# LASER DTM GENERATION FOR SOUTH-TYROL AND 3D-VISUALIZATION

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**ABSTRACT:**

In the past years laser scanner data has established itself as an accurate and reliable data basis for many applications. Highly accurate digital terrain models (DTM) can be derived by filtering laser data that contains information on the terrain and objects covering the surface. Also in wooded areas the DTM's have a high accuracy, since many of the laser pulses penetrate the vegetation and provide information about the terrain. Such DTM's can be used for hydrologic modelling, the planning of larger building projects, the modelling of avalanches or the exact ortho-rectification of optical remote sensing data. The remaining laser data points that describe the objects covering the terrain, mostly buildings and vegetation, can be used for building reconstruction or the derivation of forest parameters. In combination with a DTM this information can be used for noise modelling, city models, forest inventories and 3D visualisations. In terms of such a wide range of applications the autonomous province Bolzano/Italy decided 2003 to capture the entire area of the province, 7500 km², with laser scanner data for the extraction of a DTM. To ensure a high quality of the laser DTM Joanneum Research/Institute of Digital Image Processing, responsible for the definition of the laser data capture parameters and the data processing, had to find cost effective laser data capture parameters as well as efficient methods for the verification of the delivered data, the handling of strip mismatches, GPS height offsets, atmospheric influences and the filtering of the laser data.
This paper is meant to give an overview on the running project 'Laser DTM - province Bolzano', describing the selected parameters for the data capture, which helped to save costs, the data verification and processing. Concerning the misalignment of neighbouring stripes a new approach, BIAS (best incidence angle to surface), was developed, which improves the DTM quality and runs fully automatic. Together with a new filtering approach, hierarchic region growing, a processing chain was implemented which enables the generation of accurate DTM's in a most efficient way. In addition the possibilities of 3D landscape visualization based on laser scanner data will be discussed.

## 1. INTRODUCTION

### 1.1 Motivation

In summer 2003 the government of the autonomous province Bolzano decided, on suggestion of the departments of area planning, forestry and agriculture, to acquire laser scanner data of the entire area of the province for the generation of an accurate DTM. The project site covers an alpine environment of 7500 km² with heights varying between 230m and 3900m. In contrast to other provinces, that have acquired a laser campaign for the generation of a DTM, it was decided to split the laser data verification and processing from the data capture into two separate parts carried out by two different companies. This configuration yielded to an additional control of the scanner data by an independent project partner with specific experience in the field of laser scanning.

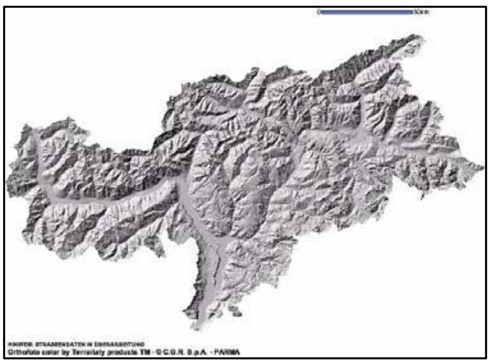


Figure1: Alpine project area 'Laser DTM - province Bolzano

### 1.2 Acquisition parameters

In a first step the individual requirements of the involved departments of the autonomous province Bolzano were analysed which yielded to the definition parameters for the laser scanner data capture. To reduce the costs of the data capture the area of the province was divided into 3 sections, each using a different definition.

- Section 1: mapped area – 4 points per 2.5m x 2.5m (the mapped area is described by detailed maps at a scale of 1:5000 and covers all valleys and areas containing most of the infrastructure, cities and villages in the province. For the extraction of detailed DTM a high point density is required / total area 2600 km²)

- Section 2: unmapped area below 2000m – 8 points per 5m x 5m (all areas below 2000m outside the mapped area up section 1 / total area 2200 km²)

- Section 3: all remaining areas above 2000m – 3 points per 5m x 5m (highly alpine environment / total area 2700 km²)

For section 1 a final DTM with 2.5 m resolution needs to be generated, the DTM of all remaining parts of the province (section 2 and 3) has to have a resolution of 5m. In contrast to other laser capture campaigns the required point density is defined via grid cells, this helps to verify the delivered point density, which is rather difficult if a point to point distance is used as a scanning parameter instead.

