'Photogrammetric Week '99' D. Fritsch & R. Spiller, Eds., Wichmann Verlag, Heidelberg, 1999.

Data post-processing of Laser Scan Data for countrywide DTM production

MARTIN KNABENSCHUH and BETTINA PETZOLD, Bonn

ABSTRACT

The last years laserscanning has become a reliable and economic technology to build up high-class DTM. After doing tests to check the quality of laserscanning results and production method for their own purposes several German Surveying and Mapping Agencies have installed the new technology as new standard method for their official DTM production. Mandate, product line, production strategies and methods of the Surveying and Mapping Agency of Northrhine-Westfalia are described with special view to tests and use of the new technology. The solution for post-processing of the laser data to check their completeness and quality of height level and terrain classification is then described in detail. Finally a short outlook is given to the next activities to improve economy of the post-processing process and the quality of its results.

1. INTRODUCTION

Since more than 20 years the Surveying and Mapping Agency of Northrhine-Westfalia deals with the field of DTM-production to get an representation of the natural terrain of the earth surface. During all of these years and activities the agency has learned that the building up of such a DTM is a very time-consuming and large-scale process. Doing such activities it has been and is necessary to solve the conflict between a short-time data availability and high-class production. The installation of the laserscanning technology as new standard method of official DTM-production has solved that conflict. The new method provides a fast and high qualified measurement for large regions as Northrhine-Westfalia (34 000 km²) and by that fact an increased throughput producing the official high-precise DTM „DGM 5" of the Surveying and Mapping Agency of Northrhine-Westfalia. But in spite of the fully automatic filtering of natural terrain points - doing the laserscanning DTM production - terrain data have to be checked and prepared interactively to get a *really* high-class terrain description, because filtering runs not faultless and data measurement is not given with the required density in any case. That interactively part bases inevitably on fully other principles as before, because method of measurement and data preparation are very different from conventional methods (as for example photogrammetry). Therefore new strategies and techniques were needed and had to be developed for post-processing of measured and already classified laserscanning data. A tested solution is implemented and ready for operational use at the Surveying and Mapping of Northrhine-Westfalia Agency; it is already taken for operational preparation of laser data captured for official DTM production the last years.

2. THE FIRST TESTS BEFORE STARTING THE PRODUCTION

To proof if the new technology really has the promised advantages over photogrammetric methods the first test flight was done in 1994. The test area concluded 16 km² including deciduous and coniferous forest and flat and hilly terrain inside and outside of the forests. Since the test area was situated within a terminal moraine region the terrain even includes high and steep dunes. The terrain height was between 20 m and 70 m.

The main flight parameters were a laser frequency of 2 000 Hz, a scanning frequency of 10 Hz, a scanning angle of ± 12 ° and a mean flight height of about 850 m above sea level. The resulting mean point distance on the ground was 3 m to 4 m, corresponding to about 350 000 laser points for one sheet of the German Base Map 1 : 5 000 (DGK 5) with an area of 4 km².

'Photogrammetric Week '99' D. Fritsch & R. Spiller, Eds., Wichmann Verlag, Heidelberg, 1999.

2.1. First Revision

The first task in the test was to verify if the result of the filtering process could be seen as plausible. Therefore the ground points served as basis for the calculation of the DTM, and the contour lines were derived. They were overlaid to the DGK 5 and the orthophoto map 1 : 5 000. At first glance there were no gross errors to be found. Quit the reverse, the contour lines and especially the shaded terrain, also derived from the DTM, seemed to be a very plausible representation of the terrain.

