New Tools for Terrestrial Laser Scanning Applied for Monitoring Rails and Buildings

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SUMMARY

A main advantage of terrestrial laser scanning is the possibility to nearly simultaneously acquire the geometrical positions of millions of object points in 3D. However this is also the main bottle neck of terrestrial laser scanning when it comes to data processing.

In this paper a new strategy will be proposed, presented and applied in order to show how to overcome the discrepancies. The modelling and processing will be done based on surface parameters which will be efficiently derived from point cloud measurements. It will be shown, that there is no need for a triangularisation of the points prior to a derivation of significant surface parameters. In such a way enormous data reduction will be achieved.

It becomes feasible to combine adjacent scans completely based on identical surface parameters derived from natural objects detected automatically in both scans. Natural objects may be used for geo-referencing as well.

Characteristic lines can be derived from the intersection of surfaces. Due to the high point density of the scan, an increased improvement of the accuracy of the surface parameters will be achieved even for small extensions of the detected surfaces. Then even deformation analysis of walls of buildings can be based on surface parameters. From the surface parameters and a defined boundary line and boundary plane also the volume under the surface can be easily determined.

Examples from rail monitoring, building monitoring and the automatic determination of the volume of a pile of coal are presented in order to demonstrate the efficiency of the concept.

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1. TERRESTRIAL LASER SCANNING IN ORDER TO DERIVE A GEOREFERENCED 3D DIGITAL MODEL

3D laser scanning as a remote and rapid surveying tool that captures up to 500,000 points per second to a point accuracy of ±15mm or better is a very powerful tool. The high point density of a laser scanned object ensures that even the most irregular geometrical object profile will be completely covered within a few minutes. Irregular formations such as boulders and overhangs are included in the point clouds. The most important benefit of laser scanning is that the measurements are remote and only cause minimal interference to construction and mining operations. However inappropriate data processing often absorbs those advantages.

To provide the complete geometrical information of the actual state of an object would be useful for a large number of applications. Not only the task of measuring against CAD would be solved where the real object could be compared to the planned CAD model. The 3D georeferenced GIS documentation of different states of a building under construction would be available and could help to derive any surface related information like surface intersections, volume changes, loading situations, deflections of objects etc. .

Also the task of reverse engineering, namely to derive CAD information from an as built state of an object could be derived in a simple way. The geometric data for the task of reverse engineering are often derived from a physical model built from wood or taken from a real object.

However available laser scanning technology for object reconstruction results in huge point clouds consisting of millions of points. The individual point measurements show inevitable resulting noise and are irregularly distributed depending on the object´s geometry. In addition there might be gaps, invisible parts of the surface, caused by shadowing effects. In addition the individual points might contain blunders due to false reflection and a bad representation of edge lines of the surface.

In order to arrive at a feasible object modelling the point cloud is often segmented into functional patches or into polygonal (triangular or quadrangular) regions. In most CAD systems this task is performed in an interactive – time consuming – way. A partially best fitting surface will be modelled for each region. However problems occur for smooth surfaces of higher order, for free form surfaces and in cases where steady and smooth transitions at the segments´ boundaries will be required.

An innovative powerful strategy, proposed and realised by the authors [Milev 2005], [Milev, Gruendig 2006] overcome those deficiencies. The concept is based on an automatic segmentation followed by an appropriate segmentation and spline approximation of the point cloud. At the end, a definite surface function results which contains all points in a best fitting way.

Essential characteristics of this way of modelling are the inclusion of non rectangular boundary edges, realised by tensor product surface fitting, and the treatment of gaps as invisible parts of the surface. Both task are handled via efficient mathematical approximation tools. Another essential enhancement relates to the mutual interconnections between the point clouds which are needed for transformation of the surface paramters into a common reference frame. Instead of using signalized identical points or spheres as described in literature, i.e. [Hoschek 1993] the authors propose to use reference planes for transformation and global parametrization, and achieved excellent results. Natural objects will be detected and used for interconnection and transformation of surfaces derived from inividual scanner positions.

1.1 Interpolation

A main prerequisite for object representation is an efficient interpolation concept in order to correctly determine a best fitting surface function. Then the task to determine the volume between two surfaces would consist of a simple integration process.