## 2. DTM GENERATION

### 2.1 Data preprocessing

To generate a highly accurate DTM from laser scanner data one has to consider the sensor calibration and measuring errors during data capture that will affect the 3D position of the laser points. The sensor position is affected by the DGPS ambiguity solution with its drift. For the determination of the distance, a time of flight measurement, erroneous oscillator calibration and changing atmospheric conditions cause deviations. And the viewing direction to the reflecting object is biased by IMU (Inertial Measuring Unit) drifts, and a sensor system dependent beam deflection calibration, which will cause so called smile affects (Katzenbeisser, 2003). Some of the resulting affects of the total error budget can be seen at figure 2 and figure 4, a fault strip alignment.

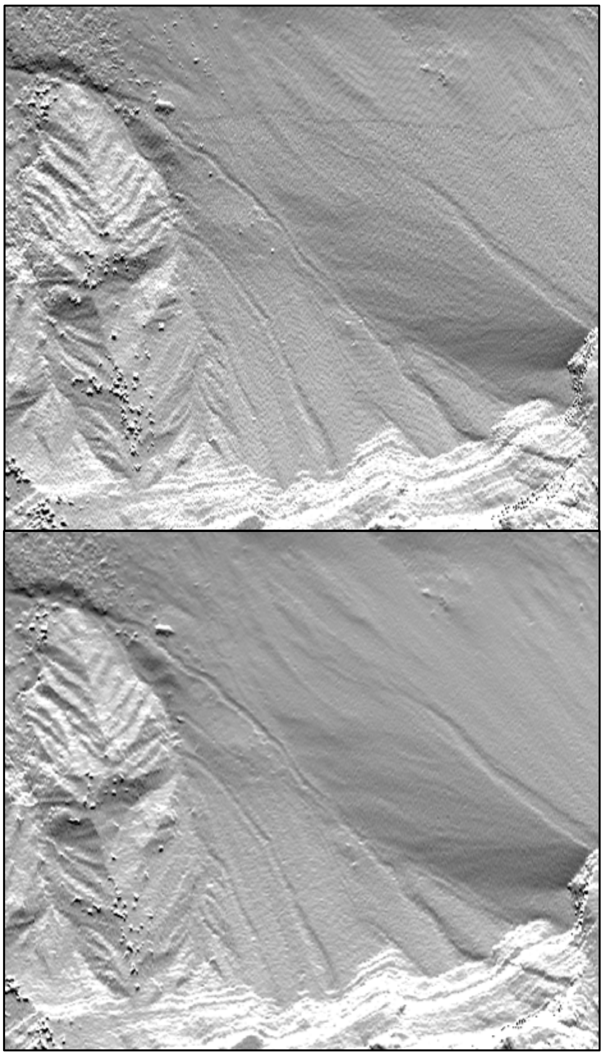


Figure 2: strip misalignment at overlapping stripes in alpine environment with over 60° slope before (upper image) and after application of BIAS – best incidence angle to surface (lower image)

To overcome these problems different time intensive strip and block adjustment techniques have been developed (Burmann H, 2002) which require many ground control and control points.
Considerations on the size of the project area to be captured with laser scanner data (~7500km²) and on the connected afford and costs involved to apply such a strip and block adjustment yielded to a search for alternative methods to improve the laser DTM accuracy.