2.2. Terrestrial Measurements

Since gross errors were not found and a reference did not exist, some more tests were run, mostly terrestrial campaigns. The main tasks were to determine the height precision of the terrain points, the reliability of the filtering technique, especially in undergrowth, and to find out how good the terrain is represented by the ground points.
The first test was to compare the derived contour lines with those of a topographic measurement. These examinations were limited to some interesting parts of the test field, for example inside of a small village and the dunes inside the coniferous forest. Whereas some bigger differences are to be seen in planimetry, of course especially in flat areas, the height differences are within 3 dm. Exceptions occurred only in some special cases.
To know more about the absolute height precision and the reliability of the filtering process, some profiles were measured in open fields and in forests, crossing the mentioned dunes and undergrowth. The results were surprisingly good. The height differences to the ground points in open terrain were in general only some centimeters. The differences to the DTM derived from the ground points were bigger especially near banks. But this was a result of the software smoothing the terrain forms and emphasized the importance of structure lines.
Also the results inside the forests were positive. The profiles pointed out the good representation of the terrain by the ground points and therefore the reliability of the filtering process.
The only exception occurred regarding small terrain forms. Since the laser scanning is not a selective restitution method the representation of small terrain forms directly depends on the mean point distance. Consequently for example small ditches are not represented.
Finally a leveling was done on a path, laying most parts in the forest. No difference to the neighboring ground point bigger than 2 dm appeared.
The investigation, very shortened here, convinced of the reliability of this new technology. In addition, the cost-benefit analysis, comparing laser scanning with the former used photogrammetric methods, was positive. Finally it was decided to use laser scanning as a standard method for the derivation of the DTM.

3. THE STANDARD PRODUCTION LINE

3.1. Demand, Mandate and Products

As generally known all spatial planning and decision making needs a description of topography of the region of interest on the earth surface and also a connection to it. The description is given by planimetry and height information represented in line map series and object structured, raster and image data. In correspondence to that demand the Official Surveying and Mapping Administration of Germany has to capture, document and deliver structure, situation and terrain of the earth surface with respect to the user´s demand and the progress in science and technology.
Contour line images as part of the official topographic line map series have been the official terrain model of the first generation. Very soon - as result of the breath-taking process of electronic data processing - the demand changed to digital terrain data with detailed high-class and homogeneous

'Photogrammetric Week '99' D. Fritsch & R. Spiller, Eds., Wichmann Verlag, Heidelberg, 1999.

height information for the entired region of interest respectively state and at the best at once available.
To meet the up-to-date demand on DTM for the *entired state* (in 1978) the very rough, but complete *DGM 25* was derived as first official DTM with simple interpolation methods from already available height profile data of official orthophoto production. The DGM 25 is characterized by a regular height grid with 50 m spacing, a grid point accuracy of - at the best - 5 m and without any respect to break lines and characteristic terrain points. That DTM is only usable for global spatial applications. In figure 1 (left) a perspective 3D grid line view is derived from DGM 25 for the region of Bielefeld with the Sparrenburg (a castle) in the front.
After finishing the production work of DGM 25, (in 1984) the second, but high-precised DTM, the *DGM 5*, was defined to meet the demand on *high-class* DTM data. It is characterized by a regular height grid, too, but with 10 m spacing and a grid point accuracy of 3 to 5 dm. Break lines and characteristic terrain points are measured as part of the DTM as good as possible. Up to now it is available for 85 % of the state of Northrhine-Westfalia. In figure 1 (right) a shaded perspective 3D view is derived from a regular 1 m grid, calculated from laser data of DGM 5 for the same region as in figure 1 (left).
Since a very short time the demand on more accurate DTM as DGM 5 exists and increases steadily especially for disaster management, but also for other municipal, other local and also global applications. Such DTM are built up in co-operation with the users or by delivered official laser data of the DGM 5 production with a mean point distance of 3 to 5 m.