To model a suitable interplolation an approximating function $g : I \to \Re$ will be chosen. Based on supporting positions $t_1,.......,t_m$ a spline function $f(t_i) = g(t_i), \forall i$ will be searched for. It is to be expected that for a sufficient number of supporting positions and for the corresponding sequence of nodes $f(t) \approx g(t), \forall t$ holds. One criterium to guarantee the solvability of the problem is a regular distribution of the interpolation points. Alternatively a definite spline function g could be chosen in advance. Then the sequence of the nodes will be available and g can be evaluated, and used for the derivation of the control points of a B-Spline. Based on suitable supporting positions $t_1,.......,t_m$ the interpolation problem becomes solvable.

Choosing unit vectors of the right hand side of the system of equations for the interpolating problem the solution can be modelled by the Lagrange-function L_k

$$\partial^{\# j} L_k(u_j) = \delta_{jk,} \qquad j = 1 : m$$

The Lagrange-function L_k decreases exponentially.

$$|L_k(t)| \le \alpha \exp(-\beta |t - u_k|),$$

where α, β are positive constants, depending on the sequence of the nodes and the distribution of the supporting positions. As shown in [Milev 2001] the solution of the general interpolation problem can be expressed by a linear combination of Lagrange-functions:

$$f = \sum_j L_j g_j$$

Due to the property of decrease of the Lagrange-function the interpolation process acts approximately local.

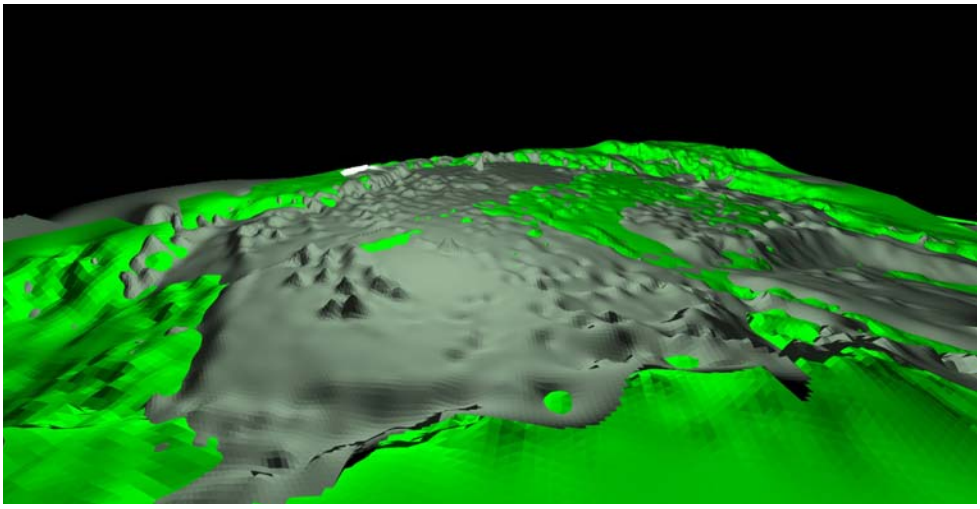


Fig. 1: Derivation of the volume and the volume change (between two years) of a land fill

In order to reduce the calculational effort of approximation, a segmentation will be chosen. Polygon models and NURBS surfaces will be generated using the spline parmeters derived from the point clouds. They will be interconnected observing boundary conditions.

Thus a number of advantages will be achieved. Storing surface area parameters only reduces the geometrical data which are needed considerably. Any time consuming triangularization of points which is traditionally proposed will be completely unnecessary. Characteristic lines will be automatically derived by intersecting surface areas. A tool for the detection of edges will not any more be required in the concept described. This becomes a very essential benefit as laser measurements to edges are the most unreliable observations.

