points representing reflection by the tops of dense tree stands. It is thus evident, that small rock towers are not detectable, when applying morphological or even more sophisticated filter methods, that are based on linear prediction, for the interpolation of the surface of the terrain. Cliffs and rock plateaus may be separated to some extent, but still the filter methods will not be capable to classify a great number of terrain points describing the local surfaces of the edges of cliffs and plateaus. The resulting digital models will thus show smoothed, more or less generalized hill-like features, where rugged and steep rock formations extend in the real world.
The object-orientated treatment of solitary rock formations, combined with additional informations provided by topographic maps 1:10000, aerial colour infrared photography and field work, significantly increases the quality of the digital terrain models. A special point of interest is the determination of the feet of cliffs and rock towers. Methods of aerial photointerpretation and surveying provide a geodetic representation of polygons surrounding the specific features. Based on the coordinates of this polygons, the correct clusters of laser data representing the rock surfaces can be extracted.

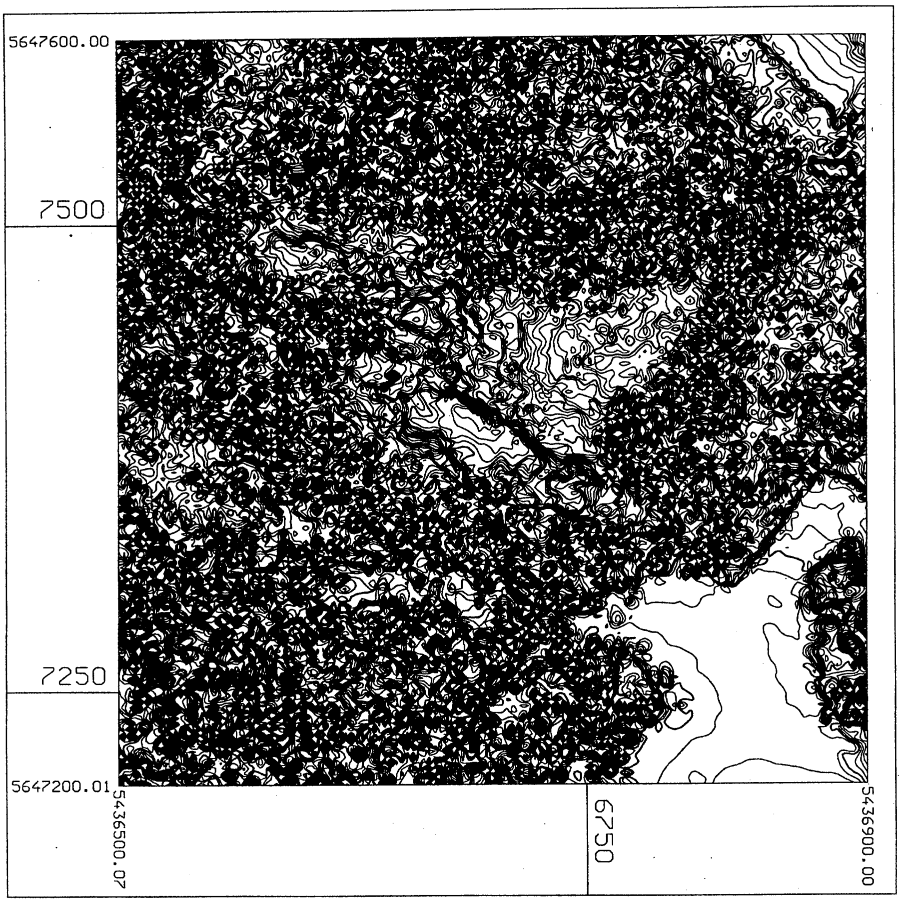

Fig.3. Contour lines of the test site „Gamrig" – calculation based on airborne laser scanner raw data (Wagenknecht, 1999)

Figures 3 and 4 show, that the semi-automatical method of laser data treatment is suitable to build a digital model of the terrain, that is of maximum precision. Interactive editing procedures had to be implemented to treat an area in the NE corner of the test site. Field verification and CIR-photointerpretation proved, that this area is dominated by extremely dense stands of spruce. Last pulse data did not penetrate the tree tops to a significant amount. It was thus not possible to extract the ground surface. In that special case even recent laser sensors, which store first-pulse and last-pulse data simultaneously, would misclassify forest stands of extraordinary density as rock surfaces. The limits of a purely automatic extraction of solitary rock formations in a wooded environment are evident (Csaplovics et Wagenknecht, 1999b).

