COMBINATION OF LIDAR, DIGITAL PHOTOGRAMMETRY AND TERRESTRIAL SURVEY TO GENERATE HIGH-QUALITY DEMS

Peter Reiss

Bayer. Landesvermessungsamt, Munich, Germany - Peter.Reiss@blva.bayern.de

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ABSTRACT:

The paper describes the work-flow that has been developed at the State Surveying & Mapping Agency of Bavaria which consists of a combination of LIDAR (in Europe laser scanning“) data collection and additional photogrammetric and terrestrial measurements for checking and complementing the mass data derived from LIDAR. This workflow is based upon procedures and recommendations for LIDAR-projects put together by a German user group that consisted of members of several German State Mapping Agencies (SMA’s). Finally some experiences and practical results are presented.

1. INTRODUCTION

1.1 Situation in Germany

In 1994 first discussions had been started about LIDAR (or airborne „laser scanning“ as it is commonly referred to in Europe) as a new technique for data collection in order to generate high-quality digital terrain models and subsequently contours for digital mapping. Several State Surveying and Mapping Agencies (SMA‘s) of the Federal States of Germany carried out tests and evaluated the results (e.g. Hoss, 1996; Petzold & Knabenschuh, 1999; Reiche, Schönemeier & Washausen, 1997).

Since these results were very promising a user group was formed in 1996 to come up with standard procedures for tenders and contracts as well as for verification and handling of the delivered data. An internal report was published to provide guidelines for other public organisations interested in the practical application of the LIDAR technique (Petzold, Reiss & Stössel, 1999). The following text contains some general results of this report as well as the work-flow developed at the “Bayerisches Landesvermessungsamt” (BLVA; i.e. *State Surveying & Mapping Agency of Bavaria* aka *Bavarian Land Survey Office*) and some experiences and practical results. Besides the 4 SMA’s represented in the above mentioned user group meanwhile other SMA’s in Germany have applied LIDAR for their topographical surveys as well.

1.2 Situation in Bavaria

The state of Bavaria is the largest of the 16 Federal States of Germany covering an area of approx. 70,550 km². Towards the end of the 1950‘s photogrammetry was introduced for topographical mapping of the Alpine regions and later on for the rest of the state as well. After analytical photogrammetric plotters replaced the analogue instruments in 1990 map compilation changed from pure graphical methods to object-coded data collection. Very flat terrain in the open fields as well as housing areas and forests still had to be completed using terrestrial survey (tacheometry) – a very tedious and time consuming task.

As of the early 90’s approx. 65% of the state area were covered by contour maps of good but not up to date quality while for the remaining part only maps of inferior accuracy were available going back as far as 1872-1920.

In 1994 a working group at the BLVA produced an internal report containing recommendations how a statewide detailed DTM could be generated with special emphasis on the 35% covered only by very old and insufficient contour map sheets. A combination of photogrammetric image correlation for open areas, stereo-compilation of building areas and laserscannig (LIDAR) for forests were recommended because LIDAR was the only technique to receive terrain data on the ground more or less automatically within wooded areas. A first test using laser scanner data was carried out in 1996 which clearly showed several results:

- The overall accuracy of LIDAR was as good as a very accurate terrestrial tacheometric survey for open fields including very flat ones as well as for building areas and even large parts of wooded areas (except for dense coniferous forests).
- Restricting LIDAR to forest areas was not economical because smaller irregularly shaped project areas would cause the same costs as large rectangular areas. This meant that there was no practical reason to apply image correlation in addition or alternatively to LIDAR.
- The automatic filtering process to eliminate points that did not hit the ground was not 100% reliable, so careful inspection and editing had to be done to remove remaining data that did not define the bare ground. This happened especially in the middle of

- larger flat roofs (e.g. of factory halls) and in the middle of wider areas covered by young and densely standing conifers.
- The Digital Photogrammetric Workstation (DPW) that was used in the beginning only for testing purposes was found to be a very efficient tool for checking and editing and therefore remained in constant use ever since.
- Depending upon the choice of parameters and the character of the terrain automatic filtering not only removed points that hit roofs or vegetation but also good measurements along ridges with steep shoulders (Figure 6).
- Although the point density was increased through the years (from an overall average of 4.5 m to 1.5 m) morphological features such as breaklines along dams or cuts, ridge or valley lines were not as precisely defined as desired.

