Assessment of parameters for avalanche modelling by means of laser scanning and aerial photos

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ABSTRACT: Avalanches constitute a constant threat to Alpine areas. Simulation models assist in delineating hazard zones and optimising avalanche control systems. Digital terrain models serve as a basis for the simulation of avalanches and are especially suitable for modelling the dense flowing component. The powder component of an avalanche is influenced not only by the terrain but also by the condition and composition of the vegetation in the avalanche path. Remote sensing basically provides an effective tool for determining the input parameters required for avalanche simulation on a large-scale basis. This paper presents methods designed to precisely derive these terrain and vegetation parameters from laser scanner data and digital orthophotos. The methods have been developed under a project financed by the Austrian Federal Ministry for Agriculture, Forestry, Environment and Water Management and are planned for operational use in avalanche simulation and in assessing the protective capability of protection forests in the future.

1 INTRODUCTION

Avalanches are one of the major natural disasters threatening human settlements and infrastructure in Alpine areas. Some 4500 avalanche paths threatening settlement areas have been registered in Austria. In order to be able to take appropriate protective measures against this natural hazard, AVL has developed the SAMOS simulation model, which allows snow avalanches to be simulated taking both dense flowing and powder components into account [Sampl & Zwinger, 1999]. The simulation results are used for delineating hazard zones and for optimising avalanche control structures. Input parameters for avalanche modelling include digital terrain models, from which slope and roughness of the terrain surface can be derived. These terrain parameters mainly influence the dense flowing component of the avalanche [Schmidt et al., 2003]. On the other hand, avalanche simulation is also based on vegetation parameters, which mainly influence the powder component of the avalanche [Schmidt et al., 2003].

The practical use of avalanche simulation has shown, however, that the availability and measurement of the above input parameters constitute a serious problem. This is especially the case when avalanche simulations must cover extensive forest areas and when the terrain is marked by complex surface structures. Until now, the digital terrain models used for deriving terrain parameters had low resolutions of 25m to 10m. These models show enormous height errors, especially in mountainous regions and forest areas, and do not include small-scale terrain structures, such as small ravines or faults that may act as barriers to avalanches. Despite continuous improvements in recording and evaluation systems, photogrammetric methods do not provide the
terrain information necessary for avalanche modelling. Vegetation parameters are recorded either terrestrially or, where available, based on the visual interpretation of infrared images. These methods, however, are extremely cost and labour intensive and thus of limited use for operational application.

This paper shows the results of a project in which an automated method was developed for automated measuring the above-mentioned input parameters in a time and cost-effective manner on the basis of laser scanner data and digital aerial images. The project was funded by the Austrian Federal Ministry for Agriculture, Forestry, Environment and Water Management and was carried out in cooperation with the Institute for Avalanche and Torrent Research, Innsbruck, and Graz University of Technology. The research work is based on the EU project HIGHSCAN and other projects carried out at the Joanneum Research Institute of Digital Image Processing. These projects have already proved that it is possible to derive forestry parameters and precise terrain information from laser scanner data, thus making them an innovative alternative to conventional methods of photogrammetry and terrestrial surveys [Schardt et al., 2002; Wack & Wimmer, 2002].

2 TEST SITE

The Stanzertal Valley (Tyrol) including the village of Schnann was chosen as a test site in consultation with the Institute for Avalanche and Torrent Research, Innsbruck. The test site covers an area of approx. 20 km². The northern part of the test site, covering the entire catchment area of the Schnann brook, was repeatedly hit by avalanches and floods, which destroyed the village of Schnann in whole or in part. The southern part includes the northern slope of the Mittagsspitze Mountain, which was also prone to avalanches in the past. The avalanche prone slopes of the test site are mainly covered with woods, the main tree species being spruce and larch. At higher altitudes the forest gradually gives way to dwarf mountain pines and alpine pastures. From a geological point of view, the south of the test site is made up mainly of gneiss and mica schist while limestone and dolomite dominate in the north.

3 DEFINITION OF INPUT PARAMETERS

Once the test site had been selected, the parameters to be derived from the laser scanner data were specified in cooperation with AVL, Graz, where the avalanche simulation model had been developed.

Terrain and roughness parameters
• Terrain model (grid width 0.5m, height resolution 30-50cm)
• Surface roughness, derived from standard deviations of terrain heights within defined image windows
• Average vegetation height and height differences of dwarf pines

Input forest parameters which can be directly derived from the data
• Tree height, tree species, crown area, stem numbers

Input forest parameters which can be calculated on the basis of growth models using the above parameters:
• Diameter at breast height (dbh)
• Timber volume (wood above 7 cm diameter)

Since the avalanche simulation model is based on a cell size of 100m², the characteristics recorded for each individual tree must be aggregated to the required cell size.
4 LASER SCANNING – FUNDAMENTALS AND DATA ACQUISITION

The laser scanner provides a dense 3D point cloud of the terrain surface, which is georeferenced by GPS and INS (Inertial Navigation System). Laser scanner data are acquired from on board an aircraft or helicopter, flying altitudes typically ranging from 800m to 1600m above ground. Data acquisition is very complex, since measurements are taken at relatively low flying altitudes and very small scan angles (±7 – 10° from nadir), which is necessary to achieve an ideal angle of incidence of the laser pulses and thus reduce shadowing effects.