In the following section a new automatic approach called BIAS (best incidence angle to surface) will be introduced which yields to an improvement of the DTM accuracy.
Referring to the error sources mentioned above the total error budget can be divided in four error sources:

- GPS error
- IMU error
- calibration error
- time of flight measuring error

The GPS error causes a small shift of the sensor position in x,y and z. The time of flight measurement error affects the length of the vector from the sensor to the ground which is rather small. The largest input for the strip misalignment affects come from an erroneous viewing direction to the reflecting object caused by IMU and sensor calibration errors. Therefore the following considerations will focus on the erroneous viewing direction.
When a laser pulse hits a reflecting surface with a viewing direction close to the perpendicular of the surface, the bias of an erroneous viewing direction will not affect the height accuracy of the point (figure 3). If the same spot of the surface is hit at a viewing angle of 10 degrees, the error of the viewing direction will affect the height accuracy. Example: at a horizontal plane a 1m offset caused by an erroneous viewing direction with perpendicular incidence angle to the surface will not affect the height accuracy. An incidence angle of 10 degrees, that has the same viewing direction error, will cause a height deviation of 17 cm (dH).
Assuming an elimination of the systematic errors of the viewing direction via strip adjustment that causes a location error reduction of 50% will still cause height deviations of 8.5 cm.

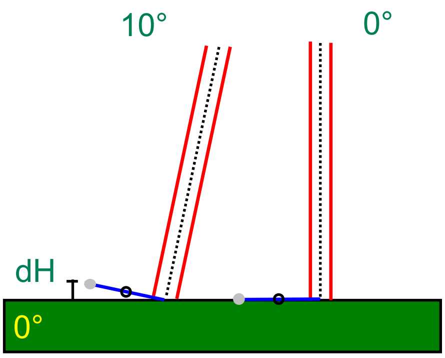



Figure 3: Affects of erroneous viewing directions at 0° and 10° incidence angle on the height of the laser point in relation to the true height. dark point: viewing direction noise /grey point: viewing direction noise and systematic error.

Therefore the application of a weighing function for the laser data points according to their individual incidence angle to the surface is suggested. This operation can be carried out by an automatic algorithm using only laser scanner data. Figure 2 shows the results of BIAS at a part of the Dolomites in South-Tyrol. The steep slopes (over 60°) are covered by several overlapping stripes whose misalignments are clearly visible. Due to the steepness of the terrain the deviations between neighbouring stripes are up to 1.5 meters. In this case BIAS increases the weight of the points captured towards the mountain side since these points viewing direction is by 10° to

20° closer to the perpendicular of the surface then the points captured in the direction towards the valley side.

Besides the error of the viewing direction also the distance error caused by atmospheric conditions and the GPS height offset need to be considered. This is done by a laser data capture of reference sites before and after each flight mission. The calculated offset for each flight mission is then added to the captured laser data. Table 1 shows the results of a verification at different independent check sites, each consisting of about 60 ground points, that have not been used for height offset adaptations accept site “bz”. Figure 4 shows the affects of BIAS at the check site welschnofen. All check and reference sites were accurately surveyed by GPS and tachyometry.

| check sites | before BIAS | | after BIAS | |
|---|---|---|---|---|
| | **mean (cm)** | **stdev (cm)** | **mean (cm)** | **stdev (m)** |
| **sar** | -9,5 | 10,6 | -2,9 | 3,9 |
| **bri** | -4,2 | 20,9 | 3,3 | 6,0 |
| **sterz*** | -6,2 | 12,5 | -6,2 | 12,5 |
| **tra** | -13,2 | 21,1 | 2,0 | 6,3 |
| **wel** | 12,7 | 13,8 | -2,2 | 3,8 |
| **bar*** | -3,0 | 7,6 | -3,0 | 7,6 |
| **stul** | 8,3 | 10,3 | 2,0 | 6,7 |
| **bz**** | 0,8 | 7,0 | 0,8 | 7,0 |
| **overall** | **-2,8** | **20,8** | **-0,8** | **6,7** |

Table 1: DTM verification at check sites with height offset correction before and after BIAS (best incidence angle to surface) application (*no overlapping stripes / ** reference site for the determination of height offsets)