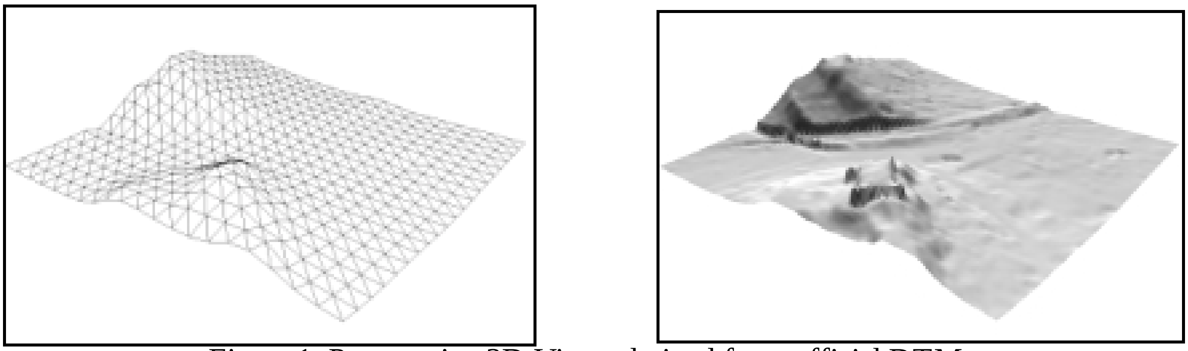


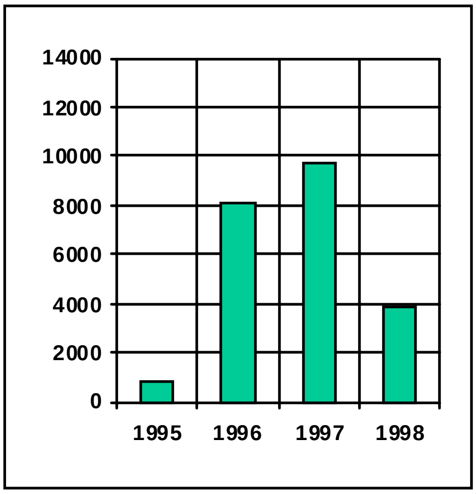
Figure 1: Perspective 3D Views derived from official DTMs.
Grid View from DGM 25 (left) and Shaded View from Laser-DGM 5 (right).

3.2. Production Methods, Problems and Strategies

In view of data production and supply with *real* respect to the demand a problem arose because of the conflict between the demand on high-class data and at the same time on data availability in a very short time. To get high-class terrain data the production was firstly done by photograph flights with an image scale of 1 : 8 000 and following photogrammetric grid height measurement including break lines and characteristic terrain points. To increase the throughput with respect to the above mentioned demand the DGM 5 was then – the start has been some years later - also built up by digitization of already available contour line sheets of the DGK 5 in a parallel manner.
The result of that strategy was a not really homogeneous DTM: Quality differences within the regions of photogrammetric measurement result from gap zones in the case of low texture and forest and settlement of high density. Quality differences between both methods result from the missing of break lines and characteristic terrain points in the case of digitization and the different quality of measurement. Moreover the reached throughput doing the parallel production wasn´t satisfactory. The continuation of that production strategy would lead to the finish of the DTM building up not earlier than 2010.

'Photogrammetric Week '99' D. Fritsch & R. Spiller, Eds., Wichmann Verlag, Heidelberg, 1999.

The new-coming laserscanning technology enabled the Surveying and Mapping Agency to solve that conflict: The new method provides at least the same measure point accuracy of all other techniques, the measure point density can easily be increased as required, the method can unlimited be used with view to the gap zone problem and automatic derivation of break lines will be possible because of the high measure point density. Thus, the natural terrain model built up by laserscanning is the most realistic and most complete one that ever can be reached with nowadays available methods and techniques of data measurement and preparation.
Moreover the costs can be decreased to 1/3 of photogrammetric measurement and the throughput can essentially be increased because of the better independence on weather conditions doing laser flights, the automatic filtering process and specific - and therefore most economic - field check methods.
As result the status of the official DTM, the DGM 5, has changed: It became the new terrain basic data set of Surveying and Mapping Administration, because laserscanning enables a homogeneous (because of the use of only one method) and up-to-date (because of a really new measurement) building up for the entired state with view to the financial and technical aspect.
The new production strategy with laserscanning technology as new standard method of official DTM production consists of an increased throughput especially by use of laserscanning - and digitization of contour lines only as exception - and completion of DGM 5 production in 2002. The up speeded production has already been reached by a huge amount of measured square kilometers (10 000 km²) in an one time activity in 1996/97 and by a now fixed annual program of at least 1 500 km² since 1998 (in 1998 even 4 000 km²) as shown in figure 2 (left). Following the building up the DGM 5 is planned to be renewed only by laserscanning for all regions of photogrammetric measurement and digitization of the building up period to get a really homogenous and up-to-date data set.