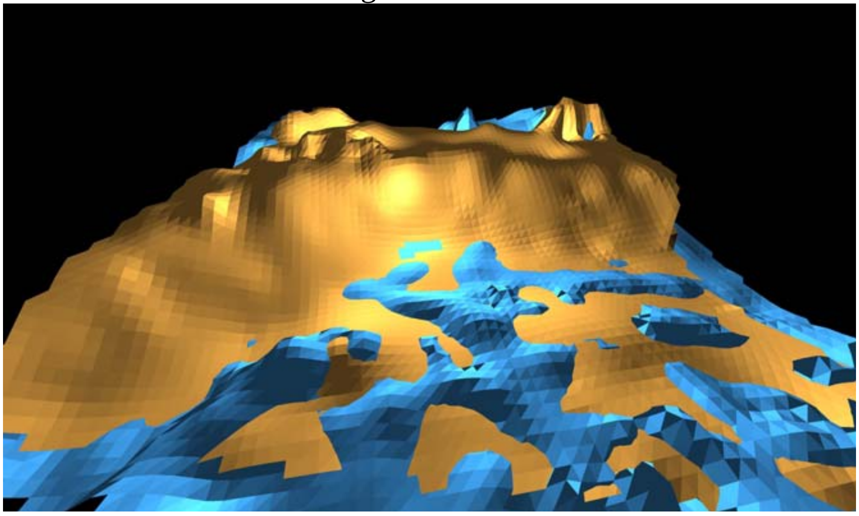


Fig. 2: Intersection of surface models for two measuring periods

The geometrical comparison between the as built and the planned situation based on surface areas is much more significant and precise than a comparison based on points only.

The parametric surface description of the concept has a number of further advantages. It easily allows for the calculation of the volume between two surfaces. Based on the volume of a land fill or of an excavation, the mass and any loading situation due to a construction process could be accurately modeled

2. AUTOMATED VOLUME DETERMINATION AND DETECTION OF DEFORMATIONS

Based on the tools mentioned above homogenous data acquisition, free of gaps is feasible in order to document the complete geometrical insitu situation of an engineering object. Fig. 3 and 4a show the result of data acquisition and parametrization for a large construction site.

2.1 Deformation Analysis

Based on the object parameterization it becomes feasible to perform an area based deformation analysis. Identical surfaces are derived from the surface representations of the two measurement epochs (10.12.2005 and 17.03.2006). Identical invariant surfaces out of reach of the construction process were compared to the (identical vertical surfaces) in the area of influence. Due to an excavation of the site the adjacent buildings show deflections. Fig. 4b visualises the deflections between wall surfaces of both epochs. A deflection of smaller than 4mm is visualized in green. The red bar indicated a deflection of larger than 1 cm.

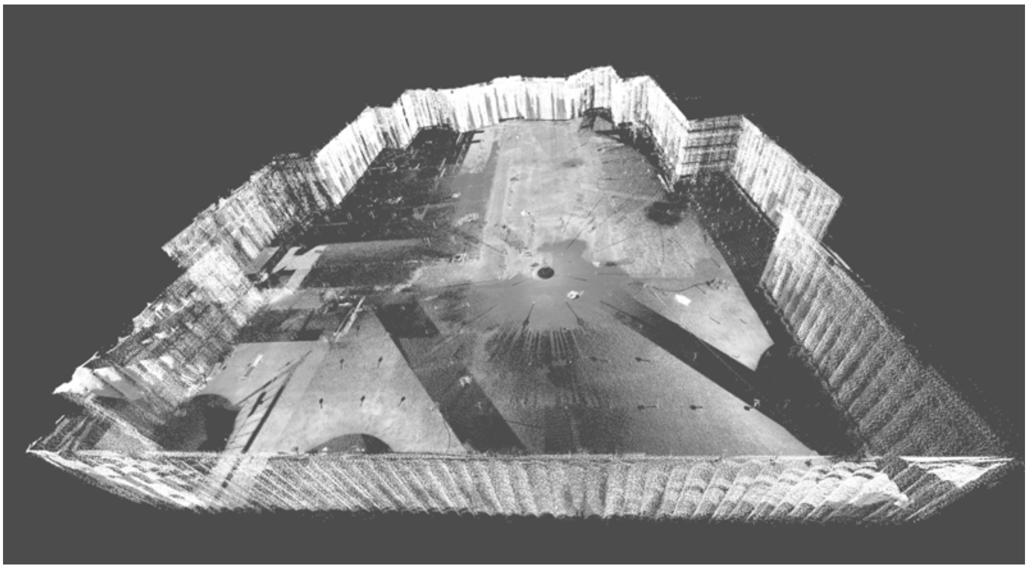
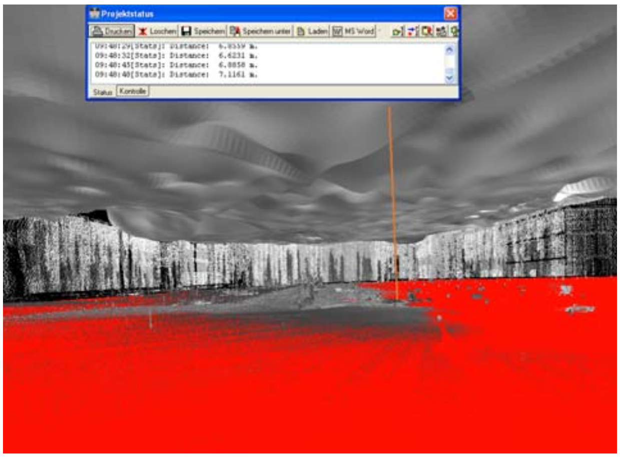