The runtime of the laser pulse is measured to determine the distance between sensor and terrain surface. This measurement may be based on the last or first return signal of the laser pulse emitted. The first type is generally referred to as ‘last pulse’ data. This last significant return signal has travelled the longest way and was thus mostly reflected from the ground (see figure 1). Due to the large number of laser pulses penetrating the vegetation, last pulse data allow precise terrain models to be derived even for wooded areas. The first return, which is referred to as ‘first pulse’, is mostly reflected from the vegetation surface and hence contains more information on the vegetation cover.

![Figure 1. Principles of first and last pulse laser scanner data](image)

This investigation is based on data obtained using the TOPOSYS laser scanner system. Data acquisition took place in two stages due to weather conditions. The southern part was recorded in the summer of 2001 and the northern part in the summer of 2002. The flying altitude was 800m, resulting in a measuring density of about 4 points per m².

5 DERIVING THE LASER DTM AND SURFACE ROUGHNESS

As already mentioned, the dynamics of the dense flowing component of an avalanche can be simulated very well on the basis of precise high resolution terrain models derived from laser scanner data as described above. The generation of digital terrain models from laser scanner data requires the data to be filtered. Many of the algorithms developed for this purpose work directly with the raw data. Some examples of filter methods are mathematical morphology [Vosselmann, 2000], adaptive TIN models [Axelson, 2000] or weight iteration [Pfeifer & Briese, 2001]. The
method used in this study is based on pre-processed gridded raw data. This approach has the advantage that DTMs can be readily calculated using digital image processing methods. A more detailed description of the algorithm can be found in [Wack & Wimmer, 2002] and [Ziegler et al., 2001]. A 0.5m resolution DTM was generated for the Schnann test site based on these methods and terrain roughness was derived from the standard deviations of terrain heights in a defined image window. Figure 2 shows a comparison of filtered and unfiltered data.

Figure 2. Digital surface model: Schnann (left) and filtered DTM of the same area (right)

6 DERIVING FOREST PARAMETERS

The dynamics of the powder component of an avalanche is strongly influenced by the type, composition and condition of the vegetation cover. The following chapter describes the methods developed for the forest parameters listed in chapter 3.

6.1 Single tree detection and crown segmentation

This step aims at detecting every single tree and segmenting its corresponding crown from the laser scanner data. The method used for single tree detection is based on an approach developed in the EU project HIGHSCAN [Schardt et al., 2002] and the project “Forest Inventory for Eucalyptus Plantations” [Wack et al., 2003]. The forest structure in the test site required these methods to be adapted for the avalanche project. The algorithms developed are described in the following.

6.1.1 Single tree detection and calculation of tree height

In the first detection step, all points of the vegetation height model are sorted into a list according to their height. The height values are calculated by subtracting the first pulse data from the filtered last pulse data. These points represent the quantity of all potential tree tops. A crown model (cone) is calculated starting at the highest point. The dimension of the model is scaled by the height of the point above ground (see figure 3). In scaling it is assumed that higher trees of a forest stand have a larger crown area than lower ones. In the next step all points within the previously defined crown model are eliminated. Once the entire list of points has been processed, only the detected crown tips will remain.
6.1.2 Crown segmentation

Now the individual crowns are segmented on the basis of the heights of the crown tips detected. The correct determination of the crown area calculated from the segments is of vital importance, since this parameter, along with tree height, is essential in assessing the diameter at breast height, which in turn provides the basis for calculating timber volume (wood above 7 cm diameter). In crown segmentation special attention must be paid to the fact that the crown area of trees of the same height may vary depending on the social position of the tree, i.e. the crown can either be very extensive (e.g. dominant trees within the stand or trees at the edge of the forest) or very small (e.g. suppressed trees).

A new, probability based approach to crown segmentation was developed under this project. The algorithm is based on the following assumptions:

- Higher trees have a growth advantage over their immediate lower neighbours. Their crowns receive more light and can spread more freely.
- The size of tree crowns decreases with stand density.
- The crown of a tree cannot exceed a certain maximum size, which is defined by the dimensions of solitary trees.