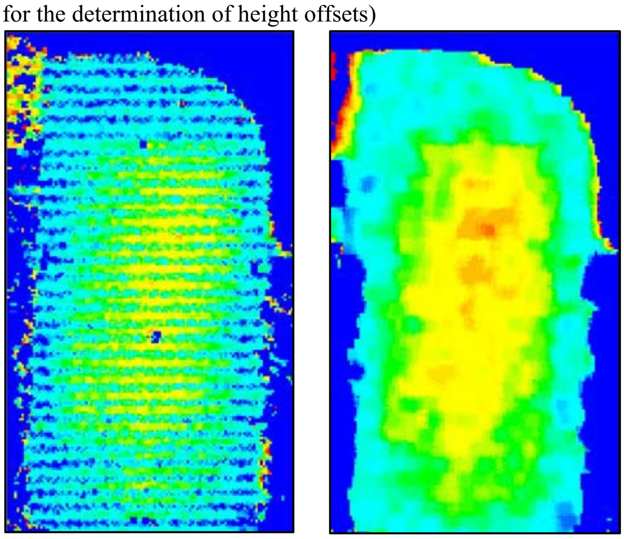


Figure 4: before (left) and after (right) application of BIAS at check site Welschnofen (soccer field). The left image clearly shows the affects a strip misalignment. The right image shows the curvature of the field which was build for drainage purposes.

Furthermore profiles in alpine environment have been measured for verification purposes. The profile of 98 points in figure 5 covers slopes of up to 60° at the Dolomites in South-Tyrol to study the effectiveness of BIAS under alpine conditions. The calculated mean deviation is 5cm with standard deviation of 38 cm.

Finally the laser points are used according to their weight for the generation of a gridded DSM which still needs to be filtered.

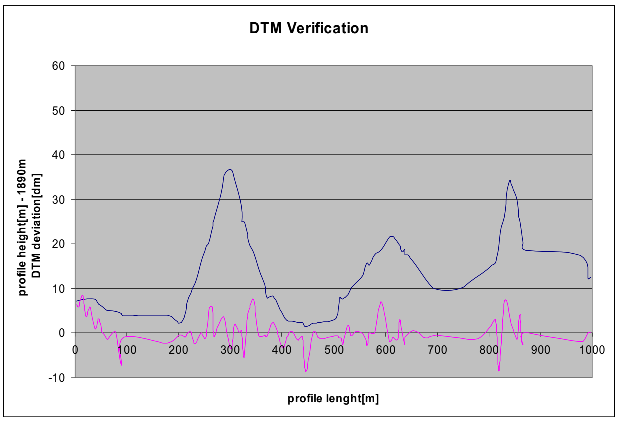



Figure 5: Verification of the DTM along a profile in alpine environment. Pink: deviation in dm/ Blue: height profile

## 2.2 Filtering

For the generation of the DTM a filtering process is required to separate the laser hits of the terrain from hits on other objects like vegetation and buildings. In the past many different approaches like active contours, slope based filter, hierarchic robust interpolation, progressive TIN densification and gridbased hierarchical weighing function have been proposed to provide this separation (Sithole and Vosselmann, 2003). Since the filter algorithm’s have to operate under various conditions like forest, alpine environment and cities, each of the above mentioned approaches requires a parameter adaptation of the algorithm to suit the environmental conditions at the captured area.

Based on the experience with the gridbased hierarchical weighing function approach (Wack and Wimmer, 2002) and its shortcomings concerning the required parameter setup, a modified approach was developed to overcome the difficulties with the parameter definition. The new approach is again hierarchic and gridbased, to allow the usage of fast image processing tools, but uses now region growing for the separation of segments in the DSM. The detected segments are classified according to their characteristics like size, roughness and height in relationship to neighbouring segments. Up to now only a classification of terrain and non terrain segments is realized, a further separation between buildings and vegetation will soon be implemented.

This approach does not require any parameter adaptations and investigations show a wide range of environmental situations that can be covered with satisfactory results. When first applied in the South-Tyrolian Dolomites the extreme alpine environment required a modification of the region growing method to handle the step slopes and rock formations.