Therefore since 1997/98 a combined method is in operational use consisting of

- laser scanning as the main input

supported by

- digital photogrammetry for checking and editing of the data gained from the scanning laser,
- analytical and/or digital photogrammetry for additional stereo compilation of features and geomorphological structures and
- terrestrial tacheometry to fill data gaps within densely wooded areas (especially young coniferous forests).

(Petzold, Reiss & Stössel, 1999; Reiss, 2001a; Reiss, 2001b).

While in the past the primary product were contours compiled at stereoplotters in order to produce contour maps with DTM data as a by-product now a bare-earth DTM derived from LIDAR / laserscanning – edited, enhanced and completed by photogrammetry and terrestrial tacheometry – is the main result with contours being automatically derived as a follow-up product from the DTM.

2. PLANNING PHASE

The planning / contracting phase for a project using LIDAR for a topographical survey includes

- definition of the project area (preferably of long rectangular shape)
- preparation of maps for the contractor
- supply of coordinates (project boundaries, GPS-reference stations, control points for datum transformation from WGS84 to local, geoid undulations)
- definition of one or more check areas for the contractor (to check the datum transformation from WGS84 to local; not to be used for adjusting the orientation in height; Figure 3)
- definition of several check areas for the SMA (for an initial overall check of orientation / transformation of the delivered mass points and – as far as applicable – individual strips; Figure 3).

3. LASERSCANNER FLIGHT, PHOTO FLIGHT, PREPARATORY FIELD WORK

Laserscanner flights for the BLVA usually have been carried out so far under the following conditions:

- flying height approx. 900 m
- strip width approx. 650 m
- side lap approx. 250 m
- resulting point density approx. 1.5 m (in the beginning about 4.5 m)

Best results are achieved if the LIDAR flights are carried out with "leaves off", i.e. between late autumn and early spring, as long as there is no snow coverage.

Parameters of the additional photo flights:

- image scale 1 : 14,000
- color film (diapositive)
- signalized control points (coordinated using terrestrial DGPS)

Image flights are made in early spring as soon as the snow is gone and before the leaves come out, i.e. from the middle of March until the middle of April.

Field work supporting LIDAR and photo flight resp.:

- signalization and measurement of control points
- set up and handling of at least 2 GPS reference stations within the project area during the LIDAR data collection
- survey of check areas to check the height accuracy (grid of about 50 m x 50 m with 10 m spacing within plane areas with little or no vegetation – usually sports / soccer fields; Figure 3)
- survey of several breaklines to check the horizontal positioning of the LIDAR data delivered

Outdoor work usually starts before the photoflight (middle of March).

4. CHECKS (ACCEPTANCE OF DATA)

Besides a report, plots (flight plan) and GPS-coordinates (of flight lines) several files of laser data have to be delivered by the company under contract (which is also responsible for the filtering process):

- file of registered points classified as ground points
- file of points classified as vegetation / buildings
- file of highest points (to define a raw surface model; optional)
- file of height differences (to define relative height of vegetation; optional)

As a first check point plots covering the whole project area are produced and inspected to validate coverage and point density (Figures 1 and 2).

Another very important check regarding accuracy and reliability consists of the comparison of the laser scanner measurements against the check areas from outdoor work. The laser data are accepted if the height difference compared with the grid surface is within |0.3 m| for at least 95% of the laser points classified as ground points (Figures 3 and 4).

Further initial checks to look for outliers / blunders can be carried out through inspection of contours and / or shaded reliefs derived from a very dense DTM-grid based on the raw laser data as delivered by the contractor (Figures 7 and 8).