Fig. 3: Excavation measured at the site of Berlin National library



```
09:48:29[Stats]: Distance:  6.8559 m.
09:48:32[Stats]: Distance:  6.6231 m.
09:48:45[Stats]: Distance:  6.8858 m.
09:48:40[Stats]: Distance:  7.1161 m.
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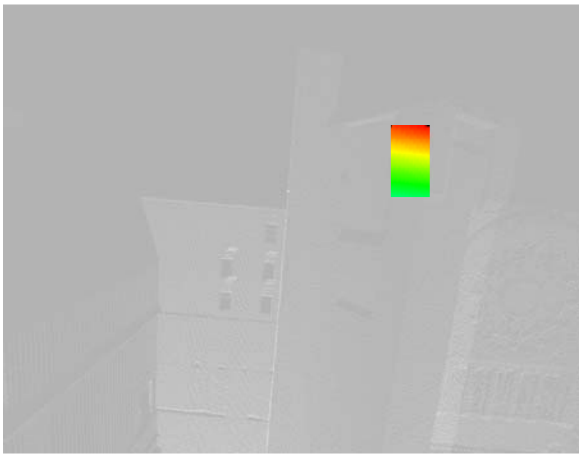
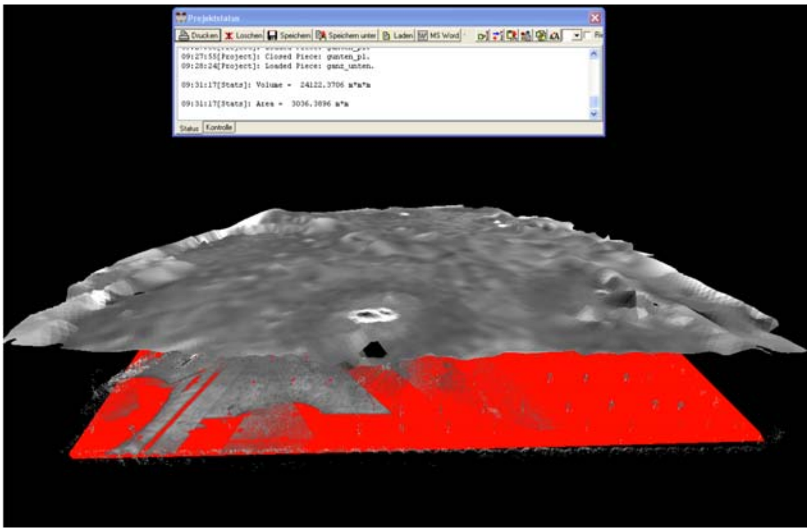


Fig. 4a: Measurements results indicating the bottom of the excavation and the former ground level.
Fig 4b: Deformations (inclinations) of effected walls



```
09:27:55[Project]: Closed Piece: gunten_pl.
09:28:24[Project]: Loaded Piece: ganz_unten.