For the filtering process of large areas like within the project ‘Laser DTM - province Bolzano’ a tiling of the laser data is required. Each tile has a size of 3km x 3km and takes about 10 minutes for the hierarchical filtering at the resolutions 5m, 2.5m and 1.25m. Within the hierarchical approach the resulting DTM of each resolution serves as a reference for the filtering process at a higher resolution. By this way buildings and trees can be removed before the region growing starts at a high resolution. Without this removal region growing and the classification of the segments would yield to unsatisfying results since small clearings in the forest or courtyards could not be connected via region growing with the open terrain segment. To avoid misclassifications, such small isolated segments, even though lowest in their vicinity are not accepted as terrain in the segment classification phase of the algorithm.

Both processing steps, the data preprocessing using BIAS and the filtering of the data are implemented as an automatic processing chain within IMPACT, a tool box, developed at the Institute of Digital Image Processing/Joanneum Research, that covers radar data processing, image and video analyses as well as laser data processing.

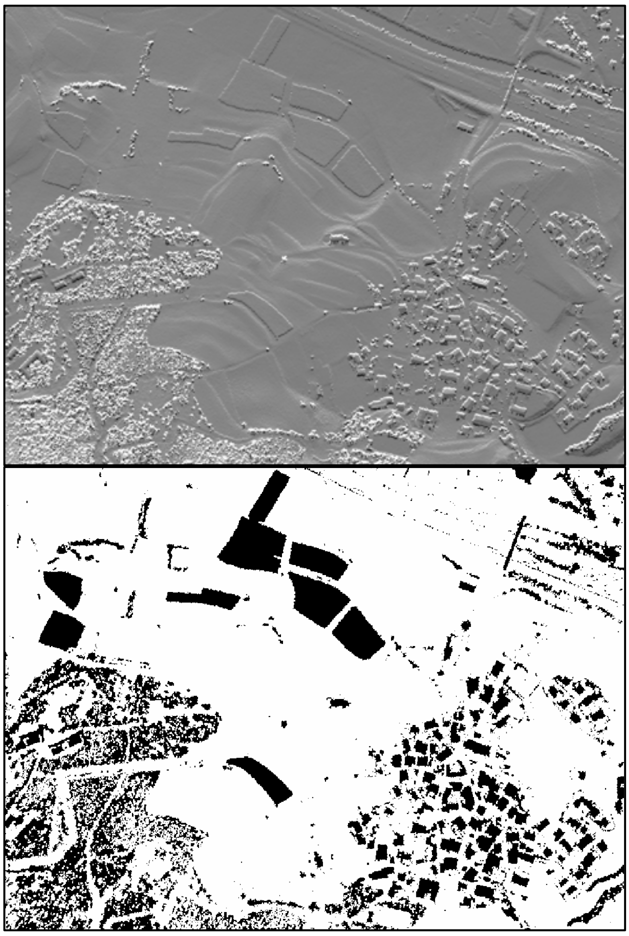


Figure 6: Laser DSM in the vicinity of Sterzing/Bolzano (top) and mask as a result of the filtering process (bottom)

### 2.3 Current project status

The laser data capture started in Summer 2004 focusing on areas located above 1500m. The capture of the defined blocks required an individual permission for capture because most of these upper regions were still covered with snow from last winter. The required information on the snow status at each block was provided by the forest department of the autonomous province Bolzano, which runs forest stations distributed all over the province. In autumn, at leaf less season, the capture of the areas below 1500m started. By now, spring 2005, 1/3 of all upper regions and over 3/4 of the lower regions area covered and were delivered to Joanneum Research. Before acceptance each data set was controlled about point density, data gaps and height accuracy.
Regarding the verification of the point density, the data could easily be checked whether the delivered data sets would comply with the defined minimum requirements, since point density was defined via points per grid cell. For the mapped regions (section 1) as well as for the unmapped regions (section 2/3) the requirements have been fulfilled for at least 95% of the respective areas. The average achieved point density is more than twice as a high as required (table 2).