5. DATA PROCESSING (EVALUATION, EDITING, ADDITIONAL DATA COLLECTION)

To enhance the results received from laser data geomorphological structures are compiled interactively at stereoplotters. Typical features are boundaries of streams and lakes, natural or artificial breaklines (especially at dams), ridge lines, valley lines, edges of cuts and fills as well as local extrema (saddle points, hills and hollows). See Figure 2, 7 and 10.

Later on the data are checked and edited in detail at several DPW's which give a stereo-scopic 3D-view (of the laser data plus the additional features) superimposed upon the stereo-models from the image flight (a 2D simulation is given in Figure 5). A superimposition of contours can be helpful as well; these are derived from an intermediate DTM out of the edited LIDAR points plus morphological features.

Areas that are not covered completely have to be filled by field survey parties using tacheometry. This mainly concerns forest areas covered by a dense population of young conifers. Outdoor data collection mainly consists of the measurement of ridge and valley lines because these are especially important for modelling the flow of water (dividers and collectors). Since 2001 outdoor data collection is done using registrating theodolites and laptop computers which results in a full digital data flow from field to office. The ArcView® software is installed on these laptops in order to visualize for the surveyor the raw contours as well as the line features in the field.

6. EXAMPLES OF PRACTICAL RESULTS

Figures 2 and 7 through 10 show sample plots out of one project covering rather rough terrain to visualize the effect of additional photogrammetrically and terrestrially collected morphological features.

7. CONCLUDING REMARKS

Since the introduction of laser scanning as the primary input for topographical survey the percentage of areas that have to be completed outdoors by a terrestrial survey went down from approx. 40% to less than 10% (large parts of Bavaria are covered by forests mainly consisting of conifers).

Traditional photogrammetric stereo-compilation has been reduced as well. This led to an increase in throughput of factor 4-5 so far which does not mark the end yet (primarily because the advantage of a complete data flow from outdoor work to office did not show in those figures yet).

8. REFERENCES

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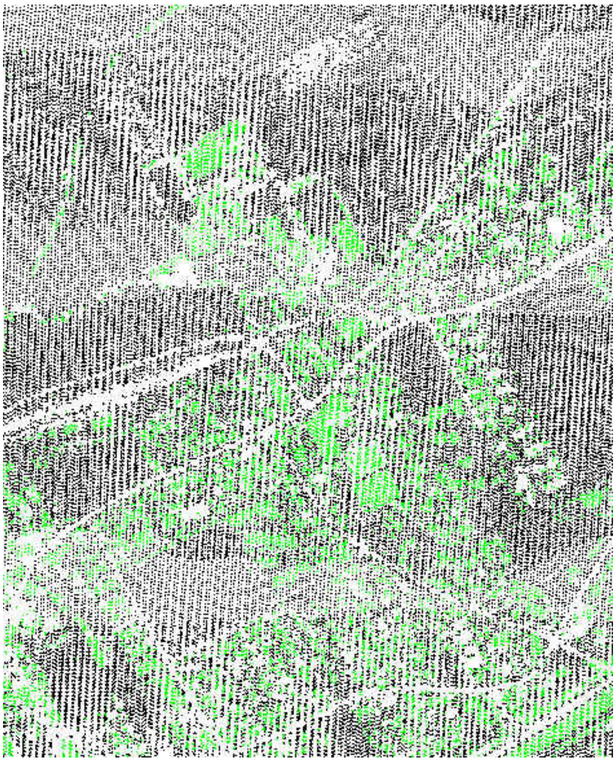

Figure 1. Point plot of LIDAR points classified as ground (black) and non-ground (i.e. vegetation / buildings; green)

Figure 2. Point plot of LIDAR points overlayed with
morphological features and markers for field check