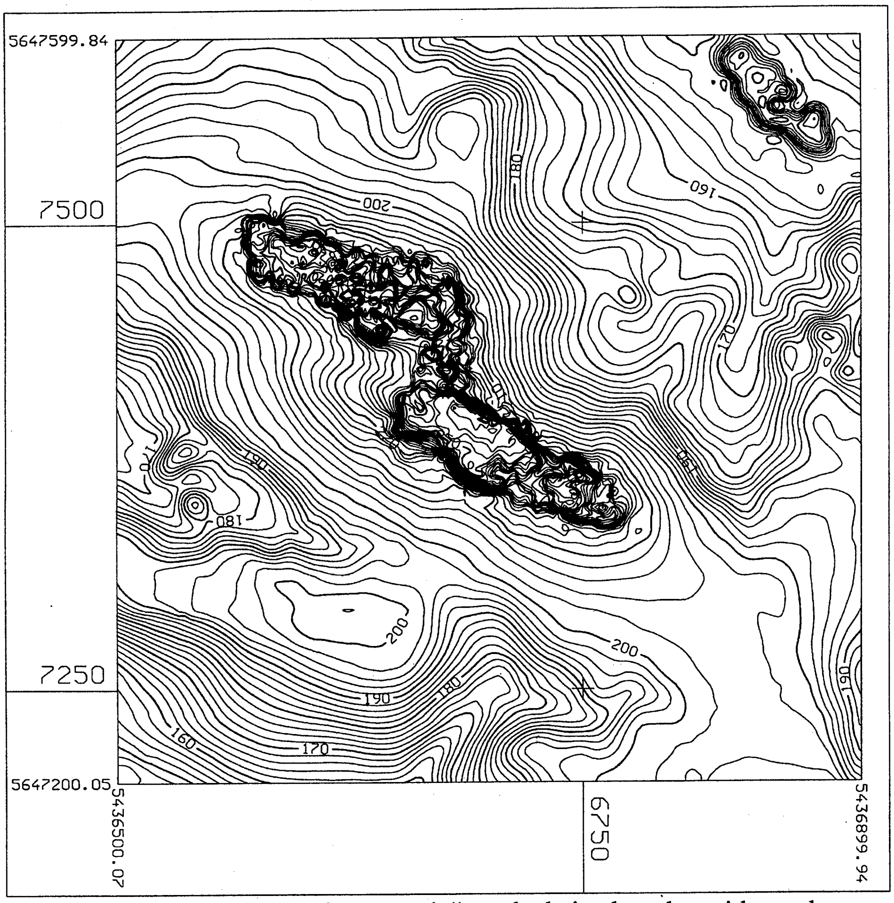

Fig.4. Contour lines of test site „Gamrig" – calculation based on airborne laser scanner data after SCOP-based filtering and object-orientated treatment of the rock surface in the center of the figure (Wagenknecht, 1999)

3 CONCLUSION AND OUTLOOK

The presented method of object-based selection of airborne laser scanner data of wooded mountainous regions describes a first step towards high-resolution digital representation of discontinuous topographic surfaces covered by more or less dense ligneous vegetation strata. There is evidently strong need to increase the density of data collection in order to provide high accuracies of approximations of edges of cliffs and plateaus of rock formations. Investigations on the additional use of first returns of pulses show, that it will be possible to extract both treetop surfaces as well as poorly vegetated rock features to some extent automatically by calculating difference models derived from first pulse and last pulse data respectively. Digital difference models of treetop and ground surfaces generally represent volumina of more or less dense ligneous vegetation layers (Magnussen et Boudewyn, 1999, Magnussen et al., 1999, Næsset, 1997a, Næsset, 1997b). Near-identical first and last pulse values are related to bare surfaces, that means bare soils in general and to buildings and rock surfaces particularly. It is thus possible to extract such solid reflectors in wooded regions to a great extent. Nevertheless it has been learned above, that extremely dense stands of trees show near identical response for both first and last pulses. It is evident, that increasing the frequency of laser pulses as well as applying advanced filter methods are limited measures for separating dense forest stands from rock towers and cliffs respectively. Intensity-based laser systems will provide radiometric informations on the scattering behaviour of the surfaces, which will contribute to an increasing precision of rock surface detection.