| | required point density | achieved point density | total area fulfilling min. requirements |
|---|---|---|---|
| section 1 | 4 pt/ (2.5x2.5m) 0.6 pt/m² | 8 pt/ (2.5x2.5m) 1.3 pt/m² | 95% |
| section 2/3* | 8 pt/ (5x5m) 0.3 pt/m² | 20 pt/ (5x5m) 0.8 pt/m² | 99% |

Table 2: Verification of the delivered data sets.(* section 2 and 3 are captured at the same point density)

For several map sheets in alpine as well as urban areas the generation of the DTM was carried out but currently no larger areas are covered without missing data from section 1 or section 2/3. Once a larger area will be finished the automatic processing will be started which is expected in summer 2005.
The ongoing data capture is expected to be completed by the end of this year with a final delivery of the DTM in summer 2006.

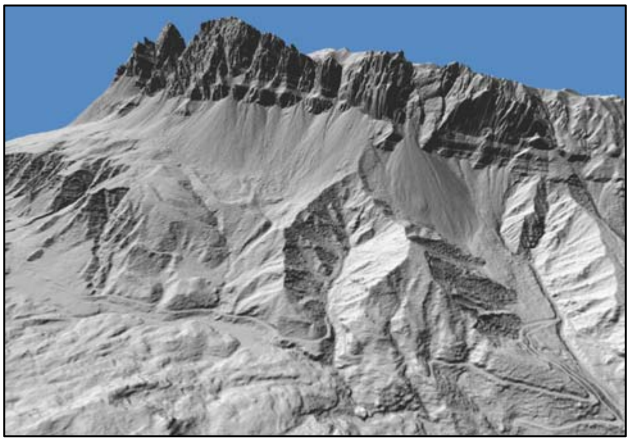


Figure 7: DTM shading of a part of the Brixner Dolomites

## 3. 3D-VISUALIZATION OF HIGH RESOLUTION LASER SCANNER RESULTS

### 3.1 Geo-data for 3D-visualization

For the realistic 3D reconstruction of ecosystems high resolution data is required as a data basis. Therefore Laserscanning is a most suitable technology to provide such 3D information of our environment (terrain, vertical vegetation structure or houses). In addition optical data is required either to provide texture for the 3D objects or, like in this case, to supply the modelling process with information from an aerial image classification that extracted 10 different classes.

### 3.2 Developement of virtual ecosystems

Beside the above mentioned geo-data from laser scanner and classification results virtual ecosystems and so called foliage effects had to be created. For these purposes an object library was developed, containing all necessary forms of vegetation like trees, scrubs, meadows, but also textures for streets, lakes or gravel. The object library made possible the combination of particular objects to virtual ecosystems and foliage effects. The construction of this database as well as the 3D visualization based on this database was carried out using the animation software “Visual Nature Studio 2“ (VNS) of the American company “3D Nature“. The building of the object library was carried out using both real 3D objects and plain 2D images (mainly vegetation photographs). Vegetations can be simulated very appropriately with 2D objects and save above all

rendertime. The 2D images are always rotated in an upright position towards the optical axis of the camera and by means of shading a pseudo 3D visualization is accomplished. Objects such as bridges or dams have to be applied as real 3D objects to guarantee a realistic visualization (3D Nature, 2003).
For the test area of South-Tyrol, textures for the specific local vegetation had to be built up almost completely, because the textures available in VNS were not appropriate for the visualization of the Tyrolean alpine areas. Respective photos of the local vegetation were integrated into the object library. A sufficient resolution of these photos and an exact release (clear separation from the background) had to be paid attention to. Thus, objects for virtual ecosystems such as coniferous forest or different shrub forms were created. In order to design the ecosystems in a realistic way also textures for understorey and ground were included. To be able to model an uneven ground structure more appropriately, also “Bump Mapping“ was applied (Stelzl et al., 2004).