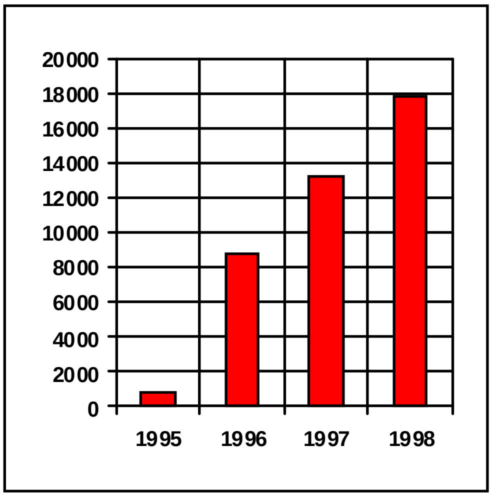


Figure 2: Production and Delivery Data (in km²) of „DGM 5“.
Through put for building up (left) and Data Delivery (right).

The first years of operational DTM production by use of laserscanning have confirmed, that the economy and speediness of production can relevantly be increased. Nevertheless and independent of the high grade of automatism of the production process an interactive part of data preparation must be done in any case - to get the required reliability of the terrain description - following the data filtering to get the laser points describing the natural terrain (ground points).

'Photogrammetric Week '99' D. Fritsch & R. Spiller, Eds., Wichmann Verlag, Heidelberg, 1999.

4. TREATMENT OF LASER DATA

The delivered filtered laser data are checked as follows: The checks concern on one hand some general tests before accepting the data delivery. On the other hand the filtering necessitates some editing as it is an automated process without any differentiation of artificial and natural terrain forms.

4.1. Controll of Completeness

First a plot of the ground points, most in a scale of 1 : 5 000, is overlaid to the DGK 5. With the help of this plot the complete coverage of the working area and the overlapping of the strips can be easily checked. In addition, the successful filtering is visualized, especially when the plot is overlaid to the orthophoto map. The reduced number of ground points in forest areas is obvious.
In figure 3 the ground points are plotted together with the DGK 5. The overlapping of the strips can be seen in the north and the south as well as the filtering that seems to be correct: There are no ground points on the houses, and also vegetation points are filtered out, visible especially along the roads and the river and in a small forest (south-west). The figure is given in the scale of 1 : 2 500.