Based on these assumptions, each point of the vegetation height model is assigned to a selected maximum/tree top with a certain probability. The probabilities automatically derive from the distance to the tree top and the height of the tree top. Correct segmentation in this method mainly depends on the correct detection of all crown tips. The results of segmentation are demonstrated in Figure 4.
6.2 Deriving tree species from aerial photos and laser scanner data

Tree species were determined with the help of a segment based classification approach using ortho-infrared aerial images and the segmented tree crowns derived from the laser scanner data. In a first step, the mean grey value was calculated for each segment in the three spectral ranges of the infrared aerial photo. The subsequent signature analysis showed that the signatures of the predominant tree species in the test site, larch and spruce, could be distinguished very well. The artificial differential channel of channels 1 and 2 (green and red spectral range) provided the best differentiation results. Classification was finally carried out segment by segment based on the threshold value method.

6.3 Deriving timber volume using growth models

Once the height, crown area and species of each detected tree are known, the timber volume (wood above 7 cm diameter) can be calculated on the basis of forest growth models. Tree height, diameter at breast height and tree species serve as input values for the timber volume formula of Kennel [Kennel, 1973]:

\[
a^1 = c_1 + c_2 \cdot \text{alog}(bhd) + c_3 \cdot \text{alog}(bhd)^2 \\
a^2 = c_4 + c_5 \cdot \text{alog}(bhd) + c_6 \cdot \text{alog}(bhd)^2 \\
a^3 = c_7 + c_8 \cdot \text{alog}(bhd) + c_9 \cdot \text{alog}(bhd)^2 \\
hf = \exp(a^1 + a^2 \cdot \text{alog}(H) + a^3 \cdot \text{alog}(H)^2) \\
\text{vorrd} = hf \cdot bhd^2 \cdot \frac{\pi}{40000}
\]

H........tree height  
Bhd....diameter of breast height  
cxy......constants in dependence of tree species  
(9 for each tree species)

Since the diameter at breast height cannot be directly derived from laser scanner data, this parameter must also be calculated in an intermediate step using growth models. The input parameters for this modelling process are height and crown area (segment size), which can be directly derived from laser scanner data, and tree species information classified from the colour infrared...
orthophotos. A new approach was developed in the course of the project, which is based on the correlation found by Hasenauer et al. (1994) between height and dbh / crown diameter of solitary trees for different Austrian tree species.

The approach functions as follows: the diameter at breast height and crown diameter of each single tree detected are calculated based on its height according to the above formula for solitary trees [Hasenauer et al., 1994]. Since the dbh of trees of the same height is usually smaller within the stand, the dbh values calculated for solitary trees must be reduced accordingly. This reduction factor is determined by comparing the crown areas of the solitary trees calculated according to [Hasenauer et al., 1994] with the crown areas derived from crown segmentation. Based on the relationship between the two crown areas, the calculated diameter at breast height of the solitary tree is reduced to the estimated diameter at breast height of the tree. An additional correction factor, which was empirically derived from field measurements (see Chapter 7), was introduced in order to take local growth conditions into account.

The timber volume of all individual trees was then determined on the basis of the diameters at breast height, tree heights and tree species thus obtained using the formula of Kennel (1973) shown above. Figure 5 shows the results of this calculation aggregated to a grid size of 10m².

Figure 5. Southern Schnann test site: timber volume aggregated to 10m (left), stem numbers aggregated to 10m (right) / light-grey areas indicate high stem numbers

7 VERIFICATION OF DERIVED FOREST PARAMETERS

86 trees of a stand (13 larches, 73 spruces) were selected for verification purposes. The following parameters were recorded in detail in the course of field measurements: position of all trees using GPS, tree heights, tree species, dbh (diameter at breast height), crown diameter by plumb-line measurements of 12 points at the crown edges and social position.

The comparison between the parameters derived from laser scanner data and the field measurements produced the following results:
• Of 70 dominant trees, a total of 67 tree crowns were correctly detected using the tree crown detection algorithm (95.7%)
• Of 16 dominated and suppressed trees, only one tree was detected, since these trees are practically invisible in the vegetation height model of the laser scanner data. These errors, however, are negligible, as the stem and timber volumes of these trees account for only a small percentage of total volume figures.
• The algorithm systematically underestimated the crown area, which is due to the fact that not all parts of the crown are ‘visible’ to the laser scanner.
• The accuracy of dbh assessment from crown area and tree height was 87.7 % for all single trees detected. It was shown that dbh was significantly underestimated and, thus, the accuracies lower unless correction factors were taken into account.
Since no reference data were gathered for timber volume for cost reasons, no accuracy assessment can be given for this parameter. It can be stated, however, that the parameters required for calculating timber volume can be derived from laser scanner data to a sufficient accuracy.

8 SUMMARY AND OUTLOOK

This study has shown that the most important input parameters for avalanche simulation can be determined using laser scanner data. New solution concepts, such as crown segmentation and dbh estimates, were developed and the methods for single tree detection from vegetation height models improved. The verification of results showed a high degree of correspondence with the reference data recorded in field measurements. Further investigations are necessary in order to be able to assess to what extent the methods developed can be transferred to other areas. The individual work steps will also have to be integrated into processing chains for effective data evaluation and user-friendly application.

REFERENCES