### 3.3 3D-visualization on the basis of an aerial image classification and a laserscanner DTM

Aerial image classification results are can be defined by a grey value image which represents the defined classes. In order to create a virtual landscape the above mentioned ecosystems were connected to the classification map, using the assigned grey value of each class. By definition of heights and densities of the different objects realistic ecosystem were created. Based on these parameters the different objects were placed randomly in the areas defined by the classification map. Figure 8 shows a comparison between a classification map draped over a DTM and the virtual landscape.

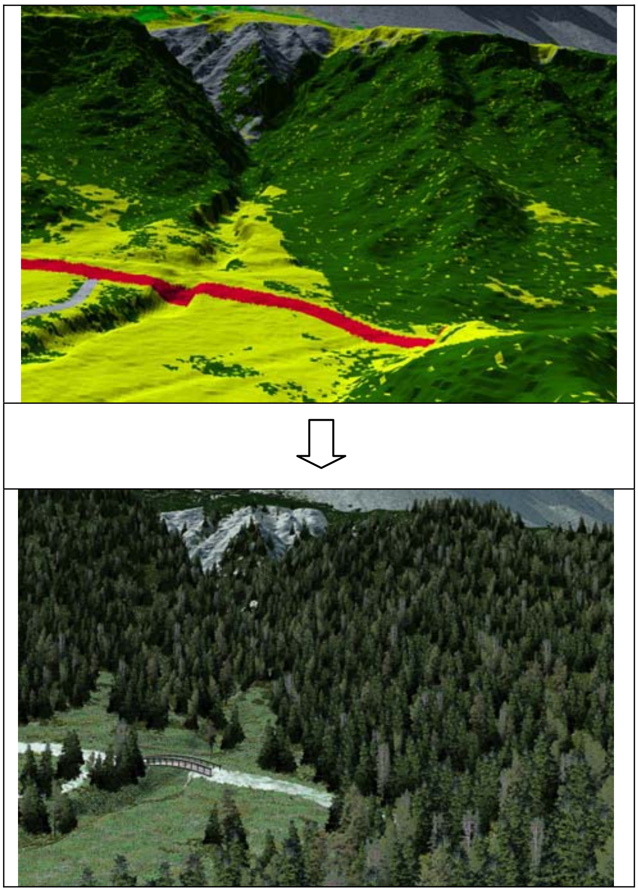


Figure 8. Classification map and virtual landscape

Changes in the landscape, which result in an updates classification can be visualized automatically by importing a new or changed raster classification.

### 3.4 3D-visualization of single tree detections from laser scanning

An even more realistic visualization can be achieved using the results a single tree detection based on laserscanner data(Wack R, 2004). The resulting vector information about the tree’s position, height and species(from a classified CIR aerial image) can be combined with the laser DTM and additional information such as line vector information about roads which was available in the test region. Similar to the virtual ecosystems described in the chapter before so called foliage effect were created to connect every vector information with objects from the object library. Foliage effects contain definitions about the used objects as well as queries which define the connection between the vector data to the specific effect. Realistic foliage effects can be produced by combining different objects and definition of parameters for density and height distribution. Some parameters (e.g. height) are taken dynamically from the attributes of the vector data (attribute in the shape-files). The selections, which vector data has to be connected to a foliage effect is done by so called search queries which define the subset of the vector data depending on the attribute values. E.g. all conifer trees higher than 10 meter are assigned a specific foliage effect. Figure 9 at the next page show the development of an virtual landscape based on laser scanner data.

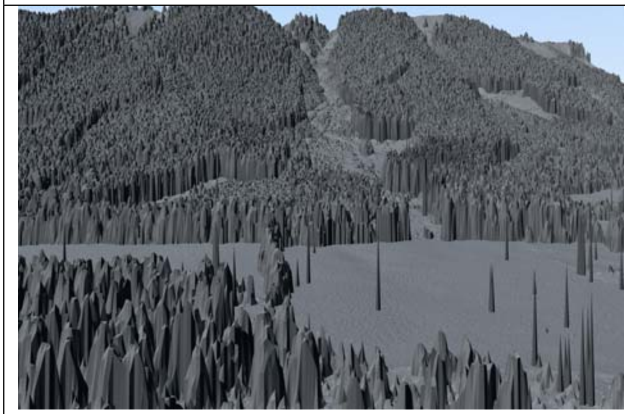
With this method a fully automatic 3D-visualization of the vegetation situation can be achieved. Every changes or planning tasks done in GIS can be visualized immediately by re-importing the changed shape-file.