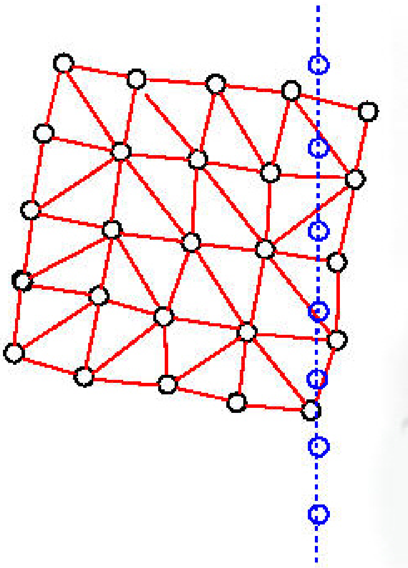

Figure 3. Check area (raw grid of check points and
footprint of one line of LIDAR measurements)

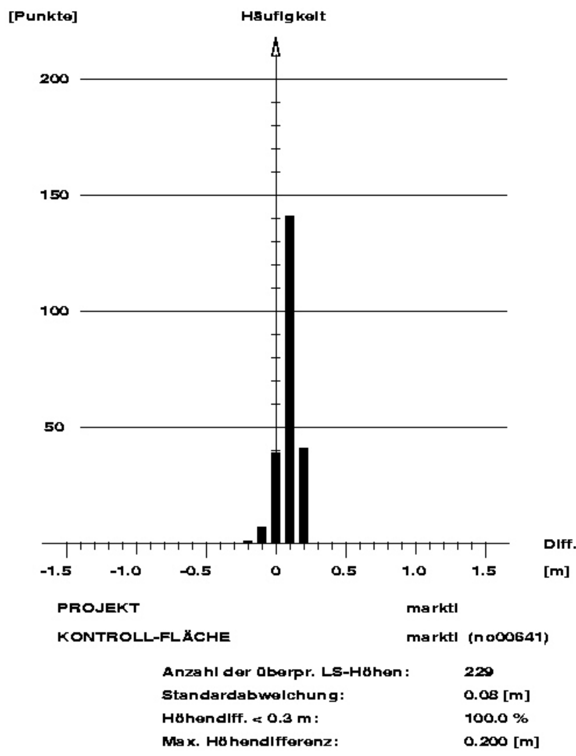

Figure 4. Histogram of height residuals within check area

Figure 5. Digital orthophoto overlaid with LIDAR measurements

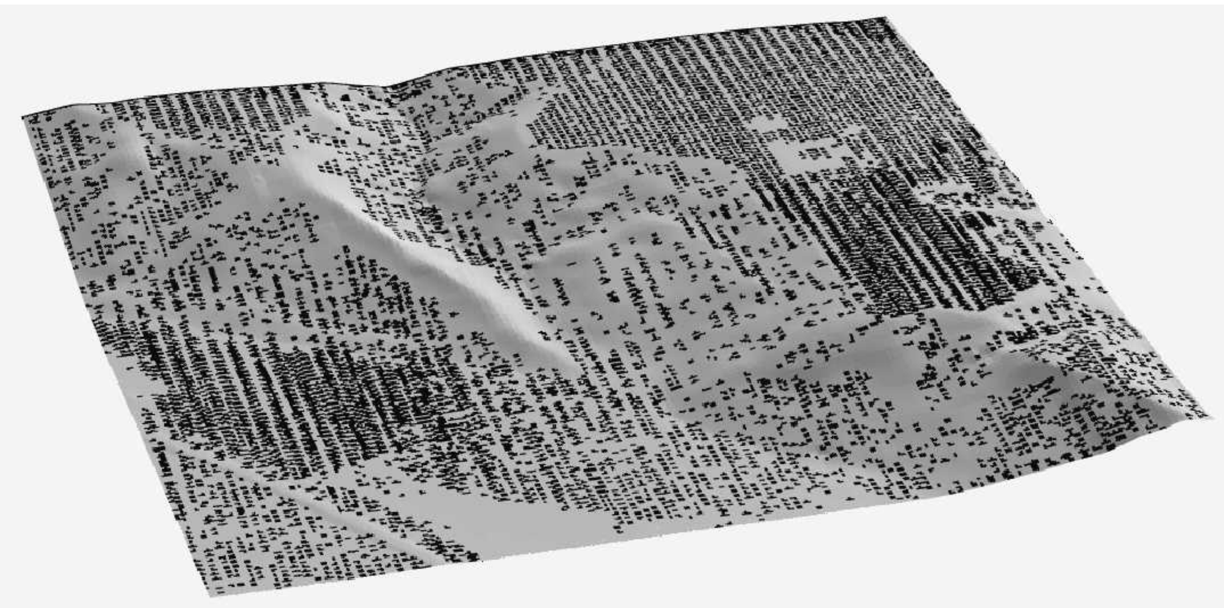