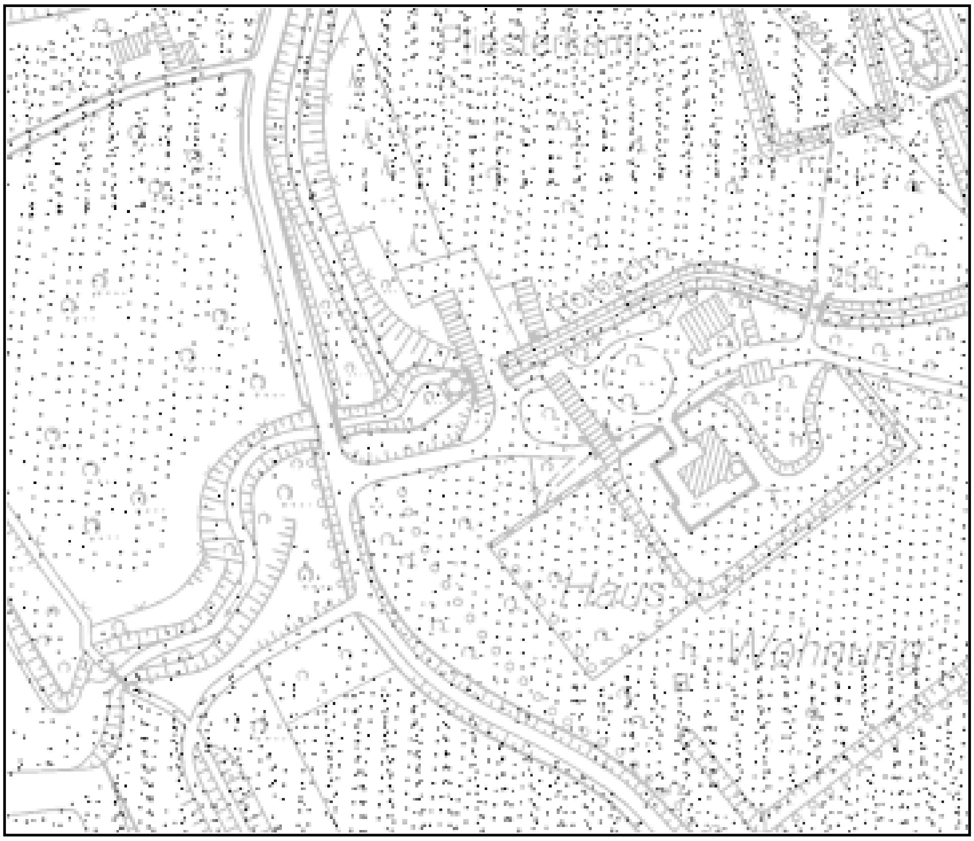


Figure 3: Ground Points plotted on the German Base Map 1 : 5 000.

Normally no errors can be detected so a first DTM is derived from the ground points. The grid width of that DTM is of 10 m spacing for a mean point distance of 5 m and can be reduced to 1 m spacing for smaller point distances.
In addition possible errors can easily be detected in products derived from this DTM. The shaded terrain and the contour lines are perfect means for checking the correct filtering, especially in forests and for large buildings. Misclassifications are shown up as artifacts, but they are really rare. In addition these derived products are supporting the following controls. The equidistance of the

'Photogrammetric Week '99' D. Fritsch & R. Spiller, Eds., Wichmann Verlag, Heidelberg, 1999.

contour lines is normally 1 m but depends on the slope of the terrain and is automatically adapted by the software.

4.2. Controll of the Height Level

To discover possible height differences between the laser points and terrestrial measured points, check areas are used. These are flat or even inclined areas and without any or at least with low vegetation only, e.g. sport fields. On these areas a dense grid of points, for example with about 10 m spacing, is measured with a height accuracy better than 1 dm. To determine the check areas different techniques are used. While in the beginning tacheometric methods were used, meanwhile terrestrial DGPS methods are predominant. One of these check areas is given to the data providing company which is using it for internal controls. For the points measured in the other check areas the height differences to the DTM are calculated. The values and distribution of the residuals concerning height are used to assess the reliability of the laser points. The check areas are distributed regularly in the surveyed area, consequently it would be possible to detect even an inclination between the derived DTM and the terrain.
The laser data are accepted if the difference between those points and the ground points are less than 3 dm for 95 % of the ground points. Normally no significant height errors of the laser data are detected.