09:31:17[Stats]: Volume =  24122.3706 m*m*m

09:31:17[Stats]: Area =  3036.3896 m*m
```

Fig. 5: Determination of the excavated mass of the site of National library Berlin

3. RAIL MONITORING

Laser scanning technology can be favorably applied for the determination of georeferenced objects in a wide range of applications if connected to the tools described above, and integrated into a global measurement and analysis system.

The steps of maintenance of existing railways of German Rail, including the process of reconstruction, requires precise and consistent information with respect to the existent rail and to the topography close by. Methods for the design of appropriate measurements, for data processing and analysis have been developed as concepts of precise engineering surveying. In addition to the geometry of the as built situation they provide all necessary information for the correct alignment and setting out of the rail lines. All information will be made available for the analysis and optimisation of the rails´ geometry and the analysis of characteristic physical properties of the railway line. The improved planned rail geometry is based on a valid consistent global coordinate system.

Precise tacheometric measurements have been used to fulfil the task in combination with differential GPS measurements. However this requires a large time consuming effort of field work followed by expensive data processing and analysis.

Based on the new concept of surface parametric management of geometrical data from laser scanners an existing kinematic measurement system has been extended which includes GPS data for providing global georeferencing. Originally the system only consisted of the components GPS data acquisition, determination of the gauge, and the superelevation of the rails. Now the enhanced system (fig. 6) allows for a complete kinematic determination of the existing position of rails and the surrounding area of interest.

With the additional laser scanning tool the topographic proximity information, and the geometrical positions of the reference bench marks which have to be observed in the subsequent planning process of the rail alignment and setting out are avaible now.

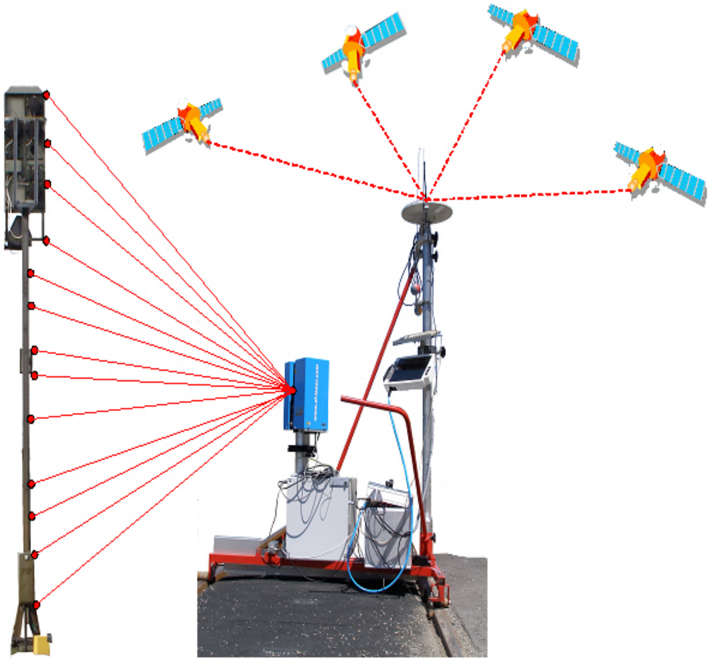


Fig. 6: 3-D multi sensor system for rail maintenance [Milev/Riemenschneider 2006]

The system consists of Laserscanner Imager 5003 of company Zoller+Fröhlich, of the GPS system for measuring global rail geometry of company Geo++ GmbH and of the software system developed by company Technet GmbH which fulfills the tasks of processing of laser scanner data as described above, and the necessary data integration of GPS data, laser scanning data, gauge and superelevation data. It fulfills the requirements of German rail for a consistent documentation of existing and new rail alignments in an efficient and sustainable way. Included in data processing and analysis is the extraction tool for finding lines of different kinds, like rails (fig. 8), electric power supply lines, edge lines of the platforms of the railway stations. Surface areas of platforms, fassades, roofs and tunnel walls may be extracted too.