We are actually planning an airborne laser scanner mission using a system, that is laid out to pulse with a frequency of 83 kHz, thus providing a density of ground/vegetation points of up to 25 points/m^2 (Baltsavias, 1999).

Advanced methods of the analysis of filtered data will not only extract first pulse and last pulse reflectance, but also take into account the scan-by-scan distribution of reflections along the flight path as an indicator for vertical as well as horizonzal density as well as for heterogeneity of the surface levels. Additionally, intensity recording will be available (λ=1.54μm), so that the knowledge of the reflectance characteristics, that is the spectral signatures of objects in the specific laser bandwidths, will support the development of laser intensity-based classification methods of landcover.

The accurate description of reflecting objects would additionally be supported by developing methods of retrieving not only first pulse and last pulse data, but also the number and distribution of all reflections along the individual paths of

beams. Analysis of these informations would then establish indicators for density and structure of near-vertical to vertical profiles of more or less heterogeneous vegetation layers.
On the other hand, recent investigations also focus on combining multi-seasonal data, that is winter last pulse with summer first pulse data, in order to get a most accurate distribution of ground points and vegetation points respectively (Kraus et Rieger, 1999).
The implementation of formlines, breaklines and edges will increase the precision of the digital terrain models to a further extent. Recent research to develop algorithms for automatically extracting these features has not yet reached a an operational level.
Analysing the spatial distribution and frequency of edges is additionally a measure for calculating structural parameters of the landscape, like patchiness or diversity (Turner et Dale, 1991).

Project-orientated research activities will focus on mapping secondary and primary zones of the German and Czech national parks as well as the surrounding landscape protection zones (692km^2). It is thus necessary to develop methods of laser data interpolation, that combine the state of art of detailed extraction of vegetation surfaces as well as of rugged ground surfaces with appropriate approaches to treat enormous amounts of data by means of medium-to-low cost hard- and software equipments.

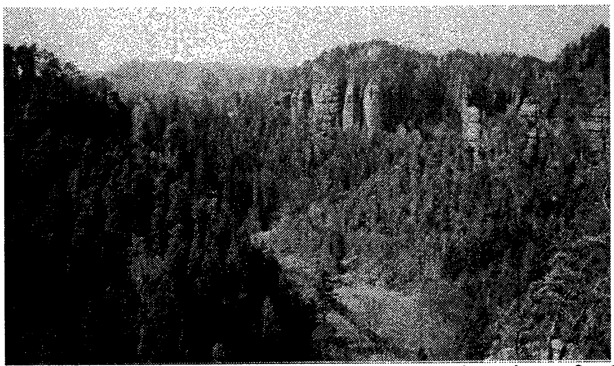
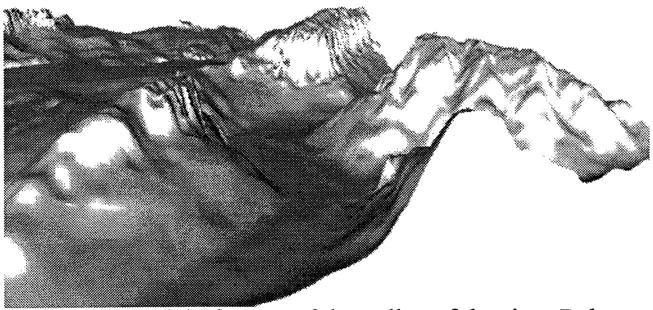

Fig.5 In-situ photograph versus perspective view of a digital terrain model of a part of the valley of the river Polenz (National Park secondary zone) - the DTM was calculated by combining SCOP-based filtering with object-related treatment of rock surfaces (Wagenknecht, 1999)

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