4.3. Plausibility Checks and Edition

Most part during the editing session is the correction of data along banks and dams, along roads, in industrial areas and in and around water surfaces. This kind of editing is caused mainly by the fact that the filtering is an automatic process and in minor parts caused by the algorithms of the DTM program. The data delivering company is ordered to filter out preferably too many points than too few. A less stronger filtering would lead to some more correct classified points for example along dams but to too many wrongly classified points on houses (for details of the filtering algorithm see Lindenberger 1993). So during editing especially the already mentioned banks and dams must be checked, using some functions to change only the classification of points. In most cases filtered points have to be changed to ground points. Another point is the editing of bridges which are normally filtered out but should be part of the DTM for using it especially for the own orthophoto production.
Another important task during editing is the filling up of too big gaps in the ground points. This is done to stabilize the DTM, calculated by the SCOP software. Since there are only some reflections to be found on stagnant water surfaces as ponds and lakes, especially in sheltered places, these gaps are filled up. The height is known by the some points always to be found at the shore. Other places where the filtering is to be reviewed are for example the entrances of underground lines into a tunnel, the entrances to underground parking places, industrial area with e.g. sewage plants, silos etc. A long list of editing rules was built up for all these special cases where no natural terrain exists and the definition of the DTM is complicate.
The editing is done by superimposing the contour lines to the digital orthophoto map and the rasterized DGK 5. Doing this, most of the critical cases can be solved, even though both, the aerial image for the orthophoto and the map, show up information gathered at another time than the laser scanning data. Only in some special cases it can not be clarified whether the ground points are representing the terrain correctly. In these rare cases a field check is necessary.

'Photogrammetric Week '99' D. Fritsch & R. Spiller, Eds., Wichmann Verlag, Heidelberg, 1999.

In figure 4 most of the mentioned cases of editing can be found. The left figure points out the situation after the automatic filtering, in the right figure the result of the edition process. The contour lines are represented as polygons only for editing. Ground points are given in black, filtered points in light grey. The annotation is omitted for this output.

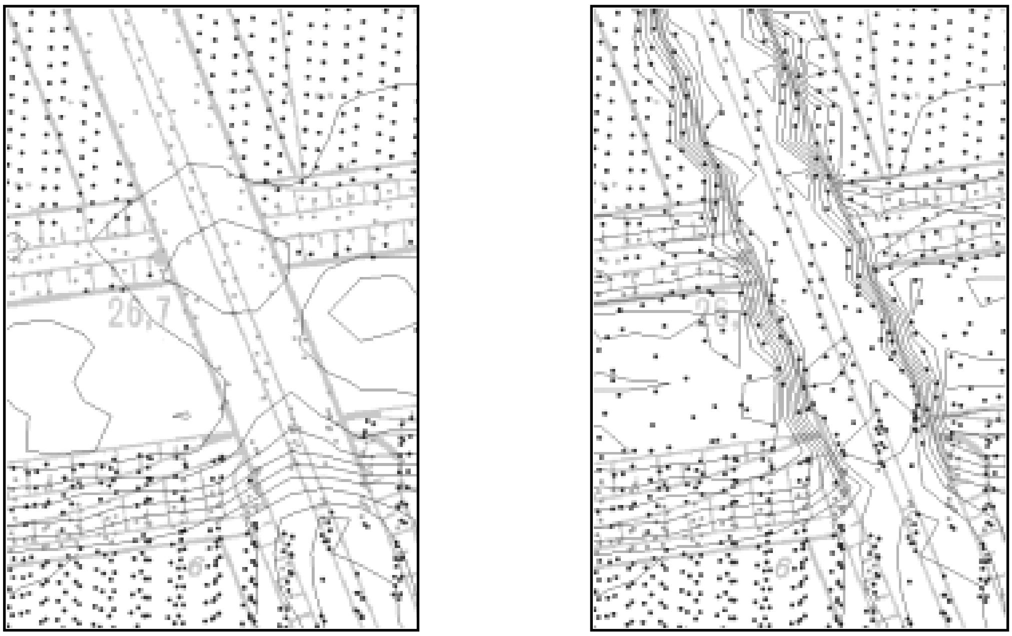


Figure 4: Channel and Dam with Bridge.
Situation before (left) and after Editing (right); DGK 5 in light grey.

As mentioned above the DGK 5 and the orthophoto do not represent the situation at the same time. That is why this editing should preferably be called a plausibility check. But we are quiet sure that the terrain is represented correctly for 99 % of the edited situations.