The new system *SurVers* allows for a simultaneous kinematic data acquisition. In one measurement run extensive three dimensional information will be made available. In addition to the data needed for the alignment and rail maintenance all information depending on the surrounding topography will be efficiently acquired, documented and made available for other space related requirements [Riemenschneider 2006].

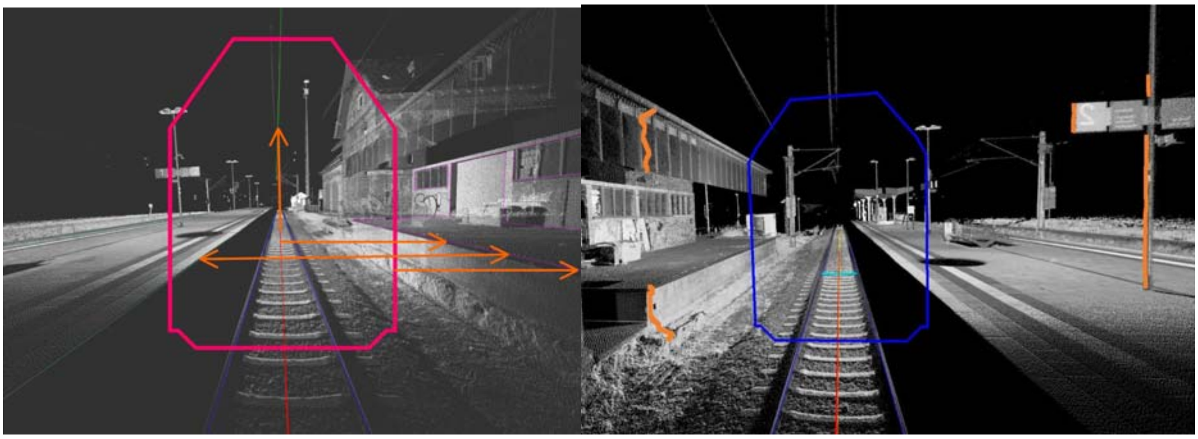


Fig. 7: Clearance profiles and adjacent objects derived from the recorded and processed data

Geocentric WGS coordinates coming from GPS measurements will be transformed in real time into the valid reference system of German rail. The coordinates refer to the phase centrum of the antenna. Based on the fixed geometrical relations of the integrated measurement frame of the system the transformation of the coordinates to coordinate system of the laser scanner will be done and thus georeferenced in real time Therefore all profiles of the proximity situation, recorded with 33 Hz, are georeferenced too. For an avarage speed of 1,5 m/s of the kinematic measurement process and the time stamp of 0.25 ms all 3 to 4 cm a georeferenced profile results. At the end of the measurement process a detailed precise areal 3D model will be available which contains the rail geometry and the topography of the surroundig.

The trajectory is the reference basis for the rail clearance (fig. 7). All necessary information especially the distance of the relevant objects near by can easily be derived from the system.

In fig. 8 the edge lines of the inner border of the rails is visualised. They are derived from the rail top surfaces intersected with the adjacent surface of the vertical surface part of the rail. The distance between those lines is the gauge.

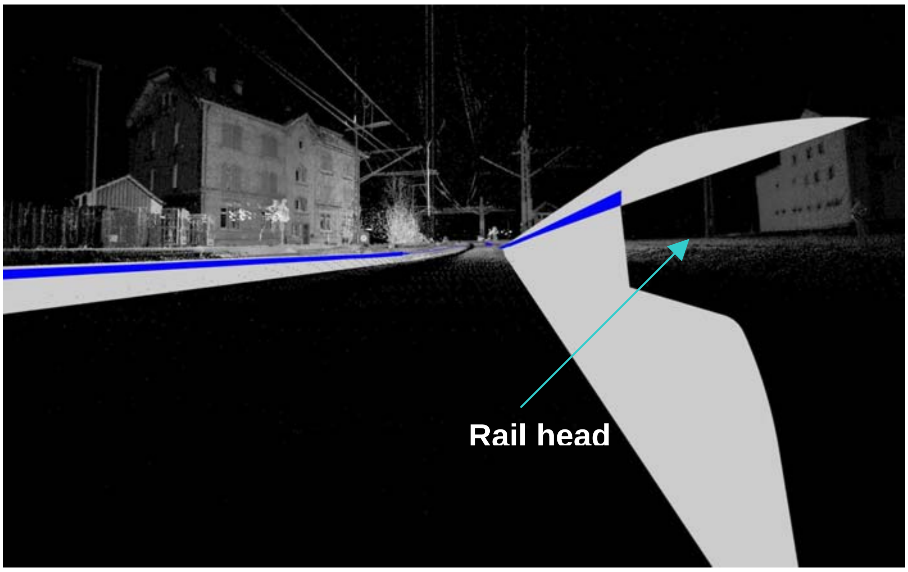


Fig. 8: Rail fitting (point cloud source Intermetric GmbH)

4. CONCLUSIONS

The presented examples document the capacity of laser scanning technology for a wide range of applications. However, this power can only be opened up in an efficient way if the processing of the enormous amount of geometrical data will be handled appropriately. In addition to saving time in terrestrial data acquisition also data processing can be performed in real time then. Immediately a geo-referenced 3D GIS will be recorded and generated which can be used to operationally manage all geometrically related tasks.

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BIOGRAPHICAL NOTES

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