## 4. CONCLUSIONS AND OUTLOOK

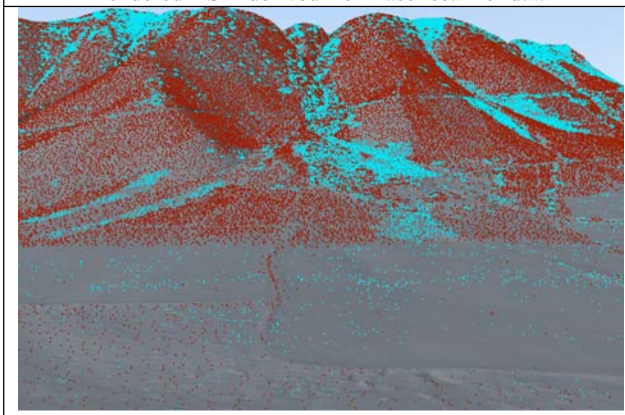
For the generation of a laser scanner DTM, covering the entire autonomous province Bolzano with 7500 km², suitable parameters for the data acquisition could be found to meet the requirements of the user and to keep costs low. Furthermore a new technique was developed for the strip misalignment problems. By using the best laser incidence angle to the surface it was possible to implement a full automatic algorithm that applies a weighing function at each laser hit. Verifications of the DTM in flat as well as step terrain show, that significant improvements can be achieved due to BIAS. In addition the hierarchic region growing filtering approach, that operates without parameter setup was modified in regard of the alpine environment. Using both of these automatic processing techniques several areas, urban as well as alpine sites, could be filtered with good results. The final delivery of the DTM covering 7500 km² is expected to be in Summer 2006, 2 years after project start.

The described methods concerning the 3D visualization offer an interface between processing of airborne laser scanner data and 3D visualization.
The automation of the visualization plays a crucial role making possible the presentation of changes and planning tasks. By this means, an innovative tool for landscape planning and decision making is made available.

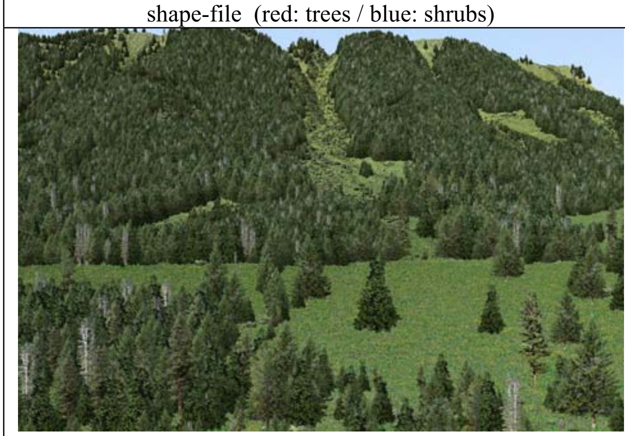
Rendered DTM derived from laser scanner data



Rendered DSM derived from laser scanner data



Rendered DTM with vegetation point positions from shape-file (red: trees / blue: shrubs)



Virtual landscape based on DTM and point shape-file

Figure 9. Development of the virtual landscape based on the DTM, DSM and derived point vector data


## 5. ACKNOWLEDGEMENT

The development of BIAS and the hierarchic region growing modification was carried out within the project 'Laser DTM - Province Bolzano' of the autonomous province Bolzano, Department of land planning, using laser data from Compagnia Generale Ripresearee (Italy) and Toposys (Germany).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