5. CONCLUSION

As seen in the first years of operational laserscanning measurement the establishment of that technology as new standard method for official DTM production enables the Surveying and Mapping Administration to fulfil the legal mandate of capturing, documentation and providing terrain data of the earth surface with respect to the user´s demand. Because of the changed principle of data capturing also *new techniques* of data preparation to get high-class products had been required. The development of such techniques was rendered more difficult because of the limits of laserscanning: Data can only be checked *indirectly* - e.g. by comparison with planimetric information - and *subsequent derivation* of further height information from the already available data set is impossible.
The Surveying and Mapping Agency of Northrhine-Westfalia has developed its own solution for laser data post-processing. A digital method is available since some years, already tested and used in the operational DTM production process. The results are satisfactory and mentioned problems to meet user´s demand were solved by that change. But nevertheless further research is required to improve the economy of production and quality of products.
Investigations to improve production economy and quality will be done in near future in the field of "*use of aerial videos or photographs captured with the laserscanning flight*" and "*reduction of the expense of interactive data preparation (e.g. by use of 3D known reference layer)*". To improve product quality, investigations are already done to get a *specific field check method (for data check*

and improvement)” and to test the reliability and quality of an already available module of “*automatic break line extraction by use of laser data*”. Such extracted break line information could be used to improve the quality of modeling of the natural terrain by the DTM grid points and by addition of the break lines to the DTM database as separate data set.

In spite of the *suitability* of laserscanning for official DTM production in general the financial expenditure for building up of such a high-class DTM for the entired state is enormous. On the other side a rapid and steady increase of DTM data demand and delivery seams to reflect the up-to-date trend in using terrain data for any kind of spatial planning and decision making as pointed out in figure 2 (right). The demand on digital surface models (DSM) of buildings and vegetation (up to real 3D object models) increases, too. Therefore each investment in developing of methods for economic building up of digital height models (DHM as generic term for DSM and DTM) and engagement in producing them is really very wise and sensible.

6. REFERENCES

Hoss, H. (1997): Einsatz des Laserscanner-Verfahrens beim Aufbau des Digitalen Geländehöhenmodells (DGM) in Baden-Württemberg. Mitteilungen des Deutschen Vereins für Vermessungswesen, Landesverein Baden-Württemberg, 44 (1), pp. 05-26.

Knabenschuh. M. (1998): Der Höhennachweis zur DDGK. NÖV - Nachrichten aus dem öffentlichen Vermessungsdienst Nordrhein-Westfalen, 31 - 2/98, pp. 140-149.

Knabenschuh, M. (1999): Einsatz der Laserscanning-Technologie für den Aufbau digitaler Geländemodelle. GIS - Geo-Informations-Systeme, 2/99, pp. 40-42.

Lindenberger, J. (1993): Laser-Profilmessungen zur topographischen Geländeaufnahme. Dissertation an der Universität Stuttgart.

Lindenberger, J. (1993): Laser-Scanner-Messung, eine neue technische Lösung in der Photogrammetrie. KAZ Bildmess GmbH, Karl-Rothe-Str. 10-14, D-04105 Leipzig.

Lohmann, P., Hug, C. and A. Wehr (1997): Topographic Mapping using the Scanning Laser Altitude and Reflectance Sensor (ScaLARS). Proceedings of the joint ISPRS Workshop "Sensors and Mapping from Space", 1997, Hannover, pp. 83-96.

Petzold, B., Reiß, P. and W. Stößel (Surveying and Mapping Agencies of the States of Northrhine-Westphalia and Bavaria) (1999): Laser Scanning - Surveying and Mapping Agencies are Using a New Technique for the Derivation of Digital Terrain Models. ISPRS Journal of Photogrammetry and Remote Sensing, 54/2, to appear.

Petzold, B. (1999): DTM Determination by Laserscanning - An Efficient Alternative. Proceedings of the OEEPE Workshop on Automation in Digital Photogrammetric Production, June 22-24 1999, Paris.

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

TopScan (1998): Münsterstraße 19, D-48565 Steinfurt.