Figure 6. Shaded relief (perspective view) showing filtering of good LIDAR measurements along steep ridges

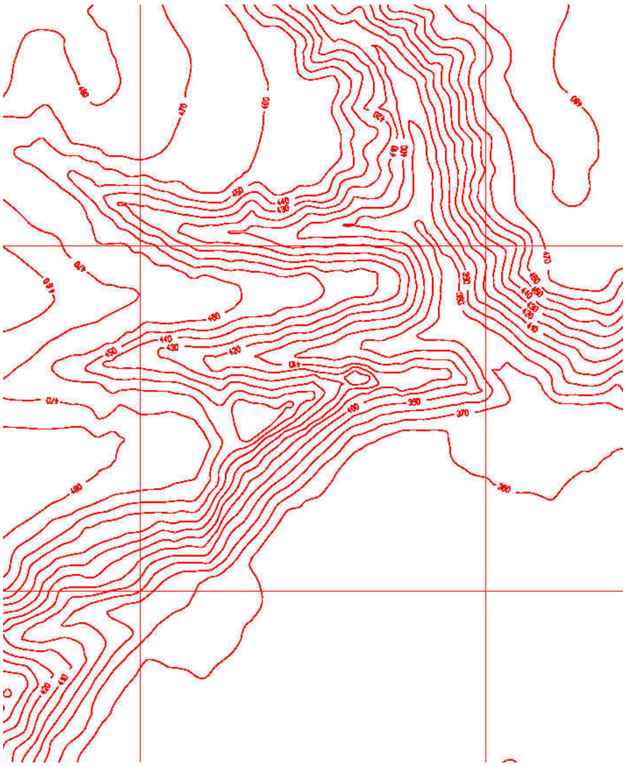

Figure 8. Contours derived from LIDAR data only

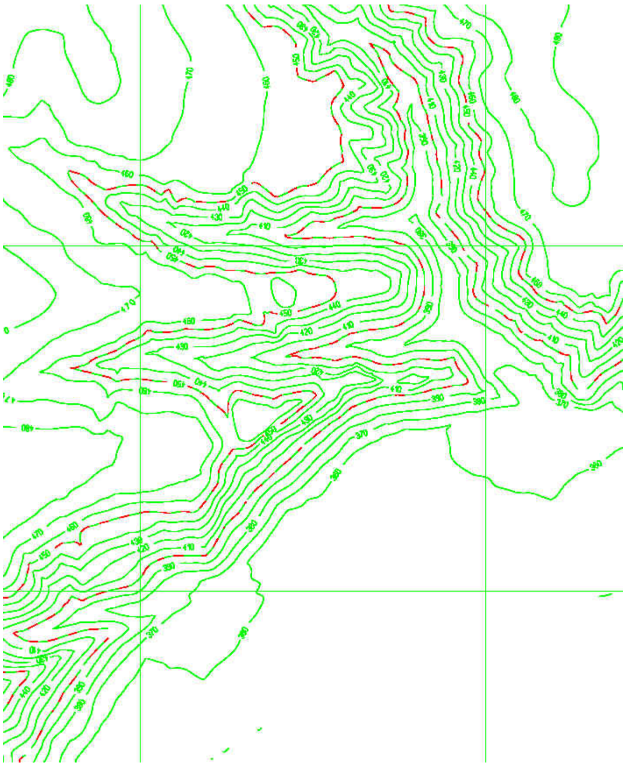

Figure 9. Contours derived from LIDAR data plus morphological features from stereo compilation

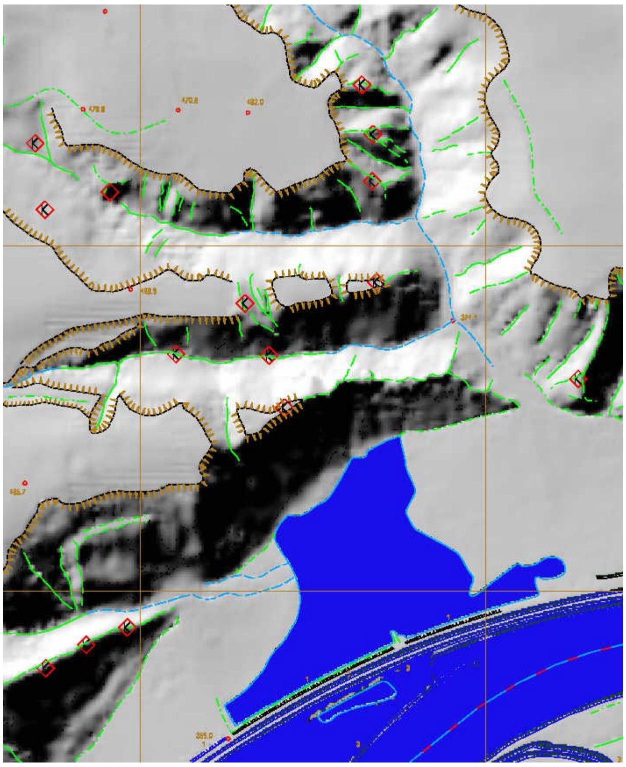

Figure 7. Shaded relief from raw LIDAR data superimposed with photogrammetrically compiled morphological features

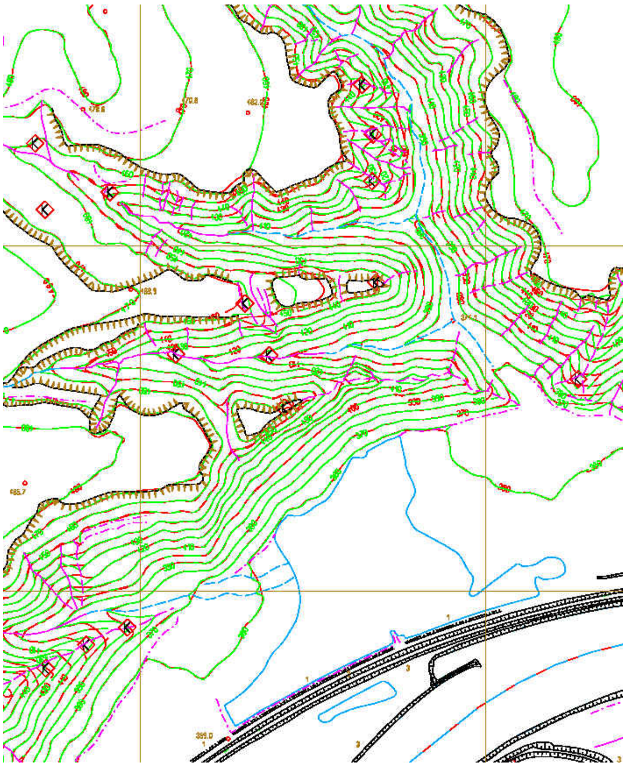

Figure 10. Overlay of contours derived from LIDAR data only and contours including morphological features